



WP5 | Socio-economic Analyses | Deliverable 5.3

Ecological finance model for Regenerative Agriculture farms

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¹ PU = Public

PP = Restricted to other project participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

List of Acronyms

Acronym	Full title	Acronym	Full Title
RA	Regenerative Agriculture	EU ETS	European Union Emissions Trading System
EU	European Union	NPV	Net Present Value
EU GD	EU Green Deal	SR	Scarcity Rent
EU SFT	EU Sustainability Finance Taxonomy	CT	Conventional Tillage
CS	Case Study	NTR	No-Tillage Rye
SOC	Soil Organic Carbon	NTV	No-Tillage Vetch
KPI	Key Performance Indicator	PAT	Pathogen Treatment
SDI	Soil Degradation Indicator	PATBAC	Pathogen-Bacteria Treatment
EUSO	European Union Soil Observatory	PATBACTRI	Pathogen-Bacteria-Trichoderma Treatment
CICES	Common International Classification of Ecosystem Services	COMP	Compost Treatment
REGENA	REGENerative Agriculture Production Function	MICRO	Micro-Organisms Treatment
PV	Present Value	C-M	Combined Compost and Micro-Organisms Treatment
VaR	Value at Risk	CNT	Treatment Control with No Fertilization
HICP	Harmonised Index of Consumer Prices	MAN	Daily Manure without Top-Dressing Fertilizer
PPP	Purchasing Power Parity	MAN-MIN	Dairy Manure with Top-Dressing Fertilizer
SO	Specific Objective	WP	Work Package

Executive Summary

The large-scale enactment of *Regenerative Agriculture* (RA) practices comprises an element of vital importance for the *European Union* (EU) and its economic transformation towards the monetization of its *natural capital conservation*. The central vehicle of the EU's RA policy is the *Green Deal* (EU GD) and the *Sustainability Finance Taxonomy* (EU SFT) as its financial leverage. The EU GD and EU SFT aim at the *paradigm shift* of financial and banking practices towards the investing on environmental technologies and practices at various sectors. Specifically, the EU SFT consists of six (6) pillars, where pillar 6 concerns "biodiversity and ecosystems' conservation" and is directly related to RA.

SIRAM D5.3 promotes these goals via pilot economic modelling testing and the utilization of data provided by 5 *Case Studies* (CSs) on *Soil Organic Carbon* (SOC) as both an *Ecosystem Service* (ES) and a *Soil Degradation Indicator* (SDI). The SIRAM D5.3 report titled "**Model / Pilot ecological finance instrument, tailored for small farms**", as part of the WP5 with title "**Socio-economic Analyses**", aims at building an integrated and consistent *financial engineering* framework to assess quantitatively the monetary value of regenerative practices, in terms of their potential to remove atmospheric CO₂ and store it in the soil in the form of SOC and further test it with real data measurements in 5 pilot plots in South Europe and North Africa via a simulated *ecological finance instrument*. SOC holds a pivotal role as *Key Performance Indicator* (KPI) for measuring the output compositions, quality and environmental values of regenerative farming practices, as it comprises both an SDI in the *European Union Soil Observatory* (EUSO) [1] and an ES in the *Common International Classification of Ecosystem Services* (CICES) v5.1 (2018) [2]. The Outline of Deliverable 5.3 is the following:

- Chapter 1. Introduction to the methodology, data and ecological finance model.
- Chapter 2. Scope of D5.3 and advancement of SIRAM project's objectives.
- Chapter 3. Classification of Case Studies (CSs) by SIRAM pillars.
- Chapter 4. REGENA financial engineering methodology for SOC PVaR.
- Chapter 5. REGENA financial engineering simulation for SOC PVaR in the 5 Case Studies.
- Chapter 6. Conclusions and future research challenges.
- Chapter 7. Extensions beyond SIRAM and commercialization for the post-SIRAM era.
- Chapter 8. Literature and references used in D5.3.

In **Chapter 1** we provide the research overview, the modelling methodology, the soil underlying index used and the potential commercial value of D5.3. In **Chapter 2** we present the SIRAM *Specific Objectives* (SOs) addressed by D5.3 and its relevance to the regenerative and carbon finance market uptake. **Chapter 3** classifies the SIRAM CSs by their examined RA pillars and their classification by similarity criteria. **Chapter 4** presents the methodological framework of the financial engineering module of the *REGenerative Agriculture (REGENA) Production Function* that was initially developed in the D5.1 report. From a financial engineering standpoint, D5.3 can be viewed as a special module of REGENA for the monetization of CO₂ mitigation and its risk-adjusted financial framework. **Chapter 5** presents the simulation results on *SOC Present Value at Risk* (SOC PVaR) with data received from 5 CSs. **Chapter 6** presents the conclusions of the work implemented in D5.3 and its future challenges. **Chapter 7** highlights the critical academic and commercial issues of SIRAM in the post-project era. Finally, **Chapter 8** presents the list of literature and references used for the D5.3 report.

1. Introduction

As regenerative and carbon farming is prioritized in the recent EU legislation within voluntary market systems for carbon removal credits [3, 4] and lifecycle impacts [5], we use the financial engineering module of REGENA [6], initially developed in D5.1 report, to monetize SOC VaR within a stochastic framework for a 30-year intergenerational ecological bond. In this context, we quantify the PV of removed atmospheric CO₂ and transformed into SOC with a risk-adjusted (to depict the SOC VaR) discount rate by a modified *Shannon entropy* index for continuous distributions, initially designed to depict biomass growth risk in discrete-time models [7].

For the simulation, we select SOC as the most representative CICES v5.1 ES (with the code 2.1.1.2) that was used in M5.2 for the identification of ESs in the 8 SIRAM CSs, coupled to the EUSO *Distance to Max SOC* SDI definition [1] for building the stochastic framework of *Gaussian* distributions [8] on SOC concentrations from the pilot plot measurements. This framework comprises the background work for structuring the risk-adjusted coefficient [8] as part of the ecological bond's discounted SOC PV, taking into consideration the differences between (a) the *exchange rates*, (b) the *Harmonized Index of Consumer Prices* (HICP) in the EU and (c) the central bank *nominal discount rates* in the 5 countries of the examined CSs, normalized in *Purchasing Power Parity* (PPP) values. The simulations demonstrate a clear prevalence of enhanced regenerative treatments in relation to conventional or moderate regenerative ones in terms of SOC value, as an indicator of a farm's conversion potential [9], potential income source and collateral asset base for upfront investment.

2. Scope of Deliverable 5.3

D5.3 addresses both to a number of *Specific Objectives* (SOs) of SIRAM, as well as the pillars of the EU SFT as the major financial vehicle of the EU GD, aiming at the substantiation of the environmental value of RA solutions. This can be considered a prerequisite so that financial institutions may direct the necessary amounts of financial capital towards RA investments with measurable impact on their credit rating profiles and monetary yields. In short, the scope of D5.3 addresses both the current scientific goals of SIRAM and the conditions for the future commercial utilization of its results. The SOs directly related to D5.3 are:

SO1: The depiction of tailored approaches to address climate change, desertification, pollution and low-income issues into a concise ecological finance instrument, applicable as the investment vehicle of RA small farms in the Mediterranean area.

SO2: The ability of the SOC ecological finance instrument to comprise a reliable underlying index for financial institutions that seek to enrich their environmental portfolios and depict adequately the positive effect of atmospheric CO₂ sequestration and its transformation to SOC via treatments that include beneficial microorganisms' species and populations, resistant local varieties and adoption of agronomical practices.

SO7: The pilot ecological finance instrument's ability to depict the potential of tested methodologies and their positive SOC effect to the income of the small farm.

The D5.3 approach on SOC PVaR contributes both to a significant gap in the global literature on environmental accounting [10] and valuation models for carbon sequestration [11, 12], as well as to the enrichment of business, investment and financial practice. The D5.3 report is an extension and generalization of the work implemented in M5.2 for *Nitrogen* (N) and *Phosphorus* (P) in attempt to

investigate their role as *causal SOC markers* and generalize the methodology for both nutrients as parts of the EUSO SDIs (when their soil concentrations are excess or deficiency). In Table 1 below we assess the relation of D5.3 background works and findings to the six pillars of the EU SFT, in terms of scientific, dissemination and commercial potential:

Table 1. Relevance of D5.3 works to the pillars of the EU SFT.

EU SFT Pillar	Relevance (1-5 Scale)	Comment
Climate Change Mitigation	5	The SOC PVaR financial instrument is compatible to the CRCF EU Regulation (EU/2024/3012).
Climate Change Adaptation	5	The SOC PVaR financial instrument can be tailored for adapting agro-ecosystems to local climate conditions.
Sustainable Water and Marine Resources	3	The SOC PVaR financial instrument can be tailored for water use in compliance to the EU WFD/2000/60.
Transition to a Circular Economy	4	The SOC PVaR financial instrument examines the effect of organic biomasses fertilization on SOC formation.
Pollution Prevention and Control	3	The SOC PVaR financial instrument can be tailored for other nutrients (N, P) to minimize excess use.
Biodiversity and Ecosystems	5	The SOC PVaR financial instrument identifies SOC as the CICES v5.1 ES 2.1.1.2 and part of the EUSO SDIs.

Although regenerative farming practices become a major trend in the EU and global agriculture [13, 14], lack of knowledge -and its standardization- on the biophysical processes and the deriving values from regenerative land management comprises a significant obstacle for its market upscale [15]; in turn, preventing financial institutions to invest in such solutions with lack of universally acceptable cost-benefit assessment frameworks [16-18] that provide a benchmark for profitability and *Return on Investment* (RoI) rates.

3. Case Studies groups by SIRAM profiles and data availability

The majority of this chapter's information is contained in the M5.1 report and is repeated in all WP5 deliverables as benchmark reference for implemented studies. The composition of SIRAM pillars is highly related to the SOC PVaR performance. Due to the diversity of applied methods by each CS to measure SOC increase, a basic typology of examined SIRAM pillars is considered of high importance for the results' commercialization. In the next sections, we present the CS classification.

3.1 Classification of Case Studies by examined SIRAM Pillars

The first step of our analysis was to classify all CSs according to the examined SIRAM Pillars. SIRAM Pillars will be used in the REGENA modelling as production factors. In Table 2 below we encode the examination of SIRAM Pillars with the values 1 and 0, where **1** = SIRAM Pillar will be examined by the specific CS and **0** = SIRAM Pillar will not be examined by the CS. SIRAM Pillars are also encoded as **A** = Agronomical Practices; **B** = Biomasses; **M** = Micro-organisms; **R** = Resistant Varieties.

Table 2. Examined SIRAM Pillars by CS.

SIRAM Pillars	CS 1 (UCSC)	CS 2 (UCSC)	CS 3 (ENAM)	CS 4 (ARC)	CS 5 (USMBA)	CS 6 (IRTA)	CS 7 (CRRA)	CS 8 (UC)
A Agronomical Practices	1	1	0	0	0	1	0	0
B Biomasses	1	1	0	1	0	1	1	0
M Micro-organisms	1	0	1	1	1	0	1	1

R Resistant Varieties	0	0	1	1	1	1	1	1
SIRAM Production Factors	3	2	2	3	2	3	3	2

As shown in Table 2, SIRAM CSs will examine either 2 or 3 SIRAM Pillars. Basic descriptive statistics of which SIRAM Pillars are examined with higher frequency by the CSs is presented in Table 3 below:

Table 3. Frequency of each SIRAM Pillar's examination across all CSs.

SIRAM Pillar	A	B	M	R
Examination Frequency	0.375	0.625	0.75	0.75

According to Table 3, the SIRAM Pillars examined with higher frequency are **M** = Micro-organisms and **R** = Resistant Varieties in 6 out of 8 CSs, while Pillar **A** = Agronomical Practices is the least examined one by only 3 out of 8 CSs. The distribution of the number of SIRAM Pillars examined by the CSs are presented below in Table 4 below:

Table 4. Number of SIRAM Pillars examined across all CSs.

Examined SIRAM Pillars	1	2	3	4
Number of CSs by Examined SIRAM Pillar	0	4	4	0

As Table 4 shows, 4 out of the 8 CSs (50%) will examine 2 SIRAM Pillars (irrespective of their specific combination), while 4 out of 8 CSs will examine 3 SIRAM Pillars. None of the CSs will examine only 1 Pillar or all 4 Pillars.

3.2 Case Studies' Groups by SIRAM Pillars' similarity

Following Table 4, we examine the combinations of selected SIRAM Pillars in CSs. We extrapolate the similarities between CSs and classified them in two main groups consisting of secondary classes according to their specific features. Table 5 below presents the primary and secondary classification of CSs by examined SIRAM Pillar.

Table 5. Classification of SIRAM CSs in Groups and Branches by examined SIRAM Pillars.

Group	Case Studies	Branches	Case Studies	Substantiation
A	CS 1 (UCSC) CS 4 (ARC) CS 6 (IRTA) CS 7 (CRRA)	A-1	CS 4 (ARC) CS 7 (CRRA)	All CSs have 3 Pillars. CS 4 and CS 7 lack Pillar A and have Pillars B, M, R with Production Factor similarity between the CSs.
		A-2	CS 1 (UCSC)	All CSs have 3 Pillars. CS 1 lacks Pillar R, while it has Pillar A that will allow us to examine econometrically (a) the trade-off between Pillars A and R with CSs 4, 6, 7 and (b) the trade-off between Pillars M and R with CS 6.
		A-3	CS 6 (IRTA)	All CSs have 3 Pillars. CS 6 lacks Pillar M, while it has Pillar A that will allow us to examine econometrically (a) the trade-off between Pillars A and M with CS 1, 4, 6 and (b) the trade-off between Pillars R and M with CS 1.
B	CS 2 (UCSC) CS 3 (ENAM) CS 5 (USMBA) CS 8 (UC)	B-1	CS 2 (UCSC)	All CSs have only two Pillars. CS 2 has Pillars A, B while CS 3, 5 and 8 have Pillars M, R that will allow us to examine econometrically the trade-off between Pillars A, B (CS 2) and M, R (CS 3, 5, 8).
		B-2	CS 3 (ENAM) CS 5 (USMBA) CS 8 (UC)	All CSs have only two Pillars. CS 3, 5 and 8 lack Pillars A, B with Production Factor similarity between the CSs.

After classifying CSs by similarity, we are concerned with the financial modelling of SOC Value at Risk (SOC VaR) for CS1, CS3, CS4, CS6 and CS7 that provided the respective data.

4. SOC Present Value (PV) at Risk (VaR)

The EUSO SDIs consist of 19 different metrics, classified into 9 categories with a secondary (2-digit) classification. From the total of 9 categories, we examine the *Loss of SOC*, measured by *Distance to Maximum SOC level*, which comprises a EUSO SDI category on its own. We utilize the observed SOC differences from three (3) applied treatments in each of the 5 CSs in relation to the maximum SOC level, to simulate the continuous distributions that are prerequisite to assess expected SOC values and risk coefficients in the discount rates of the ecological bonds. To simulate the distribution of SOC differences from the measurements in the experimental plots we utilized the received SOC data in the 5 selected CSs with 3 different tested treatments in each CS. For each treatment, the data were generated from 3-4 replicates to test SOC differences. The replicate number encodes the specific replicate measurement in each of the 3 treatments in the experimental design. Hence, statistically independent replications took place for each one of the 3 treatments.

Due to the low number of measurements (essentially 3-4 initial and 3-4 final) for each treatment, the spatial independence is convenient for the use of the *Normal Distribution* to simulate a continuous distribution of potential differences (between final and initial measurements) with higher reliability. The variability of the extrapolated distributions is then utilized to estimate the risk-adjusted discount rate via an *adjusted Shannon entropy index* that has been used in discrete-time biomass systems [7]. Here, the formulation is modified to fit continuous distributions. Via the distributions we estimate the expected SOC monetary value, considering as benchmarks the CO₂ prices in the *EU Emissions Trading System* (EU ETS) [19]. In addition, as the monetary differences between the countries of the examined CSs are significant, we normalize all values into EUR PPP [20], taking into account currency exchange rates, the EU HICP [21] and the nominal discount rates [22] in the countries of the 5 CSs to simulate the SOC VaR of the ecological intergenerational bond with a maturity of 30 years.

5. Engineering the SOC PVaR Financial Instrument

Each CS tested three (3) different treatments at soil depths of 0-30cm with 3-4 random replicates for each treatment. The CSs implemented a randomized complete design with 3-4 independent blocks in each treatment so that we can assume *statistical independence* between replications. Each replicate provides 3-4 initial and final SOC values, depicting SOC before and after treatment. This feature of (spatial) statistical independence allows the use of the *Gaussian* or *Normal Distribution* to simulate a continuous distribution on SOC differences (between final and initial measurements) with higher reliability. This is further verified by the strong indications of normality from the boxplots on the mean and variability values of replicates for each treatment.

According to the EUSO definition, soils are considered unhealthy if the measured SOC level is 60% lower from the maximum value. The 60% threshold was chosen as representative of a reasonable and pragmatic distance gap from the maximum achievable SOC level across the industrialization of agriculture, as well as its shift towards petrochemical fertilizers and pesticides since year 1800 [23]. As the major goal of regenerative and carbon farming practices is to increase SOC and reduce the distance between current levels and the maximum value, this uncertainty should be incorporated to the respective financial investment models. Specifically, any regenerative and carbon farming investment should be discounted in present monetary value with the benchmark or minimum risk

discount rate, further increased by an uncertainty coefficient. These two factors constitute the *risk-adjusted* discount rate that assesses SOC PVaR for a defined duration. The uncertainty coefficient derives from the variability of distribution of SOC differences (with a mean and a standard deviation value), measured by the replicates of each treatment. For estimating the uncertainty coefficient, a *Shannon Entropy* $H(C)$ [24] metric on the variability of SOC differences from n replicate observations per k tillage methods is used, as presented in Eq. (1):

$$H(C)_{k|n} = - \sum_{k \in [1;2;3] i=1}^n p_{k|i} \cdot \ln p_{k|i} \quad (1)$$

In Eq. (1), the replicate number n per treatment k is the replication performed for each treatment in the experimental design. Typically, although for continuous distributions the information entropy is usually proportional to the standard deviation ($H(C) \propto \sigma$), in empirical time series it can demonstrate paradoxical behavior. For instance, SOC differences may demonstrate very low information entropy with oscillating behavior, acquiring only two extreme (Min; Max) values. Such an oscillating behavior, with only two periodically observed values, would indeed yield low information entropy but would still suffer from undetected variability if the classical $H(C)$ is used without a normalization coefficient on the distribution's range. On these grounds, a generalized formulation of Eq. (1) may be postulated to include the effect of the (empirical or fitted) distribution's variability of SOC differences from k (where in our case $k=3$) treatment methods, we may re-write:

$$H(C)_{ADJ|k} = \left(\frac{MaxC_k - MinC_k}{MaxC_k}; 1 \forall MinC_k \leq 0 \right) \cdot \left(- \sum_{k \in [1;2;3] i=1}^n p_{k|i} \cdot \ln p_{k|i} \right) \quad (2)$$

Eq. (2) adds to Eq. (1) an *oscillator* function as a weight to the standard $H(C)$ metric to include the effect of the distribution's total range to the risk coefficient. The oscillator is defined by the range between its maximum and minimum SOC values divided by the maximum value, with the oscillator's value range set to $ADJ_{|k} \in (0,1]$. For values $MinC_k \leq 0$ the oscillator receives automatically a value of $ADJ_{|k} = 1$ to avoid an underestimation of the risk factor for cases where $MinC_k \leq 0$ that signify a positive probability of the treatment to be a net SOC remover and net CO₂ emitter, or where both $MinC_k$ and $MaxC_k \leq 0$ that signify certainty ($p_i = 100\%$) of a treatment being a net SOC remover and CO₂ emitter. This approach addresses the need of adopting a representative risk-adjusted entropy metric, sought by financial institutions for discounting CF investments.

The formulation for assessing the SOC risk coefficient is utilized for the postulation of an integrated SOC PVaR model (including the uncertainty from stochastic behavior), where SOC comprises both a benchmark ES and an underlying index for environmental finance portfolios. This framework can be utilized both as a general methodological context for building intergenerational bonds and as tailored standalone model. In our case, we focus on the formulation of a generalized risk-adjusted PV model, accounting for the generated revenues from atmospheric CO₂ removals and their transformation to SOC as the reference CICES v5.1 ES (with the code 2.1.1.2).

To bring the value of these future cash flows into the present, a discount rate is used. The discount rate consists of the minimum-risk yield depicting the alternative (or safest) investment -such a bank deposit- and the risk coefficient denoting the uncertainty of the expected cash flows, as described above. Hence, in order to consider a regenerative or carbon farming investment for atmospheric CO₂ removal and SOC increase as more preferable to the risk-adjusted investment, the yield at the

end of its assumed duration (in our case, 30-years) should have a positive value; quantitatively set for $NPV > 0$. In this context, we may write the generalized *Net Present Value* (NPV) ecological finance model for each treatment k as:

$$NPV(K)_{k|t:0 \rightarrow T_I \rightarrow T_K} = -\sum_{t=0}^{T_I} K_{k|t} + \sum_{t=T_I+1}^{T_K} \frac{[B_{k|t} - (O_{k|t} + \lambda_{k|t})]}{[1 + i \cdot (1 + H(C)_{ADJ|k})]^t} \quad (3)$$

In Eq. (3), K_0 is the initial financial investment at a time step $t=0$, i is the benchmark or minimum-risk discount rate and $H(C)_{ADJ|k}$ depicts the risk coefficient per treatment k ; expressed in terms of adjusted Shannon Entropy as depicted in Eq. (2). The discounted SOC cash flows are equal to the net sum of *Operational Revenues* (B) minus the sum of *Operational Costs* (E) and *Scarcity Rents* (SR) (λ) at each time step (t). The SR expresses the net lifecycle depletion of any resource used as an infrastructure element [7]. For instance, the use of rare minerals for digital monitoring induces a scarcity effect on their proven reserves, as this type of resource is exhaustible. Even logging, as part of the CICES v5.1 ESs list, can cause a net scarcity effect if the wood biomass is extracted at higher rate from its natural replenishment rate. In overall, discounted profits must be positive at the end of the infrastructure's technical lifetime T_K , with the upfront investment (K) taking place at the preparatory period $t:0 \rightarrow T_I$ before the infrastructure becomes fully operational and starts generating revenue. Analytically, the nominal (i.e. undiscounted) revenue flow at every time step, as soon as the infrastructure becomes operational, is equal to the expected monetary value of CO2 removals from the atmospheric and its transformation into SOC, as presented in Eq. (4):

$$B_{k|t:T_I+1 \rightarrow T_K} = \beta_k \cdot \sum_{t=T_I+1}^{T_K} \left(\sum_{i=MinC_k}^{MaxC_k} p_{k|i} \cdot C_{k|i} \right) \cdot \overline{P_{CO_2}} \cdot (10^{-6}) \quad (4)$$

Eq. (4) suggests that the expected cash flow (B) at each time step t for each treatment k is equal to an atmospheric CO2 removal coefficient (β), multiplied by the expected value of atmospheric CO2 removal by the treatment within its distribution's range ($MinC_k$ and $MaxC_k$), further multiplied to the mean annual price of CO2 emissions right in the EU ETS -normalized to turn tons to grams (g) of SOC per kg of soil. In addition, the amount of Eq. (4) is normalized into PPP_{EUR} to compare regions with different monetary systems as:

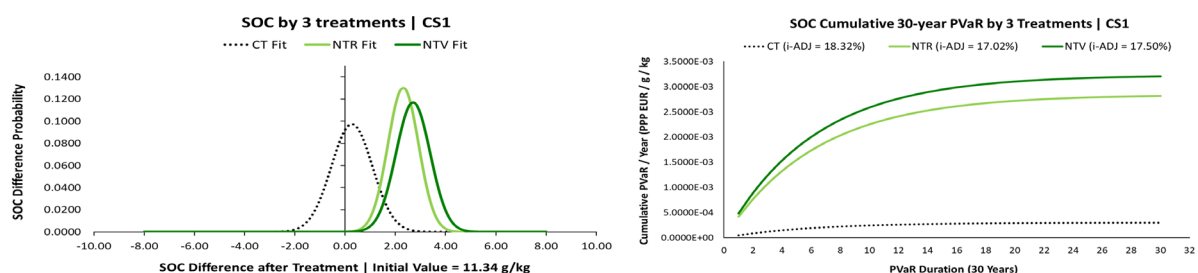
$$B_{k|t|PPP_{EUR \rightarrow i}} = B_{k|t|EUR} \cdot (R_i / R_{EUR}) \cdot (HICP_{EUR} / CPI_i) \quad (5)$$

Eq. (5) suggests that the PPP of each EUR currency unit in the country i of each examined CS is equal to the exchange rate (R_i) to the EUR, multiplied by the $HICP$ to the CPI_i ratio. The HICP is assumed to be common to all CSs in the countries of the EUR zone, while the CPI of each non-EUR zone country was examined separately. For convenience, the monetary effect of variables K , O and λ are left out of the analysis, as they will add negligible practical value in the modelling, considering that there are several uncertainties that would require rational assumptions to compensate for the lack of data. For instance, the replicate plots are very small in size without achieving economies of scale that would depict the real cost level (O). Hence, we focus on the size of cash flows (B) at each time step and the financial instrument's components, as presented in Eq. (1)-(5). The results of the analysis with every PVaR constituent and the total 30-year PVaR are presented in Table 6 below:

Table 6: PVaR components and accumulated discounted 30-year value for each of the 3 treatments tested in each of the 5 CSs.

Treatment by CS	Nominal i	PPP	H(C)	ADJ	H(C) _{ADJ}	Risk-ADJ i	g C kg ⁻¹ Soil, t=30, EUR
CS1 (IT)							
CT	4.800%	1.0000	2.8289	1.0000	2.8289	18.38%	2.9856E-04
NTR	4.800%	1.0000	2.5448	1.0000	2.5448	17.02%	2.8187E-03
NTV	4.800%	1.0000	2.6458	1.0000	2.6458	17.50%	3.2033E-03
CS3 (MA)							
PAT	2.250%	9.6193	0.0930	0.1538	0.0143	2.28%	1.0398E-01
PATBAC	2.250%	9.6193	2.0571	0.6538	1.3450	5.28%	1.0399E-01
PATBACTRI	2.250%	9.6193	1.8426	0.6087	1.1216	4.77%	1.0271E-01
CS4 (EGY)							
COMP	21.500%	27.0192	1.9209	0.5357	1.0291	43.63%	5.3731E-02
MICRO	21.500%	27.0192	0.8581	1.0000	0.8581	39.95%	1.4155E-03
C-M	21.500%	27.0192	2.3420	0.5250	1.2296	47.94%	7.0724E-02
CS6 (ES)							
CT-CNT	3.150%	1.0000	3.4049	1.0000	3.4049	13.88%	7.8818E-04
NT-MAN	3.150%	1.0000	2.4319	1.0000	2.4319	10.81%	2.3396E-03
NT-MIN-MAN	3.150%	1.0000	2.8801	1.0000	2.8801	12.22%	1.6586E-03
CS7 (TN)							
COMP	7.490%	2.6575	3.1065	0.8868	2.7548	28.12%	1.1583E-02
MICRO	7.490%	2.6575	2.6861	0.8857	2.3791	25.31%	8.5666E-03
C-M	7.490%	2.6575	2.8194	0.7551	2.1290	23.44%	1.4380E-02

Table 6 presents the financial instrument's components for each one of the 3 treatments in each CS, as well as the accumulated SOC VaR from each treatment, in terms of grams of SOC per kilogram of soil, formed from CO₂ sequestration. The CO₂ transformation is assumed to take a common (for all treatments of all CSs) coefficient (β) of 3.67g of atmospheric CO₂ uptake, applying for a tree-covered area [25]. This assumption is purely conventional as the uptake coefficients may vary significantly per plant type. In addition, for the monetary value the expected value of CO₂ uptake is multiplied with the 2024 mean annual carbon permit price in the EU ETS (=57.03 EUR / ton CO₂) [19]. This price is assumed constant for the financial instrument's whole duration of 30 years for analytical simplicity, with respective cash flows also assumed constant. This may underestimate the level of cash flows, as it is quite likely that carbon permit prices in the cap-and-trade markets will be increasing across the depletion of atmospheric CO₂ carrying capacity in the next decades. It is also important to denote that such schemes are assumed to take place in obligatory (cap-and-trade) CO₂ markets and not in voluntary ones. Finally, the expected value of SOC difference in each treatment, is assumed to derive exclusively from atmospheric CO₂ sequestration. The distributions of SOC differences and SOC PVaR results are presented in Figure 1 below:



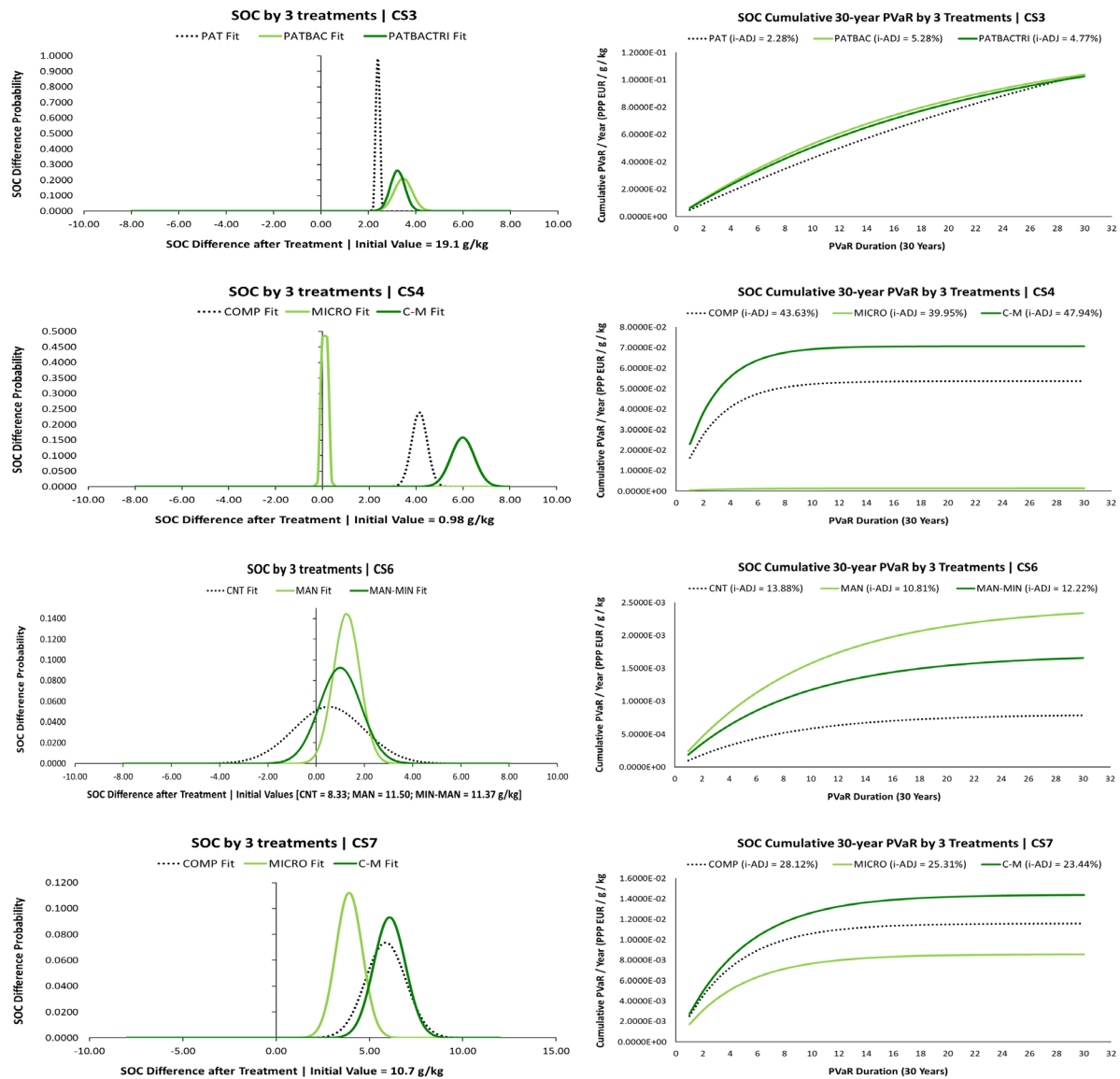


Figure 1: Derivation of SOC PVaR from the moments (Mean; StDev) of SOC difference distributions for each treatment: (a) Continuous distributions of SOC differences (as g of Carbon / kg of soil) after the application of each treatment in each CS; (b) 30-year SOC PVaR in PPP EUR values per treatment in each examined CSs.

The economic rationale of risk-adjusted discounting is that the treatments with higher SOC formation uncertainty should compensate investors for the cost that they would bear to hedge this uncertainty via additional insurance instruments [26]. From Table 6 and Figure 1 we conclude that the highest performance in terms of SOC PVaR is achieved by CS3, with a range of 1.0271E-01 to 1.0399E-01 EUR of each SOC g/kg of soil. In addition, the performances of all 3 treatments in CS3 have the minimum distance between them, signifying that as alternative solutions have a relatively equivalent effect. A similar view is observed for CSs in non-EUR zone countries (CS4, CS7), with SOC PVaR performance within a higher order of magnitude in relation to the CSs in the EUR-zone (CS1, CS6). At this point, it should be denoted though that the significantly higher performance of CS3, CS4 and CS7 derives in its majority from the high PPP coefficient; combined with the lower risk-adjusted discount rate that allows the higher PV of future cash flows, especially for CS3. What the PPP essentially suggests is that one EUR currency unit has higher purchasing power in Morocco, Egypt and Tunisia respectively than in Italy and Spain. It means that if the EU ETS pays one EUR unit to a carbon farmer that transforms one unit of atmospheric CO₂, this EUR unit could purchase 9.6193 more goods in Morocco, 27.0192

more goods in Egypt and 2.6575 more goods in Tunisia. This effect is in part compensated by the high benchmark (minimum-risk) discount rates in CS4 and CS7 countries, dragging downwards the PV of their future cash flows at a faster rate.

Even though these performances do have a tangible economic meaning, a direct conclusion that the value of selected treatments in CS3, CS4 and CS7 is biophysically higher to deal with SOC scarcity or soil degradation, should be avoided. The most essential diagnostics on the biophysical performance of each treatment in Table 6 are the Shannon Entropy $H(C)$, the adjustment coefficient ADJ and the adjusted Shannon Entropy $H(C)_{ADJ}$. These indices are completely independent from monetary effects between countries and the net effect of selected treatments in terms of SOC differences. Specifically, a basic view of a best performing treatment would locate its distribution's Mean value to the right of the SOC differences (horizontal) axis with a minimum possible range (Standard Deviation) that would graphically appear as narrow as possible.

The biophysical meaning of such a combined statistical behavior with high Mean and low Standard Deviation would suggest that a specific treatment is very effective at transforming atmospheric CO₂ to increase SOC significantly with high certainty; further indicating high resistance towards external conditions, such as temperature, wind and precipitation variability. This behavior is very attractive for investors and is reflected in the risk-adjusted discount rate that expresses the environmental risk of manifesting the expected SOC cash flows across the 30-year period with predictability. The size and predictability of expected cash flows in environmental investments is of imperative importance to investors for managing their financial liquidity [27] and costs from additional financial instruments that function as insurance instruments against hydroclimate variability [26]. Such features concern exclusively the size and environmental uncertainty of cash flows from SOC, irrespective of a country's background economic conditions, such as exchange rates, benchmark discount rates and consumer price levels [28]. The components of Table 2 indicate that CS3 achieves the highest performance even by these criteria, with the lowest $H(C)$ and ADJ indices, followed by CS4 and CS7.

In contrast, CS1 and CS6 demonstrate the lowest SOC PVaR performance that is also reflected in the respective environmental diagnostic indices in Table 6, along with the Micro-Organisms treatment in CS4 as the only exception to North African CSs. Partially, this could find its explanation in the fact that microorganisms in this experiment (as well as in CS3) have been applied for biocontrol, while in CS1 and CS7 also for nutrition and abiotic stress resistance. However, it should be denoted that CS1 and CS6 apply relatively mild treatments. Those mainly concern 3 alternative tillage methods in CS1 and 3 alternative fertilization methods in CS6 where direct sowing is applied in all of them. CS1 is the only one testing a *Conventional Tillage* (CT) treatment that is compared to *No-Tillage Rye* (NTR) and *No-Tillage Vetch* (NTV) treatments as its regenerative alternatives. From Table 6 and Figure 1, CT yields low SOC PVaR with a 42.06% probability to either maintain a net zero carbon balance (no net release or uptake) or release soil carbon to the atmosphere. With such a low probability of atmospheric CO₂ transformation into SOC, the CT cash flows are very low, irrespective of the distribution's variability; as also depicted in the accumulated 30-year PVaR. A similar case concerns the MICRO treatment in CS4, with the probability of net SOC output being only marginally higher than 50%. A slightly better view is observed in the CNT (control treatment with no fertilization) with a 61.71% probability of net SOC formation.

With the same rationale for CS1 treatments, NTR has only 0.010% probability of net zero or negative carbon balance, while respectively NTV has 0.0065% probability. Hence, the probabilities of NTR and

NTV treatments to become net carbon emitters can be considered negligible. Respectively for CS6, the dairy manure without fertilization at top dressing (MAN) treatment has only a 1.66% probability of net zero or negative carbon balance, while the same treatment applying mineral fertilization at top dressing (MAN-MIN) has a probability of 14.77%. In addition, the best average SOC distances from the optimal EUSO value are achieved in CS3 with 36.96% for the PAT treatment, with 33.73% for the PATBAC treatment and with 34.41% for the PATBACTRI treatment; in CS7 with 51.37% for the COMP treatment, with 57.12% for the MICRO treatment and with 50.75% for the C-M treatment; and CS1 with 65.92% for the CT treatment, slightly lower than the tolerance value, with 59.92% for the NTR treatment and with 58.77% for NTV treatment. The NTR and NTV treatments are within the limits of maximum tolerable SOC distance and significantly better than CT.

6. Conclusions and future research challenges

For the quantitative modelling, we designed and engineered a 30-year maturity intergenerational ecological bond with PVaR applied to atmospheric CO₂ removal and its transformation into SOC for 5 CSs, in *Purchasing Power Parity* (PPP) EUR units for normalizing differences in exchange rates and price indices between CSs in the EU (CS1, CS6) and North Africa (CS3, CS4, CS6). As the atmospheric CO₂ is considered a pollutant with a monetary cost that is negotiable in the cap-and-trade EU ETS, the bond essentially becomes an ES value financial instrument deriving from soil regeneration. This environmental asset is endowed to current and future generations, addressing the aforementioned challenge of financial institutions to upscale investments in regenerative systems via a rich inventory of proper underlying indices for monetizing the deriving environmental benefits. The simulated PVaR results show an impressive performance of enhanced regenerative practices in terms of long-term SOC value.

7. Extensions of D5.3 and WP5

From the analysis on the ecological finance instrument, we may identify the following major post-SIRAM extensions of *Work Package* (WP) 5 research with commercial interest:

- What is the global projection on the future demand for RA products, providing a signal to the financial sector for preparing an inventory of instruments to invest in RA practices?
- What is the total potential of RA in the EU in terms of output, certification costs and value added?
- How can the establishment of RA practices affect structurally the EU CAP and the allocation of agricultural products between its country-members?
- What is the RA-derived IP value for private investors and their critical investment variables, such as Return on Investment (RoI) periods, risk coefficients, use of weather derivatives?
- How to establish a breed of new ecological finance instruments that cover the full range of RA challenges in the EU Taxonomy and Green Bond Standard (GBS)?

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