CARBON 4 SOIL QUALITY

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ACTION PLAN FOR TESTING CARBON FARMING

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EXECUTIVE SUMMARY

This document presents an Action Plan concept to prepare the groundwork for a future testing phase of carbon farming in the Interreg Euro-MED area, translating the outcomes of the CARBON 4 SOIL QUALITY study work into a structured, real-life pilot project consistent with the Euro-MED "Study to Test" logic. The Action Plan outlines how carbon farming techniques, collaborative business models, and governance approaches could be tested in a coordinated manner across Mediterranean territories, and it defines the key components required for implementation, including the overall goal, specific objectives, activities, timelines, stakeholder roles, and a feasible financial architecture. It also integrates the enabling elements necessary for credible and scalable testing, namely soil quality and carbon monitoring procedures, capacity building and training activities, targeted communication actions, and alignment with the European Commission's Carbon Farming Initiative. A defining feature of the Action Plan is its territorial and environmental representativeness: it envisages at least five pilot sites in different countries, including at least one IPA country and one new Interreg Euro-MED territory, while ensuring coverage of different Mediterranean climate zones (sub-tropical, oceanic, semi-arid, arid), erosion conditions, and soil types to reflect real-world variability and support transferability. The approach builds on the project's technical and strategic deliverables, including SOC reference benchmarks and soil quality index logic, harmonised monitoring methodologies, the catalogue of carbon farming techniques, socio-economic collaborative business model pathways, and recommendations for certification and carbon credit scheme readiness under emerging EU frameworks, complemented by cross-country feasibility analysis and a transferable training package. Operationally, the Action Plan is structured around three interlinked implementation pillars: (i) the selection and testing of carbon farming techniques in pilot territories with harmonised monitoring and comparable reporting; (ii) Living Labs and end-user verification to assess practicality, barriers, costs and adoption potential while upgrading and scaling training materials to different target groups; and (iii) upscaling and capitalisation to consolidate evidence into transferable recommendations, strengthen policy integration (including CAP-related pathways), and maintain transnational cooperation through a Carbon Farming Cluster and final dissemination event. Overall, the Action Plan provides a coherent basis for preparing a Euro-MED Test project proposal by combining robust technical foundations with an uptake-oriented training and stakeholder engagement strategy, enabling future pilots to generate credible evidence, strengthen adoption conditions, and support wider diffusion of carbon farming across the Mediterranean region.

INTRODUCTION

The action plan is designed to prepare the groundwork for **possible future testing of carbon farming in the Interreg Euro-MED area**. It will outline how carbon farming **techniques, business models, and governance models** could be tested in a structured way across the Mediterranean region.

The plan will define **the overall goal, specific objectives, activities, timelines/deadlines, key stakeholders, and financial aspects** needed to implement future testing. It will also address enabling elements such **as soil quality and carbon sequestration monitoring, training activities, communication actions**, and **contributions to the European Commission's Carbon Farming Initiative.**

A key feature of the plan is its territorial and environmental coverage: it will consider **at least five testing sites in different countries**, including **at least one IPA country** and **one new Interreg Euro-MED territory** (examples mentioned: **Bulgaria and Extremadura).** The action plan will also ensure representation of different **Mediterranean climate zones** (subtropical, oceanic, semi-arid, arid), as well as **varying erosion conditions and soil types**, to reflect diverse real-world contexts. The action plan will propose **potential pilot areas**, identify relevant **stakeholders**, define **monitoring procedures**, and describe suitable **carbon farming techniques**, including their **expected impacts on CO_2 reduction and soil quality improvement.**

DELIVERABLE D1.1.1

Catalogue of soil organic reference values

Deliverable **D1.1.1** develops a practical methodological foundation for future **carbon-farming** and **soil-health** actions in the **Euro-Mediterranean (Euro-MED)** area by doing two things:

1. Defining **reference ("benchmark") SOC values** (concentration and stock).
2. Building a **Mediterranean soil quality index** that combines **physical, chemical and biological** dimensions through a participatory, probabilistic approach.

The deliverable notes that comparable SOC stock estimates are still difficult because national monitoring campaigns often use **different sampling and analytical methods**, and data access/compatibility is limited. It points out that many EU-wide projections rely on **CENTURY-type models**, but long-term uncertainty remains high (especially for slow/passive pools). It also reports that Mediterranean Europe is the only region expected to **lose SOC** even under optimistic scenarios.

To illustrate available evidence in partner contexts, the report summarises examples such as:

- **Slovenia (OrgC programme, 2016–2022)**: 485 sites sampled; Mediterranean subset used for C4SQ. Reported mean SOC stocks (0–30 cm) include **arable land 68.5 t/ha**, **vineyards 53.3 t/ha**, **permanent grassland 87.0 t/ha**, and **trees/shrubs 95.9 t/ha** (among others).
- **Italy**: highlights the lack of one comprehensive national SOC stock database; summaries include limitations of older datasets (e.g., agricultural estimates approximated to ~2000) and model-based estimates for natural/permanent ecosystems (e.g., CENTURY-based work).
- **Greece**: describes extensive soil mapping and sampling (large numbers of profiles/locations and lab analyses) supporting national soil information.

For a comparable Euro-MED reference map, the deliverable selects harmonised datasets: **LUCAS Topsoil 2015** (soil), **CRU TS 4.07** (climate), and **MODIS/Terra NPP** (primary production). It notes that Western Balkan LUCAS samples existed but lab analyses were not yet available, so the European-scale modelling focuses on **Greece, Italy, Slovenia and Spain**, while **North Macedonia** is used for national-scale validation (261 points).

Two tested approaches (mutually validating)

APPROACH 1 — PEDOCLIMATIC CLUSTERING (GMM):

The initial idea (separate climatic + pedological clustering) was not satisfactory for Mediterranean variability (too many clusters with too few points). The report therefore applies a **Gaussian Mixture Model (GMM)** to identify pedoclimatic zones using variables linked to SOC controls (texture fractions, elevation, temperature/precipitation descriptors, NPP). **Reference SOC** is then set as the **median SOC of grassland points** within each cluster.

APPROACH 2 — MACHINE LEARNING (RANDOM FOREST):

A **Random Forest** model is trained on **grassland** points to predict SOC from soil/climate covariates, then applied to other land uses to estimate **"grassland-equivalent SOC"** (what SOC could be if converted to grassland). In the reported implementation, the model is trained on **600 grassland points** and tested on **243**, then applied to remaining points; cluster reference values use medians of predicted grassland-equivalent SOC.

North Macedonia validation and carbon stock interpretation

North Macedonia is analysed separately due to **different sampling depth** (30 cm vs LUCAS 20 cm). Croplands are identified as the most SOC-depleted; clustering identifies four groups, and Random Forest helps estimate reference SOC even where grassland points are scarce. The deliverable concludes that the **two approaches align well**, enabling **cross-validation**, and that Random Forest is promising where reference data are limited. For policy relevance, SOC is converted to **carbon stock (kg/m²)** for the **top 20 cm** using bulk density and coarse-fragment corrections; maps of current vs "saturated" stock are produced. Across Euro-MED clusters, reaching saturation increases stock everywhere, with an **average gain of ~0.80 kg/m²**. For North Macedonia, orchards and croplands show little difference between current and predicted stock (possible near-saturation), but the report stresses that **more soil analyses** are needed because cropland observations are limited.

Because soil quality is **multidimensional** and "universal thresholds" are difficult (different stakeholders prioritise different functions), the report proposes a **Bayesian Belief Network (BBN)** to connect:**soil properties → soil functions → quality dimensions (physical/chemical/biological) → overall index**, and then converts the BBN into an **Influence Diagram** using expected-utility logic to produce a single overall soil quality indicator. To keep the system tractable and compatible with existing datasets, the BBN uses a compact set of indicators: texture, bulk density, SOC, salinity, pH, total N, available P, Cu, Zn, microbial biomass, discretised into a small number of classes using literature and/or expert judgement.

The BBN outputs show consistent expert expectations: **higher quality** is associated with **finer texture**, **lower bulk density**, **higher SOC**, **neutral pH**, **lower salinity**, **better nutrient status**, and avoidance of limiting contamination; microbial biomass contributes positively but more moderately.

When summarised into an overall index (**Q1 high / Q2 medium / Q3 low**) while holding other variables at Euro-MED median values, the results show clear patterns—for example: coarse texture and very low SOC tend toward **Q3**, fine texture and higher SOC toward **Q1**; **high/medium salinity** pushes the index downward; **high Cu** tends to reduce quality; and higher nutrients/microbial biomass generally improve outcomes.

Conclusions and recommended next steps

SOC benchmarks: Reliable SOC reference values are essential for credible carbon credit/carbon-farming governance. The deliverable demonstrates that the **GMM clustering** and **Random Forest grassland-equivalent** approaches provide **consistent results**, enabling mutual validation and use under different data availability conditions.

Data improvement: Robustness depends on increasing the number of observations and integrating **regional/national databases** alongside LUCAS—paired with harmonisation/standardisation protocols.

Complementary modelling: The report suggests exploring **deterministic mechanistic soil carbon models** as an additional line of evidence next to probabilistic and ML approaches.

Soil quality index: BBNs are presented as a strong way to quantify expert judgement and disagreement without forcing a single rigid threshold system. The deliverable recommends improving robustness by strengthening elicitation (more questionnaires and richer causal links between properties and functions) and then extending to Mediterranean-scale mapping.

DELIVERABLE D1.2.1

Methodology for organic carbon analysis and soil quality monitoring

Deliverable **D1.2.1** sets out a **harmonised technical basis** for potential future testing of carbon farming in the **Euro-MED area** by translating standards and scientific approaches into an **implementable monitoring and assessment toolbox**. It focuses on:

1. comparable monitoring of **soil organic matter (SOM)** and **soil organic carbon (SOC)**
2. assessing **soil quality (SQ)** through indicators and **Soil Quality Indices (SQIs)**
3. using **SOC sequestration models** to upscale monitoring and test scenarios
4. identifying **consistent databases** and data rules so results remain comparable across sites and countries.

The deliverable's stated objectives include: selecting indicators for soil functioning and defining a **Minimum Data Set (MDS)**; standardising reference values and sampling schemes; proposing analytical SOC methods plus simple on-field "self-check" procedures; introducing scalable options such as **Near-Infrared Reflectance Spectroscopy** and **colorimetry-based methods**; proposing carbon sequestration models adapted to Mediterranean agriculture; and reviewing how practices, **Soil Improving Cropping Systems (SICS)** and climate pressures influence SOC sequestration and production.

A central point is that SOC varies strongly across space (and depth), so results depend heavily on **how sampling points are chosen**, not only on lab accuracy. The deliverable distinguishes:

- **Design-based sampling** (probability sampling; uncertainty based on repeated hypothetical random samples), and
- **Model-based sampling** (geostatistics; uncertainty expressed via a spatial model).

It reviews typical designs (simple random, stratified, systematic, cluster, two-stage) and notes that monitoring systems often use **combined designs** (e.g., stratified random plus spatial structure) to improve representation while keeping costs manageable.

Key reference protocols to “borrow” for Euro-MED harmonisation

The document reviews established protocols as building blocks for Euro-MED standardisation:

- **JRC/AFRSS protocol** for certifying SOC stock changes in EU mineral soils: emphasises precise **GPS geolocation** for resampling and recommends **undisturbed sample volumes (≥100 cm³)** for bulk density determination where feasible.
- **LUCAS Topsoil Survey** methodology: a multi-stage stratified random approach with land-cover stratification and **standardised topsoil sampling + lab procedures**, enabling revisited points for change analysis.
- **USDA field guidance**: stresses that sampling must be paired with systematic **site description and management history,** so SOC values are interpretable and comparable.

The deliverable highlights that monitoring is only verifiable if supported by **field metadata**. It emphasises recording:

- current and historical **land use**,
- **litter/woody debris**, and
- management practices (cropping, tillage, fertilisation, **organic inputs**) because these strongly influence carbon pools and help interpret variability and change.

For **disturbed samples** (chemical analyses), it discusses depth strategies (interval sampling, mid-interval, horizon-based) and recommends higher depth resolution near the surface (example: **≤10 cm intervals in the first 30 cm**, larger intervals deeper), since management signals typically appear first in topsoil. It also notes that very shallow depths may be used for properties like **SOM/pH** (e.g., **0–15 cm**) in specific monitoring contexts.

To reduce within-site heterogeneity, the deliverable highlights **composite sampling**: in LUCAS-style practice, **five sub-samples** (one central + four around) are mixed into one composite, with about **500 g** transported for laboratory analysis.

A major technical warning: **SOC stock** (t C/ha) requires **bulk density (ρb)** and **coarse-fragment correction**; otherwise, comparisons across soils (and over time) can be misleading. Bulk density is framed as both:

- an important soil property related to porosity/structure, and

- a frequent source of uncertainty because it varies with depth, moisture, structure and stoniness, and methods behave differently across conditions.

The deliverable reviews:

- **core/cylinder** method (known-volume, oven-dry to constant mass),
- **clod/paraffin** methods,
- **excavation/volume replacement** (often best in stony soils or steep slopes; volume measured with sand of known density or water), and
- **radiation-based** indirect methods (require calibration).

It recommends selecting methods based on site constraints and using replicates plus explicit reporting of sampling moisture conditions to strengthen reliability.

Laboratory SOC methods: reference options and operational alternative summarise three main analytical pathways for organic carbon:

- measure total C and inorganic C then subtract inorganic C,
- remove/destroy inorganic C then measure total C, or
- use dichromate oxidation and quantify unreduced dichromate by titration/colorimetry.

Dry combustion is treated as a reference approach; **automated instruments** are described as fast and precise because they convert C to CO_2 and quantify it via IR absorption, conductometry or gas chromatography. **Loss-on-ignition** is flagged as riskier for SOM quantification because mass loss includes water and other volatiles.

Within dichromate methods, **Walkley–Black** (no heating) is described as widely used but often not fully quantitative, while the heated **Mebius** variant is presented as a more quantitative approach in the same family.

In the conclusions, D1.2.1 highlights rapid options that can complement reference methods:

- improved **quick dichromate oximetric/colorimetric** techniques (refluxing with external heating), reported in the document as capable (in some contexts) of producing SOC values comparable to automated dry combustion, and
- **mild permanganate oxidation** to estimate labile carbon, positioned as an early indicator of SOM quality change.

To overcome cost/time barriers, the deliverable proposes **diffuse reflectance spectroscopy** as a rapid, non-destructive alternative/adjunct that can estimate multiple soil properties from a spectrum. The deliverable argues that improvements in VIS-NIR equipment make **in-situ measurement** increasingly feasible and links spectroscopy to innovations relevant for carbon accounting (e.g., combining vis-NIR with gamma-ray attenuation on fresh cores for bulk-density-related characterization).

Monitoring soil quality and constructing SQIs

Soil quality is framed as the soil's ability to perform functions. Since function measurement is often infeasible, SQ is inferred from **physical, chemical and biological indicators**. The report stresses there is no universal indicator list, so SQI design must match target functions and local contexts.

An SQI is defined as a numerical integration of an **MDS** capturing soil's capacity to perform functions. The deliverable reviews MDS selection through:

- expert judgement, and/or
- statistical reduction (ANOVA, PCA, PLS-based approaches, redundancy/factor analysis).

It notes that many SQI applications converge to **~6–8 indicators**, and that the "best" approach depends on data availability, monitoring purpose, and stakeholder neds.

After selecting indicators, values are normalised to standard scores (often 0–1) using **scoring functions**. The deliverable contrasts:

- **linear scoring** (simpler), and
- **non-linear scoring** (often better represents soil-function complexity),

and lists common non-linear shapes: "more is better", "less is better", "optimum range", "undesirable range". SQI aggregation then combines indicator scores with weights (equal or evidence-based, e.g., statistically derived or expert-set), producing a single interpretable index.

Process-based modelling (RothC highlighted) and an example Euro-MED workflow

RothC is presented as a widely used multi-compartment SOC model with broad application across climates and management and evidence of good performance when well parameterised and validated.

A featured application demonstrates a workflow relevant to Euro-MED: a **spatially explicit (cell-based) RothC simulation** of cropland SOC dynamics in **northern Greece** over 2009–2018, covering around **140,000 ha**. The example uses **Copernicus land cover** to mask agricultural land, processes EO data via Google Earth Engine, and implements modelling in R using **SoilR** with a differential-equation approach—illustrating how EO and spatial processing can support scalable modelling for MRV and scenario planning.

To address the limitation that process-based models often lack spatially detailed soil-property inputs, the deliverable presents **digital soil mapping** frameworks (SCORPAN regression–kriging) and notes the growing role of machine learning for SOC mapping (e.g., Random Forest, Gradient Boosting, Cubist, Quantile Random Forest). These approaches relate SOC observations to environmental covariates (DEM derivatives, climate layers, land cover, EO biophysical indicators) to produce spatial prediction and change estimation.

It also highlights a Europe-wide SOC change example using **quantile Generalised Additive Models (qGAM)** with repeated **LUCAS** measurements (revisited points in 2009/2015/2018). qGAMs are described as flexible non-parametric models capturing non-linear relationships via smooth effects, with robustness when variance changes with predictors.

D1.2.1 treats data infrastructure as a prerequisite for standardisation. **LUCAS** is identified as a key harmonised European reference because it applies standardised sampling and lab analysis across member states and includes revisited points—supporting trend analysis and calibration/validation of spatial models.

The deliverable also points to global soil-profile initiatives (e.g., **WoSIS**) and national/regional soil monitoring datasets, stressing that interoperability depends on consistent metadata: depth conventions, bulk density and coarse-fragment reporting, analytical method and units. It implicitly recommends defining these metadata requirements early in Euro-MED pilots to avoid unreliable dataset merging for MRV and modelling.

The deliverable's literature synthesis concludes that SOC sequestration in croplands can be strengthened through integrated systems and practices including **conservation tillage, cover crops, crop rotation and fertilisation strategies**—and that sustainable practices can improve soil health and yields while enhancing SOC storage and climate-change mitigation.

At the same time, Mediterranean regions are presented as highly exposed to land degradation pressures (fires, intense cultivation and inadequate management), leading to desertification, erosion, landslides and SOC decline. This implies Euro-MED pilot design must be **climate-zone aware** and explicitly address erosion and drought risks, because these processes can offset sequestration gains and complicate interpretation of monitoring results.

What D1.2.1 "hands over" to the Action Plan?

Sampling & fieldwork: explicit sampling design, GPS-based revisits, composite sampling, and mandatory bulk density + coarse-fragment handling for SOC stock calculations.

Analytics: documented SOC method choice (dry combustion where possible), complemented by validated rapid techniques (quick dichromate colorimetry) and labile-carbon tests (permanganate oxidation) for early-warning signals.

Scalability: spectroscopy (VisNIR/MIR) supported by calibrated spectral libraries and transparent predictive modelling (PLS/SVR/CNN).

Soil quality: MDS-based SQI construction with clear scoring/weighting rules and Mediterranean degradation sensitivity built in.

Modelling: combined use of validated process-based models (e.g., RothC) and data-driven spatial models (ML/qGAM), anchored in harmonised datasets such as LUCAS.

D1.2.1 mentions a few "simple / practical" ways to monitor **soil quality** and/or **SOC-related change** (as proxies for carbon sequestration). The document is clear that each method has trade-offs, but these are the most "lightweight" options it highlights:

1) Quick SOC testing with colorimetry-based dichromate oxidation**:** The deliverable notes **quick dichromate oximetric/colorimetric techniques** (with refluxing + external heating) that can provide **SOC values equivalent to automated dry combustion**.

2) Mild permanganate oxidation for "labile" (easily decomposable) carbon**.** The deliverable highlights a **straightforward and efficient** method using **mild permanganate oxidation** to measure **easily decomposable carbon**, useful to detect **early changes in SOM quality**.

3.) Simple" soil quality indicators / indices (easy to calculate but limited)**.** The deliverable notes examples of **simple SQIs** based on **one parameter**, such as:

- the **metabolic quotient (qCO_2)** (respiration / microbial biomass),
- **microbial biomass C / total organic C ratio**,
- and **enzymatic measurements** linked to microbial activity—while also warning that single indicators often miss important soil functions.

DELIVERABLE D1.3.1.

Guidelines for Carbon Farming Techniques

Deliverable **D1.3.1** compiles **practical guidelines** on carbon farming techniques that can **increase or preserve Soil Organic Carbon (SOC)** while improving **soil quality** and resilience in the **Mediterranean / Euro-MED context**. The document is written as a "decision support" overview: it explains what each practice is, where it can work well, what co-benefits it brings, what risks/trade-offs it has, and what cost/feasibility issues to expect.

A key starting point is that many Mediterranean soils are already under stress (erosion, drought, organic matter decline). The report notes that maintaining existing SOC stocks is itself a major climate and soil-health benefit, because projections indicate SOC decreases in parts of Southern Europe under climate change if no countermeasures are taken.

The deliverable groups practices into four families, and for each practice provides: **Definition – Mitigation potential – Co-benefits – Disadvantages/risks – Costs – Geographical suitability**.

1. Soil management

ORGANIC MULCHING means keeping the soil surface covered with organic material (e.g., straw, chipped pruning's, wood chips or other biomass). It supports SOC mainly by adding carbon inputs and by limiting erosion and rapid drying of the topsoil. In Mediterranean conditions it can improve moisture retention, reduce surface crusting and temperature extremes, and create better conditions for soil biota—often translating into improved structure and infiltration. Practical constraints are usually about biomass availability, transport and spreading, and the need to manage weeds/pests that may benefit from cover. Costs vary widely: they can be low if residues are on-farm, but rise quickly with purchased material and hauling, so the best fit is where erosion or water stress is a dominant problem and local organic material is accessible.

CONSERVATION TILLAGE reduces the intensity and/or frequency of soil disturbance compared with conventional inversion tillage, while usually keeping a protective residue cover on the surface. By disturbing aggregates less, it can slow SOC mineralisation and help retain carbon near the surface; residue cover also reduces erosion losses. The deliverable reports that in warm/dry temperate (Mediterranean-type) contexts, additional SOC storage has been observed, but responses are variable and may plateau over time as soils approach a new equilibrium. Co-benefits often include better stability, improved infiltration, and lower fuel/labour needs. Main trade-offs are the transition learning curve, possible short-term yield variability, and, in some systems, greater reliance on herbicides for weed control. Suitability is broad, but requires good residue and traffic management to avoid compaction or poor seedbeds.

NO-TILL is the most intensive form of reduced tillage: crops are seeded with minimal soil disturbance (often a narrow slot), and residues remain on the surface year-round. The technique aims to protect SOC by avoiding aggregate breakdown and by keeping soil covered, which strongly reduces erosion—an important benefit on Mediterranean slopes and in intense-rainfall events. Reported SOC gains can be significant but are often concentrated in the topsoil, and outcomes depend on residue inputs, rotations and moisture regime. Co-benefits may include improved water retention, more stable structure, and reduced fuel use, but trade-offs include higher weed pressure and a management shift toward herbicide-based control, plus possible surface compaction if traffic is not managed. Adoption typically works best when combined with cover crops/rotations and tailored machinery.

STRIP/PRECISION (ZONE) TILLAGE disturbs soil only where the crop row will be, leaving the inter-row largely undisturbed and residue covered. It is a compromise between conventional tillage and no-till the tilled strip can reduce bulk density locally and improve seedbed conditions, while the untilled zones retain structure, biological activity and surface protection that help conserve SOC and reduce erosion. The deliverable notes that Mediterranean-specific sequestration rates are not yet well quantified, but the approach is linked to better water storage and improved soil properties in undisturbed areas. Typical trade-offs mirror other reduced-tillage systems—equipment needs, learning curve, and sometimes increased herbicide use—yet operating costs are often lower than full conventional tillage. It can be useful where growers want residue cover but still need a reliable seedbed in challenging soils.

2. Organic additions

MANURE APPLICATION (solid, slurry or liquid; often with bedding) is added to soils as an organic amendment. It can increase SOC by supplying both readily decomposable and more stable organic fractions, while also improving soil structure and biological activity. In Mediterranean contexts, the deliverable reports substantial SOC benefits in some studies (e.g., strong increases in topsoil stocks), alongside improvements in bulk density, aggregation and water retention. Key risks relate to nutrients rather than carbon: phosphorus accumulation and runoff, nitrate leaching if timing/doses don't match crop uptake, and possible trace element build-up depending on sources. Practical costs are often dominated by transport, spreading and storage, so feasibility depends on proximity to livestock systems and compliance with nutrient regulations. Best performance is usually achieved when manure is integrated with good rotations, residue management and erosion control.

RETURNING CROP RESIDUES (straw, stover, prunings) to the soil—either incorporated or left as surface cover—raises carbon inputs and supports SOC maintenance, especially where residues would otherwise be removed or burned. The deliverable notes long-term cases where residue retention increases SOC both in topsoil and deeper layers but also warns outcomes can vary high C:N residues may temporarily immobilise nitrogen, and faster decomposition can increase CO_2 emissions (sometimes described as "priming") if conditions favour rapid mineralisation. Co-benefits include better aggregation, erosion reduction, improved microbial habitat and nutrient recycling. Trade-offs include potential pest/disease carryover and operational constraints (machinery, timing). It is widely applicable in Mediterranean systems but works best when paired with cover crops/rotations and nutrient management that avoids N limitation during decomposition.

COMPOST APPLICATION - Compost is stabilized organic matter produced by controlled aerobic decomposition. It contributes to SOC by adding humified material that can persist longer than raw residues, while improving soil structure and nutrient availability. The deliverable reports Mediterranean long-term trials with large SOC stock increases in some cases, but results depend on compost quality, application rates, soil texture and baseline SOC. Co-benefits can include improved water retention, aggregation and sometimes disease suppression, with potential yield/quality benefits. Risks arise mainly from poor-quality feedstocks or insufficient composting: contaminants may enter the soil, and inadequate processing can disturb soil microbiology. Costs depend on whether compost is produced on-farm or purchased; transport and spreading are major factors. It is generally suitable across Mediterranean zones, especially where organic matter is chronically low.

BIOCHAR AMENDMENT - Biochar is a carbon-rich material made by pyrolyzing biomass under limited oxygen. Its key feature is persistence: the deliverable notes long residence times (from decades to millennia depending on properties), making it attractive for long-term carbon storage. Biochar can also improve soil water holding, nutrient retention and microbial habitat, potentially supporting drought resilience and reducing some emissions (e.g., N_2O) in certain contexts. However, effects are highly variable: some soils show strong benefits, while others show limited yield/SOC response. Risks include nitrogen immobilisation, uncertain long-term impacts on soil biology, and contamination if feedstock or production quality is poor. Costs can be high (production, transport, application), so feasibility often depends on incentives or linking to local biomass/pyrolysis supply chains and quality standards.

SEWAGE SLUDGE (biosolids) is treated material from wastewater treatment, sometimes applied to land as an organic amendment under strict regulation. It can add organic carbon and nutrients and improve physical properties (porosity, aggregation, moisture retention) and microbial biomass. The deliverable stresses that SOC gains are strongly dose- and context-dependent; some long-term trials report SOC increases mainly at very high rates, and the net climate benefit can be offset by increased CO_2/N_2O emissions if decomposition is stimulated. The primary concerns are contaminants and hygiene: heavy metals, organic pollutants, microplastics and pathogens require robust treatment, monitoring and compliance with national rules. Farmer costs may be low if disposal is subsidised by treatment plants, but acceptability, regulation and public perception often determine practicality.

DIGESTATE APPLICATION - digestate is the residue from anaerobic digestion (biogas production) of manure and/or biomass. It typically has a liquid fraction rich in readily available nitrogen (often as ammonium) and a solid fraction with more stable organic matter. The deliverable notes that many studies are short-term, but multi-year applications often show SOC increases, especially where the solid fraction contributes persistent carbon. Co-benefits include partial substitution of mineral fertilisers and potential improvements in aggregation and microbial activity. Risks relate to handling and nutrient losses: digestate production is continuous, so storage capacity is needed; application windows may be restricted (e.g., nitrate rules), and there can be risks of salinity/alkalinity build-up or ammonia losses if applied incorrectly. Practical feasibility depends on proximity to biogas facilities, storage infrastructure, and nutrient management planning to avoid water pollution.

3. Cultivation practices

CROP ROTATION means planning a multi-year sequence of different crops on the same field (often including legumes, deep-rooted crops, and/or cover crops). In carbon-farming terms, rotations support SOC by diversifying biomass inputs (above- and belowground), spreading residue types over time, and improving nutrient cycling that sustains plant growth and carbon return to soil. Rotations can also reduce disease and pest pressure, improve soil structure, and stabilise yields—important under Mediterranean climate variability. The main limitation is that SOC response is highly context-dependent: benefits are stronger where rotations increase total biomass and root inputs and where residues are retained. Trade-offs can include extra management complexity, market constraints for alternative crops, and the need for machinery/knowledge to handle different crop types. Rotations are generally low-risk and widely applicable, often acting as the "backbone" practice that improves the performance of other techniques.

COVER CROPPING introduces non-cash crops between main crops or within perennial systems (e.g., orchards, vineyards) to keep soil covered and biologically active. The deliverable reports strong SOC benefits in Mediterranean woody systems in some syntheses, largely driven by increased carbon inputs and erosion reduction. Co-benefits include improved aggregation and infiltration, reduced runoff and erosion, weed suppression, and increased biodiversity. The key Mediterranean trade-off is water: in semi-arid zones, cover crops can compete with the main crop for moisture and reduce yields if not carefully managed (species choice, timing of termination, and irrigation strategy). There can also be variability in SOC outcomes if residues stimulate rapid decomposition ("priming") under some conditions. Overall, cover crops are presented as a high-potential practice when designed to fit local rainfall and farming systems.

INTERCROPPING grows two or more crops in the same field at the same time (or integrates understory species in orchards/olive groves/vineyards). The technique aims to raise SOC by increasing total biomass production, extending soil cover duration, and diversifying root systems and residue quality. It can also support soil structure, nutrient cycling (especially with legumes), and ecological pest regulation. In Mediterranean contexts, performance depends strongly on design: crop pairing, planting density, competition management, and especially water availability. The major risk is competition for scarce resources (water, light, nutrients), which can reduce cash-crop yields if mixtures are not well adapted. Intercropping is most suitable where management capacity is high and where water stress can be managed (through species choice and timing).

INCREASING ROOT BIOMASS targets the belowground carbon pathway by using crop species, varieties, or management that allocate more carbon to roots and root exudates (and/or increase rooting depth). Because belowground carbon inputs can be more effectively stabilised in soil, this practice is framed as promising for SOC and soil structure improvement. It can also enhance aggregation, water infiltration, and drought resilience, which matters in Mediterranean climates. However, outcomes depend on crop choice and local limits: in dry or nutrient-poor systems, pushing for higher root biomass can create trade-offs with aboveground yield or require supportive fertility and water management. The deliverable treats it as a practice that often works best as part of broader system redesign (rotations, cover crops, reduced tillage), rather than as a single isolated measure.

CONVERSION TO GRASSLAND - converting cropland to permanent or long-term grassland replaces annual disturbance with a more stable vegetation cover and continuous root turnover. The deliverable cites sequestration rates from syntheses and long-term experiments and describes the practice as effective for SOC increases and erosion control, with additional biodiversity and landscape benefits. Grasslands can build SOC through dense root systems and reduced soil disturbance, and they often improve soil structure and water regulation. Key trade-offs are socio-economic and system-level: farmers may face income loss without incentives, and if conversion is linked to intensified grazing, livestock emissions (CH_4/N_2O) can offset climate benefits. Carbon gains can also be depth-distributed, meaning monitoring limited to topsoil may not capture full changes. The practice is best suited where erosion control and land restoration are priorities and where business models (fodder, extensive grazing, payments) support viability.

4. Cultivation systems

AGROFORESTRY integrates trees with crops and/or livestock on the same land. In carbon-farming terms, it increases total biomass production and channels carbon into both aboveground woody biomass and belowground roots, while also supporting SOC through litter inputs and improved microclimate. In Mediterranean settings it can reduce erosion, improve infiltration, buffer temperature extremes, and enhance biodiversity and landscape values. The benefits are strongly site- and design-dependent (tree density, species choice, spacing, management). Key trade-offs include competition for water and light—critical in semi-arid zones—plus higher management complexity (pruning, harvesting, machinery access). Establishment costs can be significant and benefits accrue over longer timeframes, so agroforestry is best suited where long-term land stewardship, erosion control and diversification benefits are priorities and where water competition can be managed.

ORGANIC FARMING is a system approach based on avoiding synthetic fertilisers and pesticides, and relying more on rotations, organic amendments, biological regulation and soil-building practices. The deliverable links organic systems to SOC and soil-quality improvements in many contexts, mainly because they often increase organic inputs (manure/compost, residues), diversify crops, and build soil biological activity. Co-benefits can include improved structure, water retention, and biodiversity, plus market premiums where supply chains exist. Trade-offs include possible yield gaps during transition or under high pest pressure, higher labour/management needs, and risks of nutrient imbalances if organic inputs are not well planned. Certification requirements and market access also shape feasibility. In Mediterranean regions, organic performance depends heavily on moisture regime and the ability to maintain cover and organic inputs without increasing water stress.

CONSERVATION AGRICULTURE is presented through three core principles: minimal soil disturbance, permanent soil cover, and diversified cropping (rotations/cover crops). As a system, CA aims to build SOC by reducing mineralisation from disturbance, increasing residue/biomass inputs, and limiting erosion—often making it particularly relevant for Mediterranean erosion-prone landscapes. Co-benefits include improved aggregation, infiltration, and potentially better drought resilience due to higher soil cover and organic matter. The main challenges are implementation and transition: weed control may rely more on herbicides, specialised seeding equipment is often needed, and farmers face a learning curve to manage residues, traffic and rotations effectively. Outcomes vary by soil and climate, but CA is framed as a robust “package” when its principles are applied together rather than partially.

Across all techniques, the report repeatedly stresses that outcomes depend on (i) Baseline SOC, soil texture, climate zone, and erosion risk (highly relevant in Mediterranean conditions), (ii) Time horizon: many practices show meaningful SOC change only over several years (or longer), and sometimes mostly in topsoil unless deeper processes are influenced, (iii)

Trade-offs: some techniques can raise SOC but also create risks (e.g., nitrogen losses / N_2O increases, water competition in dry regions, contaminants in amendments).

The deliverable also highlights “real-world adoption” barriers: know-how gaps, equipment needs, yield uncertainty during transition, regulatory constraints, and the need for incentives/support where income loss or extra management is expected.

D1.3.1 is most useful as a **ready “selection + design” guide** for future **Action Plan for testing carbon farming**, because it helps to move from a generic ambition (“test carbon farming”) to **concrete pilot packages** (what to test, where, with whom, how to manage risks).

D1.3.1 can be used as a **practical "design manual" for the Action Plan**, because it **helps translate the general idea of carbon farming into concrete pilot tests.** It provides a structured catalogue of techniques with their expected effects on SOC and soil quality, typical co-benefits (erosion control, moisture retention, biodiversity, yield stability), and the most common trade-offs (water competition in dry zones, nutrient losses, herbicide reliance in reduced tillage, contamination risks from some organic amendments). This makes it suitable for selecting and justifying a shortlist of techniques and bundling them into pilot "packages" that fit different farm types (arable vs. woody crops), soil conditions and Mediterranean climate zones. It also supports the Action Plan by offering a basis for a site-by-technique matching matrix (which practice where and why), by helping define multi-criteria success indicators beyond carbon (SOC + soil function + resilience), and by feeding directly into a pilot risk register with mitigation measures and monitoring triggers. In addition, the deliverable helps identify which stakeholders need to be involved for each practice (farmers, advisors/research, businesses such as machinery or compost/biogas operators, and public authorities/regulators), and it highlights where training and advisory support will be essential for adoption. Finally, it informs feasibility and budgeting assumptions by indicating where costs typically arise (equipment change, transport/application of amendments, long establishment times, compliance and quality control), helping the Action Plan realistically plan resources and incentives for future testing.

DELIVERABLE D1.4.1.

Carbon farming socio-economic models

Deliverable provides 4 cooperation models, that could be tested, based on action plan:

1. WITHIN THE AGRI-FOOD CHAIN (VALUE-CHAIN COLLABORATION)

In this model, farmers collaborate with **food retailers and/or food processors** to build **sustainable / green value chains**. The collaboration is often organised through **agricultural cooperatives** or larger enterprises working with smaller farmers, where farmers are **rewarded for sustainable or organic farming** (e.g., price premium, preferred supplier status, contract conditions linked to practices). For a future Action Plan, this model is ideal to test "market pull": whether downstream actors are willing to pay for verified practice changes and how requirements (traceability, minimum standards, audits) affect adoption. A pilot can test: (a) the **incentive design** (premium per ton/product vs per hectare vs per practice), (b) contract rules, (c) advisory support provided by the buyer/co-op, and (d) how carbon-farming practices integrate with quality/food safety schemes. Success can be measured by farmer uptake, continuity after the pilot, and the ability to scale through existing supply-chain networks

2. OUTSIDE THE AGRI-FOOD CHAIN (PAYMENTS FROM NON-FOOD ACTORS / DONORS)

Here, farmers receive payments for land-management practices from **companies outside the food chain** (examples given include **event industry** and **ecotourism**), as well as from **public institutions or NGOs**. Funding can come via cooperatives or **direct payments from donors**, supported by environmental awareness, **green procurement**, civil society /company donations, or even voluntary contributions linked to **carbon offsets (voluntary carbon credits)**. For the Action Plan, this model is useful to test "external demand" for ecosystem services: who pays, for what outcome, and under which conditions. A pilot can test different payer types (private sponsor vs NGO vs municipality), payment logic (practice-based vs outcome-based), and credibility mechanisms (basic monitoring vs third-party verification). It also allows testing storytelling/communication components that are often central to donor-backed schemes.

3. AT THE FARM LEVEL (DIRECT-TO-CONSUMER / DIRECT-TO-BUSINESS VALUE CAPTURE)

   In this model, farmers work directly with **environmentally conscious consumers or businesses** who recognise added value and are **willing to pay more**. Trust is built through **certification mechanisms or advertising** (i.e., communication and proof of improved practices). For a future Action Plan, this model can test whether carbon farming can be financed through **product differentiation** rather than external subsidies: e.g., premium pricing, membership/CSA-type relationships, farm branding, or B2B niche supply agreements. A pilot can test the minimum evidence needed to maintain trust (simple documentation + occasional soil tests), which communication formats work, and how sensitive the premium is to yield variability and added labour. This model is especially relevant for smaller farms with strong customer relationships and for regions where "local and sustainable" narratives can be mobilised.

4. LOCAL ADMINISTRATION / REGIONAL GOVERNMENT LEVEL (PUBLIC INCENTIVES + FUTURE COMPLIANCE MARKETS)

   This model relies on public-sector instruments: farmers benefit from **payments to promote low-carbon farming** (e.g., **CAP-type support**), **payments for ecosystem services (PES)**, **green procurement**, or **tax incentives**. The document also notes an expectation that soon the EU or national governments may establish **official carbon credit markets**, enabling farmers to earn credits and sell them to companies seeking offsets. For the Action Plan, this model is best for testing "policy-driven scaling": how to design an administratively feasible scheme, what monitoring and documentation are realistic, and how to align carbon-farming actions with existing rural development tools. A pilot can test administrative workflows (application, eligibility, control checks), farmer support services, and minimum MRV rules that remain credible without becoming too burdensome—plus how public funding could later blend with (or transition to) regulated carbon credit mechanisms.

Deliverable provides a **ready-made evaluation framework** for designing and testing carbon farming pilots in a structured, comparable way. It is built around a simple but robust logic: every pilot should be assessed in **two phases**—a **baseline measurement (before implementation)** and a **post-implementation evaluation (after implementation)**—so that the Action Plan can clearly show *what changed*, *for whom*, and *why*. The baseline captures the "starting point" (current practices, socio-economic conditions, environmental challenges), while the post-implementation phase measures outcomes linked to the chosen carbon farming approach and collaboration model.

DELIVERABLE D1.5.1.

Recommendations on agriculture carbon credit schemes and environmental certification systems

Deliverable **D1.5.1 – "Recommendations on agriculture carbon credit schemes and environmental certification systems" (Dec 2025)** provides a policy- and market-oriented foundation for how **carbon farming in Euro-MED** could move from "good practices" to **credible certification and financing mechanisms**, while staying compatible with emerging EU rules (especially the **CRCF**) and Mediterranean realities (drought, erosion, low SOC baselines, fragmented farms). The deliverable positions carbon farming as a **dual opportunity** for the Euro-Mediterranean region: climate mitigation through increased **soil organic carbon (SOC)** and **soil quality/resilience** benefits (water retention, structure, reduced erosion), but it underlines that **incentives and credible MRV** are the limiting factors for uptake. It therefore reviews (1) the **EU policy/legal framework**, (2) existing **carbon credit and certification schemes**, and (3) proposes a **conceptual Mediterranean-adapted certification approach**, followed by **policy recommendations** for scaling and readiness.

The deliverable clarifies how a "scheme" typically combines a **standard/methodology**, governance rules, a **registry** to prevent double counting, and a market mechanism; and it distinguishes:

- **Compliance markets** (e.g., EU ETS logic), which generally exclude agricultural soil carbon due to permanence and uncertainty but set expectations about integrity and tracking.
- **Voluntary carbon markets (VCM)**, currently the main space where soil carbon projects operate, including corporate demand and project developers; plus "**insetting**" (value-chain internal reductions/removals rather than external offsets), which may suit Mediterranean cooperatives and high-value perennial supply chains.

  It highlights major voluntary standards and what they imply for Mediterranean design choices:

- **Verra/VCS** as widely used, but with concerns around model calibration and uncertainty that can be especially problematic under Mediterranean variability.

- **<u>Gold Standard</u>**, more conservative and co-benefit oriented; **Plan Vivo** (community/smallholder focus); **Climate Action Reserve** (high-rigour permanence rules but tuned to other contexts).

It also points to Mediterranean-relevant initiatives (as learning references, not "copy-paste" solutions): e.g., **Cultiva Carbono (Spain)**, **AgreenaCarbon** operating across southern Europe, **Label Bas-Carbone** applications in southern France, and research projects like **LIFE CLIMAMED** that generate field evidence and monitoring insights.

The overall conclusion is that **no existing scheme is directly transferable**: most are built for temperate/high-productivity conditions and do not fully capture SOC dynamics and risks in dry, erosion-prone landscapes.

MRV and credibility (the backbone problem)

A central part of the review is MRV feasibility and integrity. It outlines:

- Soil carbon MRV must detect **small annual SOC changes** in a variable medium; this is harder (and costlier) in Mediterranean mosaics of land use, shallow/stony soils, and high interannual climate variability.
- The IPCC "Tier" logic is used to show why higher-quality approaches typically require **regional calibration and modelling + measurements**.
- Three MRV strategies are compared: **measurement-based** (accurate but expensive), **model-based** (scalable but risky without calibration), and **hybrid MRV** (sampling + models + remote sensing), described as increasingly preferred and aligned with the direction of CRCF expectations

Instead of proposing a finished scheme, the deliverable proposes **design principles** for a Euro-MED adapted approach, meant for **future piloting/testing**:

- **Mediterranean-specific baselines and stratification** Baselines should not rely on broad EU averages; they should be built through stratification by **soil texture, rainfall, slope, land use and erosion susceptibility**, reflecting local pedo-climatic realities.
- **Practice eligibility based on Mediterranean evidence** High-potential practice families are flagged (e.g., **agroforestry, perennial systems, organic amendments, controlled grazing, erosion-control measures**), while noting that some commonly promoted practices (e.g., certain reduced tillage/cover cropping variants) may have **inconsistent carbon outcomes** in dry conditions if not adapted.
- **Multi-scale, hybrid MRV architecture** to lower cost and increase credibility The proposal combines: (i) farm-level logs + basic sampling + land-use

checks, (ii) landscape remote-sensing indicators (cover/biomass, erosion-risk proxies)

Policy recommendations and "path forward"

The recommendations converge on a staged readiness pathway:

- invest in **soil monitoring infrastructure** and Mediterranean-calibrated baselines.
- promote **hybrid MRV** and shared calibration resources.
- design permanence rules proportionate to Mediterranean risks.
- build **aggregator governance** (cooperatives/advisory structures) to reduce cost and complexity.
- ensure alignment with **CRCF + EU registry** and manage interactions with **CAP and LULUCF** to avoid double funding/double counting.
- prioritise **capacity building** (farmers, advisors, administrations) and a **phased approach** using pilots to refine assumptions before standardisation.

DELIVERABLE D2.1.1.

Strategic analysis for soil quality improvement in Mediterranean climate

Deliverable provides a **comparative "readiness and feasibility map"** for scaling carbon management / carbon farming in Mediterranean agriculture. It synthesises evidence from **six partner countries (Greece, Italy, Montenegro, North Macedonia, Slovenia, Spain)** and explains what currently enables carbon farming, what blocks it, and what needs to be put in place before large-scale future testing and implementation can work.

A key message is that Mediterranean agriculture is operating under intensifying climate stress: hotter/drier summers, more variable precipitation, and more frequent extremes. Drought, land abandonment, fire risk and erosion are strongly shaping soil resilience and management choices. The report also stresses **biophysical limits** for sequestration in many Mediterranean soils: shallow soils, carbonate-rich soils, coarse textures, high mineralisation rates, and in some locations SOC saturation. This means "one model fits all" approaches do not work; carbon farming must be **site- and zone-specific**, and sometimes the biggest benefit is **avoiding further degradation** rather than claiming large SOC increases.

Key findings from the PEST analysis (cross-country)

POLITICAL AND REGULATORY READINESS

There is broad alignment with EU strategies (Green Deal, CAP strategic plans, CRCF), but a clear **implementation gap** across countries. Common weaknesses include:

- no formal/legal definition or recognition of carbon management,
- lack of certified **MRV protocols**,
- fragmented coordination among institutions, and
- lack of functioning carbon markets/registries.

Italy and Spain appear most advanced in integration and innovation (often regionally driven), while Montenegro and North Macedonia are still building basic legal frameworks and enforcement capacity. The CRCF is framed as a major opportunity to "close the gaps" but requires national translation into workable systems.

ECONOMIC FEASIBILITY

Across all countries, economic support is dominated by the **CAP** (eco-schemes/AECMs) and is mostly **practice-based**, not tied to verified carbon outcomes. No country has a fully functioning agricultural carbon credit market; Italy and Spain are the most advanced in registry development.

Major barriers for farmers (especially smallholders) include:

- high upfront costs (equipment, practice change, monitoring),
- unclear return on investment,
- limited access to affordable MRV/certification,
- carbon price uncertainty or absence.

SOCIAL ACCEPTANCE AND CAPACITY

Farmer awareness of "carbon farming" as a concept is generally low (even if soil conservation practices are partly familiar). Where the term exists, it is often associated with bureaucracy and uncertain benefits. Resistance is both **cultural** (traditional practices like deep tillage, monocultures) and **economic** (risk and costs).

At the same time, the report notes growing interest among **younger, better educated farmers**, NGOs, advisors/consultants and research organisations—especially where demonstration activities exist. However, training and advisory systems remain fragmented and not yet scaled to mainstream carbon management.

TECHNOLOGY AND MRV READINESS

Scientific capacity exists in several countries (notably Italy, Spain, also Slovenia and Greece), but farm-level adoption is constrained because tools are often too expensive, too complex, or not standardised. The region lacks farmer-friendly platforms and a shared MRV backbone; there is a gap between strong R&D and practical uptake. Pilot technologies (sensors, GIS, blockchain/traceability platforms, digital farm tools) are mentioned as emerging mainly through EU projects, but the report emphasises that scaling requires **integration into extension systems**, lower cost, and national MRV standardization.

Stakeholder analysis: who matters for future testing and scaling

The stakeholder mapping confirms that:

- **Ministries** (agriculture/environment) are most influential, but their prioritisation of carbon farming varies by country.
- **Research institutions** are highly engaged and often drive method development and pilots, but their policy influence depends on science–policy links.
- **Advisors and cooperatives** are key intermediaries for translating practices into farm reality, yet carbon metrics are not fully mainstreamed in extension curricula.
- **Farmers**, especially smallholders, are central implementers but face the strongest barriers (profitability, knowledge, access to technology and incentives).
- **Consumers** currently have low influence/awareness; demand for carbon-labelled food is not yet a driver, although interest in organic/local food is rising in some contexts.

Recommended strategic actions

Carbon farming can meaningfully improve Mediterranean agricultural resilience and long-term productivity, but success is context-dependent and currently constrained by the enabling environment. The recommended strategic actions (highly relevant for an Action Plan for future testing) are to:

- prioritise **locally adapted approaches** that deliver benefits beyond carbon (water regulation, biodiversity, food quality),
- accelerate creation of **MRV infrastructure** compatible with the **EU CRCF**,
- develop **economic instruments** (subsidies, PES, carbon credits) that reduce adoption risk—especially for smallholders,
- expand **training/extension/advisory services** and integrate carbon management into national systems,
- strengthen **technology transfer** from research to practical farmer tools.

DELIVERABLE D2.2.1.

Training material for carbon farming

Deliverable **D2.2.1** is essentially the project's **ready-to-use training package** and a tested methodology for **upscaling carbon farming knowledge** across the Euro-Mediterranean area. Its strongest practical value for a future **Action Plan for testing carbon farming** is that it already provides: (1) a **structured curriculum**, (2) an **eLearning delivery system**, (3) **multi-format materials** suitable for different audiences, and (4) **evidence from pilot trainings** showing what works and what needs adaptation when training diverse target groups.

D2.2.1 prepares a set of **transferable training materials on carbon farming**, specifically designed to introduce carbon farming to five key stakeholder groups: **advisors/agronomists, farmers/practitioners, policy makers, researchers, and students**.

For an Action Plan that aims to stimulate **wider uptake of carbon farming**, this deliverable provides a concrete "training backbone" that can be scaled without starting from scratch.

The training package is organised into **five modules** that cover the core logic needed for future testing and implementation:

- **Soil quality** (definition, importance, benefits of improvement)
- **Soil carbon cycle** (global and soil carbon cycle, sequestration, how practices influence SOC, techniques for measuring soil carbon)
- **What is carbon farming?** (definition, practices, aspects and opportunities)
- **Benefits of carbon farming & how to choose techniques** (environmental/economic/social benefits; selection guidance)
- **Practical guide for farmers to benefit from carbon credits** (carbon credit basics, how agriculture fits, EU framework for certifying removals, trends shaping future markets)

A key "upscaling" feature is that the materials are not only slides. D2.2.1 packages each module into multiple learning formats:

- **Presentation (PDF)**
- **Video of the presentation** (typically ~11–15 minutes)
- **Brochure** (for most modules)
- **Self-evaluation quiz**
- **Additional resources** for deeper reading.

All materials are hosted in a dedicated **eLearning platform** provided by Aristotle University of Thessaloniki (AUTH), with course topics structured so participants can access content **before and after live sessions.**

The training materials are intended to be **ready-to-use**, **publicly available**, and transferable for future projects or direct use by practitioners.

FOR FARMERS AND PRACTITIONERS, the most appropriate content is delivered through Module 1 on soil quality, Module 3 on the definition and logic of carbon farming, and Module 4 on the benefits of carbon farming and the criteria for selecting techniques, while Module 2 can be used in a simplified form to explain only the parts of the carbon cycle that support practical decision-making, and Module 5 can be included when farmers are expected to engage with incentive or credit schemes. This combination is expected to increase farmers' understanding of why soil management matters, reduce uncertainty about what to implement in pilots, and improve implementation quality by strengthening the link between practices and observable co-benefits such as water retention and erosion control.

FOR ADVISORS AND AGRONOMISTS, the recommended curriculum consists of Modules 1–4 as a coherent technical basis and Module 5 as an additional component that enables advisory services to interpret certification and carbon-credit narratives for farms and cooperatives. This pathway is expected to generate a multiplier effect because trained advisors can translate general guidance into site-specific recommendations, support troubleshooting during pilot implementation, and thereby reduce adoption risks and increase the likelihood of continued uptake beyond the pilot period.

FOR POLICY MAKERS AND PUBLIC ADMINISTRATIONS, Module 5 should be prioritised because it addresses the practical logic of carbon credits and the EU framework for certifying carbon removals, and it should be complemented by Modules 1 and 2 to ground decision-making in soil functions and sequestration mechanisms and by Module 4 to communicate why practice selection must be adapted to local conditions. This configuration is expected to improve the enabling environment for future testing by strengthening policy alignment, supporting realistic MRV and incentive design, and improving the institutional capacity to justify and scale carbon-farming interventions.

FOR RESEARCHERS AND ACADEMIC ACTORS, Modules 1 and 2 are most central because they establish the conceptual basis for soil quality assessment and carbon-cycle processes and introduce measurement-relevant content, while Module 4 is useful for structuring evidence on the conditions under which techniques perform well. This pathway is expected to strengthen the scientific support of pilots by improving baseline design, interpretation of monitoring results, and the production of transferable evidence that can be applied across different Mediterranean pedo-climatic contexts.

FOR STUDENTS AND EARLY-CAREER LEARNERS, the full sequence of Modules 1–5 is appropriate because it provides a complete introduction from soil quality fundamentals through carbon-farming practices to the policy and market context of certification and credits. This pathway is expected to build long-term capacity by normalising carbon-farming knowledge within education and by contributing to a future workforce capable of supporting advisory services, research, and implementation, which ultimately supports diffusion beyond the lifetime of individual pilot projects.

Peer review findings on "Capacity building materials"

In the peer review session, the Natural Heritage Mission (NHM) team highlighted the training package (D2.2.1) as a key leverage point for transferring C4SQ results to target audiences, because the materials are "ready-to-use," hosted on an eLearning platform, and were already tested through six pilot trainings across six countries. The peer review notes that the training was broadly well received, with high satisfaction across countries and stakeholder groups, and that participants appreciated the relevance and structure of the course while also providing clear suggestions for improvement.

The peer review consolidates the main improvement directions into four practical needs for future upscaling: the development of **tailored training pathways** for different stakeholder categories, a stronger link between **theory and practical application**, deeper integration of **economic, environmental, and policy dimensions**, and regular consultation with stakeholders so the training remains responsive to evolving regional needs.

It also captures a concrete list of content upgrades that should increase training effectiveness and adoption potential, namely: adding **real-world case studies** from participating countries, providing **localized recommendations** by climate/soil/farming system, expanding **economic content** (risk analysis and links to CAP/EU Green Deal instruments), adapting delivery with more **visual aids and interactive/practical formats** (especially for farmers), strengthening the **academic basis** with more scientific references, and addressing emerging themes such as the role of **microorganisms** in carbon/water cycles and the potential of **micro-biogas systems** in livestock farming. The peer review stresses that stakeholder groups have different expectations that must be explicitly managed in the training design: researchers and policy makers requested more depth and rigour, farmers and advisors wanted concise and directly applicable guidance, and environmental professionals emphasized integrating broader policy and ecological perspectives. The peer review frames targeted adaptation to these needs as essential for improving both comprehension and real-world application across sectors.

ACTION PLAN FOR TESTING PHASE

The **Interreg Euro-MED will open “Fast Lane” call** as a **targeted call for Test projects** that is **open only to a small list of pre-selected Study projects. Carbon 4 Soil Quality** is one of the project, that could apply to this call. The calls purpose is to allow Study projects to **step up into a Test phase**, i.e., to **adapt, fine-tune and test** the solutions/strategies/action plans developed during the Study phase in **real-life pilot conditions**, with a stronger focus on measurable results and transferability.

Test projects are expected to experiment and validate outputs already developed in the Study phase. The Terms of Reference highlight typical Test activities such as:

- (if needed) limited feasibility/preparatory studies,
- pilot testing of solutions in real conditions,
- monitoring and assessment of pilot results, and
- building a transferability plan so results can be taken up elsewhere.

The call expects Test projects to define **pilot areas** and **target groups** that fit the new testing activities. Target groups can include public authorities, agencies, service providers, NGOs/interest groups, research/education bodies, business support organisations, enterprises/SMEs and the general public, with a strong emphasis on public authorities as core programme target groups. Projects must also actively engage in the Mission thematic community and coordinate with Governance projects, including contributing to shared activities (e.g., meetings, workshops) and pedagogical material for the **Interreg Euro-MED Academy**.

Proposals should have active duration of 24 months, be composed of maximum 10 partners while ERDF budget should not exceed 2 million Euros.

Overall goal of the testing project

To **test and validate carbon farming and regenerative farming solutions** in the Euro-MED area through **lighthouse pilots and living labs**, and to **upscale adoption** via a transferable training and capitalization package that supports wider replication and policy uptake (e.g., integration into CAP-related measures).

POSSIBLE SPECIFIC OBJECTIVES:

1. **Select and test carbon farming / regenerative farming techniques** in at least five Mediterranean pilot territories (covering different climate zones, soils, and erosion conditions) and demonstrate measurable improvements in **soil quality** and climate outcomes (SOC/CO_2 proxies)

2. Establish a **harmonised monitoring and assessment approach** for pilots (e.g., a practical **soil health/soil quality index** plus agreed sampling/monitoring routines) and generate comparable results across sites.
3. **Design, test, and assess collaborative carbon farming business models and value-chain options** (including incentives) using **participatory Living Labs** with end users, resulting in evidence-based recommendations for business sustainability.
4. Deliver **lighthouse demonstrations** (flagship farms/areas) and prepare **on-farm regenerative habitat plans** to strengthen biodiversity synergies and improve acceptance and visibility of carbon farming.
5. **Upscale capacity building** by upgrading and deploying training materials for farmers and advisors (version 2.0), supported by study visits and a transnational Carbon Farming Cluster for continuous learning and adoption.
6. Produce a **transferable Action Plan + policy sandbox outcomes** that support cooperation with Ministries and facilitate practical integration of measures into CAP-type instruments and national/regional support schemes.

POSSIBLE WORK PACKAGE STRUCTURE:

WP1 – TESTING CARBON FARMING

Purpose: WP1 will translate the existing carbon farming guidance (D1.3.1) into **regenerative-farming pilot packages**, implement them in **lighthouse pilot territories**, and generate **comparable evidence** on soil-quality and carbon outcomes using a feasible monitoring approach. The WP ends with a **final Catalogue of Farming Techniques** (what works where, under which conditions, at what cost/risk).

A1.1 - Selection & Testing of Carbon Farming techniques

Based on the D1.3.1 Guidelines for Carbon Farming Techniques, each soil specialist partner will select and test in practice 3 carbon farming techniques in their territory. Testing will be done in the growing season 2026 (May-October). Since partners are coming from different pedoclimate zones within Mediterranean area, they will select those techniques, that are in their opinion the most effective from the perspective of improving soil quality and sequestering greenhouse gas emissions. Testing report will be prepared containing the aspects of advantages, disadvantages, impact on soil quality, impact on CO_2 sequestration, feasibility and costs.

A1.2 – Transnational peer review of Carbon Farming techniques

Monitoring of carbon sequestration and soil quality will be done in the pilot areas. For monitoring the catalogue of soil organic reference values (D1.1.1.) will be used as benchmark reference for SOC values combining with Mediterranean soil quality index to determine baseline. For monitoring, partners will use the results of the D1.2.1 Methodology for organic carbon analysis and soil quality monitoring, using the feasible monitoring methodology, taking the metabolic quotient, microbial mass and enzymatic measurements or other method depending on partners expertise.

After receiving results from monitoring, transnational peer review will be conducted to normalize results and align them with the reality of Mediterranean soil situation.

A1.3 – Testing of carbon farming socio-economic models

Based on deliverable D1.4.1. guidelines for establishment of carbon farming socio-economic models will be prepared. Common transnational guidelines for following Models will be prepared: (i) models within agrifood chain, (ii) models outside agrifood chain, (iii) models at farm level and (iv) models including local administration and regional government institutions. Models will be tested in the growing season 2027 by soil expert partners.

Testing will be done in the growing season of 2027, partners will use one carbon farming technique in combination with one of socio-economic models. Transnational evaluation will be done in the end of the testing period and guidelines will be prepared as the deliverable.

WP2 – TRANSFERABILITY AND CARBON FARMING LIVING LABS

A2.1 Establishment of Carbon Farming living labs

One of EU Mission Soil's goal is to establish 100 real-world "Living Labs" by 2030 to test and promote soil-friendly practices, including carbon farming (capturing carbon in soil/plants), by involving farmers, researchers, and stakeholders in co-creative experiments participative co-design: techniques, value chains, soil quality including workshops with end users for definition of challenges, strengths and weaknesses of CF. Activity will establish MED Carbon Farming living labs in 5 (?) MED territories. Methodology for living labs will be prepared, followed by formal establishment including selection of the participants, preparation of action plans and their implementation. Living labs will be baseline for implementing activities A2.2, A2.3 and A2.4.

A2.2 Improving end users' capacities for carbon farming

Training material for carbon farming (D2.2.1) will be upgraded according to Natural Heritage Mission peer review recommendations. Training material will be tailored for different stakeholder categories as well as a stronger link between theory and practical application will be established. Training material will be added with real-world case studies from participating countries, localized recommendations by climate/soil/farming system and visual aids and interactive/practical formats (especially for farmers). Additional scientific references and addressing emerging themes such as the role of microorganisms in carbon/water cycles and the potential of micro-biogas systems in livestock farming will be added to material. Training material will be available online for free use as well as added to Euro-MED academy for further dissemination purposes and uptake. Deliverable will be training material upgraded into version V2.0.

Trainings will be implemented in 5 (?) countries, each of the partners (PPx) will implement one physical training and one online training in the local language, with at least 50 participants (both events combined). If 50 participants will not be reached, additional trainings will be implemented until the envisaged number of participants will be reached.

Additionally, partners XY will organize study visits to testing fields for farming advisors, extension service providers or decision makers in order to support upscaling the carbon farming in those areas.

A2.3 Transferability of carbon farming techniques to end users

In the growing season 2026, partners will use living labs as test-beds to transfer carbon farming techniques (from A1.1) to end-user farmers. In each of the living labs, at least 5 farmers will implement at least one of the carbon farming techniques in their own field. Expert partners will help them with implementation and help them with knowledge, expertise or other means of support to ease the process and mitigate the possible costs for end users. During this process end users will learn how to implement carbon farming techniques and provide partners will valuable feedback on implementation. One of the goals will be to prepare farmers for future use of carbon farming techniques, especially in the CAP 2027-2034 when farmers will have to more actively contribute to minimizing carbon emissions as well as contribute to improving biodiversity, including soil microbiota and soil quality.

A2.4 End user verification of carbon farming techniques for improvement of soil quality

Within living labs, farmers will provide end-user feedback on the carbon farming for soil quality by structured interviews. Feedback will focus on advantages, disadvantages, impact on soil quality, impact on CO2 sequestration, feasibility and costs. Euro-MED feasibility matrix will be prepared from the end-user point of view to supplement the knowledge produced in A1.2.

WP3 – UPSCALING AND CAPITALIZATION

A3.1 Transnational strategy, localised action plan

Strategy and action plan for carbon farming mainstreaming will give a red line for carbon farming mainstreaming. Strategy will provide vision of carbon farming development; action plan will give roadmap for carbon farming uptake and mainstreaming. Activity will build upon D2.1.1 (Strategic analysis for soil quality improvement in Mediterranean Climate". D2.2.1 stressed biophysical limits for sequestration in many Mediterranean soils: shallow soils, carbonate-rich soils, coarse textures, high mineralisation rates, and in some locations SOC saturation. This means "one model fits all" approaches do not work; carbon farming must be site- and zone-specific, and sometimes the biggest benefit is avoiding further degradation rather than claiming large SOC increases

Action plan will therefore take into consideration specificities of different partner regions, political and regulatory readiness, economic feasibility, social acceptance and capacity as well as technology and MRV readiness.

Policy meeting with decision makers will be organized to discuss and define measures and further cooperation under CAP 2027-2034 to mainstream carbon farming.

A3.2 Operation of Carbon Farming Cluster – transnational connectivity & capacity building

Partners will join Transnational "Carbon Farming Cluster", registered at European Cluster Collaboration Platform. LP will upgrade existing cluster by new members from Euro-MED area. Official transnational recognition of the cluster within the network will enable further connections with complementary clusters (food, processing, environmental…) and apply for future joint activities after project end. Cluster" will implement activities to cooperate with other EU initiatives and link EU policies. Cluster stakeholders will support EU Carbon Farming Initiative (launched in 2021) for example with providing inputs for public consultations, communicate results of the project, link the EU initiative to regional stakeholders and actively participate in forming European Commission's policy and activities on carbon farming. Cluster will also prepare contribution to 2027-34 CAP delivery model and better integration of sustainable farming to the "From Farm to Fork" initiative actions. Cluster will organize two yearly online transnational seminars on the future of carbon farming to discuss latest policy developments.

A3.3 Final conference

Activity will be organized as final project conference, presenting project results, scientific papers and contributions to popular media.

The aim of the conference will be twofold: (i) to present state-of-the-art developments of carbon farming (ii) to raise awareness of decision makers and final users on the benefits of carbon farming (CF)

The conference will have speeches focused on the following aspects, for example:

1.) Practical results of testing different carbon farming techniques in different Mediterranean pedo-climate environments.

2.) Carbon farming as ecosystem services for improvement of soil quality

3.) Future of carbon farming under CAP 2027-2034

4.) Innovative aspects of carbon farming

5.) Future steps for Euro-MED region policy mainstreaming CF.

The conference will be organized in Thessaloniki by AUTH. Representatives of agricultural extension services, regional/national agricultural and environmental decision makers and key stakeholders will be invited. Each partner will cover sots of at least 2 external experts/policy makers.

A3.4 Contribution to the Results Amplification Strategy and to the Programme activities

The activity will allow the improvement of capitalisation and governance approaches for ensuring a stronger impact of project results.

The lead partner will appoint the coordinator for result amplification.

The coordinator will:

- Actively participate in the activities of the thematic community of projects
- Deeply study the Amplification Strategy of the Programme.
- Ensure that project outputs are designed in a transferable way.

- Mobilise the relevant partners to perform joint activities related to the implementation of the Results Amplification Strategy (at project and Programme level).
- Contributing to Euro-MED academy organized by JS/horizontal projects.
- Implement coordination with TCPs and IDPs

The coordinator will ensure that all materials produced by the project will be reusable, combinable and valorised thanks to the synergies with other projects. Activity will include participation on at least two events per year and regular exchange of information between projects and between project and Programme.

POSSIBLE PARTNERSHIP

Implementation of the action plan will require mix of skilled partners with knowledge of carbon farming, soil quality, cooperation models, living labs and agriculture policy. Partners that produced specific deliverables from CARBON 4 SOIL QUALITY used in the action plan will be required to upgrade or transfer these deliverables and outputs in the testing phase. Currently partnership is unbalanced towards research partners, therefore new partnership may require more partners with direct contact with end users (farmers). Partners from new countries, not taking part in the study project, could be added to support transferability to new territories. CREAF was identified as possible partner, since they performed valuable peer review and they are also part of

the Euro-MED Natural Heritage Mission linking project with the Amplification room of the Natural Heritage Community. This would help project to achieve strong uptake and transferability in the future. Partners from CARBONICA project could be added to the consortium, for example North Macedonia national extension service, Greek Ministry of Environment and Energy, ERATOSTHENES Centre of Excellence or Cyprus Pan Agrotikas Association. Possible policy partner could be Region of Emilia Romagna / DG Agriculture (Giampaolo Sarna), who presented policy aspects at the final conference of C4SQ project.

TABLE OF POSSBILE USE OF DELIVERABLES FROM STUDY PROJECT IN THE ACTION PLAN OF TESTING PROJECT

Study deliverable (C4SQ)	What it provides	How it will be used in the Action Plan / next (Test) project	Where it fits (WP / component)
D1.1.1 – Catalogue of soil organic reference values + Mediterranean soil quality index	SOC reference/benchmark values and soil quality index logic for Mediterranean contexts.	Used to set baseline reference values and interpret pilot results; supports defining the starting point for each pilot and comparing change across sites.	WP1 Monitoring & assessment (baseline framing; interpretation of change).
D1.2.1 – Methodology for organic carbon analysis and soil quality monitoring	Harmonised monitoring methodology (sampling, analysis and indicator options).	Provides the standard monitoring protocol for pilots to ensure comparability; guides selection of feasible indicators and measurement approaches depending on partner capacity.	WP1 Monitoring protocol + QA/QC; informs MRV feasibility.
D1.3.1 – Guidelines for carbon farming techniques	Catalogue/guidelines for carbon farming techniques, including benefits, risks and suitability by context.	Main basis to select and design pilot technique packages; partners select techniques based on the guidelines and test them under Mediterranean conditions.	WP1 Selection & testing; feeds the final technique catalogue.

Study deliverable (C4SQ)	What it provides	How it will be used in the Action Plan / next (Test) project	Where it fits (WP / component)
D1.4.1 – Methodology for assessing socio-economic and environmental factors of collaborative business models (4 models)	Framework and four collaborative business model pathways for carbon farming adoption.	Used to test adoption and incentive pathways by combining a technique with a business model and evaluating feasibility and outcomes; supports drafting transnational guidance for business models.	WP2 Living Labs & end-user verification; business model testing.
D1.5.1 – Recommendations on agriculture carbon credit schemes and environmental certification systems	Policy and market review with recommendations for certification and carbon credit schemes.	Used to frame crediting/certification readiness and guide policy and scaling aspects; supports training and policy components on carbon credits, MRV integrity and governance.	WP3 Upscaling & policy integration; supports training content on credits/certification.
D2.1.1 – Strategic analysis for soil quality improvement in Mediterranean climate	Cross-country feasibility/readiness analysis (PEST factors, stakeholder mapping and barriers).	Used to tailor strategy and local action plans to different national contexts (readiness gaps in MRV, incentives and capacity); supports evidence-based policy engagement and mainstreaming pathways.	WP3 Strategy, localisation and policy sandbox.

Study deliverable (C4SQ)	What it provides	How it will be used in the Action Plan / next (Test) project	Where it fits (WP / component)
D2.2.1 – Transferable carbon farming training materials	Modular training package, eLearning delivery and evidence from pilot trainings.	Becomes the capacity-building backbone, upgraded to Training V2.0 (more practical, visual and localised); deployed via national and transnational trainings and online channels.	WP3 Upscaling & training rollout; supports WP2 engagement.
Cross-cutting: Transnational peer review mechanism	Process to align interpretation and comparability of results across pilots.	Used to validate and normalise results across sites, ensuring consistent conclusions despite differing soils, climates and implementation conditions.	Cross-WP: WP1 results validation; supports WP3 capitalisation.