



WP5 | Socio-economic Analyses | Deliverable 5.2 Update

Product Environmental Footprint (PEF) assessment for selected CSs

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¹ PU = Public

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

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

Overview of Deliverable 5.2 Update

The updated Deliverable Report 5.2 (D5.2) of Work Package (WP) 5 of research project SIRAM under the title “**Product Environmental Footprint for Selected Cases Studies (CSs)**” includes significant new inputs, enriching the fundamental work implemented in the first version (.v1) on the methodology and calculation of life-cycle environmental impacts of *Regenerative Agriculture* (RA). As the interest in RA practices gains an increasing scientific and commercial interest, the updated D5.2 incorporates pivotal new inputs aiming at the better understanding of *global* supply chains’ dependence and their impacts on even the most environmental-friendly *local* agricultural practices, as well as the provision of integrated information to all stakeholders in a coded and user-friendly way. In particular, the D5.2 update pillars are: (1) the more detailed description of Scope 1, 2 and 3 emissions as part of Chapter 4 and Chapter 5 on the *Product Environmental Footprint* (PEF) methodology and explanation on the effect of global suppliers that either do not account at all or account but perform poorly on lifecycle environmental impacts; (2) a new PEF scenario for the benchmark (conventional agriculture) and the

three selected RA Case Studies (CSs) that differentiates from the basic scenario in the assumption of consuming the agricultural products exclusively at national (instead of international) level, affecting significantly the life-cycle impacts at the *Transport, Use/Consumption* and *EoL* stages and partially at the *Raw Materials Extraction* and *Manufacturing* stages; (3) the proposal of a RA labeling scheme, as a complementary to the PEF universal signaling and enriched by the social prerequisites of revenue streams of RA farms for them to acquire this highest quality level certification.

List of Acronyms

Acronym	Full title	Acronym	Full Title
AR	Assessment Report	GWP	Global Warming Potential
BioL	Bio-Leasing	GhG	Greenhouse Gas
CA	Conventional Agriculture	IPCC	Intergovernmental Panel on Climate Change
CAP	Common Agricultural Policy	IT	Information Technology
CE	Circular Economy	LCA	Life Cycle Assessment
CICES	Common International Classification of Ecosystem Services	OEF	Organization Environmental Footprint
CS	Case Study	PEF	Product Environmental Footprint
EoL	End of Life	PMSL	Principle of Maximum Safety Limits
EPR	Extended Producer's Responsibility	PPP	Polluter Pays Principle
ES	Ecosystem Service	RA	Regenerative Agriculture
ESG	Environment, Society, Governance	SDG	Sustainable Development Goal
EU	European Union	SEEA	System of Environmental-Economic Accounting
EU GD	EU Green Deal	SO	Specific Objective
EU SFT	EU Sustainability Finance Taxonomy	SoV	Store of Value
FCBA	Full Cost-Benefit Accounting	WFD	Water Framework Directive
FT	Fair Trade	WP	Work Package

Executive Summary

The D5.2 report of WP5 of research project SIRAM under the title ***“Product Environmental Footprint for Selected Cases Studies (CSs)”*** utilizes the data received from the CSs in Milestone 5.1 (M5.1) in combination to the findings of WP3 on sequential mechanisms in soil-plants-microbes interactions (T3.1, T3.2). As postulated in D5.1, the large-scale enactment of RA practices comprises an element of vital importance for the *European Union* (EU) in the context of the *EU Green Deal* (EU GD) [1] and the *EU Sustainability Finance Taxonomy* (EU SFT) as its financial vehicle [2]. The corner stone for the establishment of RA as a mature practice with a growing share in European agriculture or even its prevalence over conventional agricultural practices that are based on petrochemical fertilizers is the scientifically accurate quantification of its value with the use of *Full Cost-Benefit Accounting* (FCBA) methods.

The purpose of applying FCBA methods is the full comparability of all types of costs and benefits of alternative (agricultural) production practices with different environmental impacts. A frequent issue emerging between the selection of alternative and -quite often- competitive production methods was that only conventional business costs and benefits were considered with the environmental cost of the finally selected practice not being accounted for. In addition, the environmental *benefit* of the not selected practice was respectively not accounted for. This combined result created a significant

distortion in the *prices mechanism* as the foundation of the *market*. In addition, it provided a wrong signal to financial markets that were unable to assess the value of environmental damages or of the benefits generated and incorporate this effect into the cost of financial capital.

The landmark for the incorporation of FCBA methods in the EU was the 2000/60 Water Framework Directive (WFD) [3], where the FCBA included two main categories; (1) *Conventional Costs*, such as initial capital investments, depreciation costs, administration costs and (2) *Environmental Costs* that were further classified into (a) *Resource Depletion Costs* and (b) *Ecosystems' Degradation Costs*, so that even if the conventional costs of a production process were lower, no final conclusion could be assessed before its environmental costs were also assessed. A second landmark towards the FCBA in the EU was the *System of Environmental-Economic Accounting* (SEEA) [4] as integrated framework to account the economic and environmental costs and benefits at the *lifecycle* level for both corporate and national organizations. The analysis of the updated D5.2 report focuses on the *Life Cycle Analysis* (LCA) of RA and *Conventional Agriculture* (CA) as two competitive agricultural practices with two (2) alternative scenarios, one where the agricultural products are distributed in global markets and one where products are distributed exclusively in national markets. The LCA is a technical basis via the *Product Environmental Footprint* (PEF) method for the valuation of environmental costs and benefits of CA, RA, as well as any mixed practice. The updated D5.2 report structure is presented below:

- Chapter 1. Introduction to the Life Cycle Analysis (LCA) methodology and the value of D5.2.
- Chapter 2. Scope of D5.2 and advancement of SIRAM project's objectives.
- Chapter 3. Features of selected SIRAM Case Studies.
- Chapter 4. The Product Environmental Footprint (PEF) method and its SIRAM treatment.
- Chapter 5. Estimated PEF values for each selected SIRAM CS for two (2) scenarios.
- Chapter 6. Proposal for a Regenerative Agriculture Certification and Labeling (RACL).
- Chapter 7. Current state of D5.2, achievements and scheduled future updates.
- Chapter 8. Conclusions, publications and next steps towards D5.2 update and D5.3.
- Chapter 9. Extensions beyond SIRAM and commercialization design for the post-SIRAM era.
- Chapter 10. Literature and references used for D5.2 substantiation.

In **Chapter 1** we provide the research overview, the LCA methodology and commercial value of D5.2. In **Chapter 2** we present the SIRAM *Specific Objectives* (SOs) addressed by D5.2 and its relevance to the 6 pillars of the EU SFT. **Chapter 3** describes the criteria and features of the three selected SIRAM CSs by their examined RA pillars and economic data provided in M5.1. **Chapter 4** contains the core innovative work with the description of the PEF method as an EU-wide LCA standard, the necessities it addresses, its compatibility to the monetization of the environmental costs (resource depletion and ecosystem services), as well as its utilization as a basis for a labeling system of RA products for consumers' information. **Chapter 5** presents the updated PEF assessment results for each of the 3 hypothesized farms for the *global* and *national* scenarios with standardized features based on the respective selected CSs and their pillars in comparison to the PEF assessment for a CA benchmark hypothetical farm of the same size and composition. In this work we take into consideration the high incorporated uncertainties attached to Scope 1, 2 and 3 emissions (e.g. the embodied emissions of global suppliers of critical infrastructure such as photovoltaics, Information Technology (IT), sensors etc.), lack of detailed information on embodied GhG emissions by crop and final agricultural product,

by agricultural practice and by geographical location (i.e. localized baseline values), as well as high complexity across the incorporation of ESs by the *Common International Classification of Ecosystem Services* (CICES) v5.1 (2018) into the PEF variables. **Chapter 6** is a new addition in the updated D5.2 report, presenting the methodology and related visualizations of a RA labeling system enriched with the ten *Fair Trade* (FT) principles beyond the PEF performances. **Chapter 7** provides the current state of WP5, the contributions of D5.2 for the previous and next works (D5.1, D5.3). **Chapter 8** describes the next steps and required actions of the SIRAM consortium, the M5.2 report on charted ESs in 8 SIRAM CSs and the upcoming D5.3. **Chapter 9** highlights the critical academic and commercial issues of SIRAM in the post-project era with reference to D5.2 results. Finally, **Chapter 10** presents the list of literature and references used for the D5.2 report.

1. Introduction: Environmental LCA and the value of Deliverable 5.2

The FCBA at lifecycle level in agriculture aims at revealing the total environmental costs and benefits of an agricultural practice and the composition of total costs and benefits across the lifecycle stages. The work performed in D5.2 is a prerequisite for the enrichment of the REGENA *Production Function* (PF) developed in D5.1, as well as for D5.3 aiming at structuring ecological micro-finance instruments that are EU Taxonomy compliant, following the paradigm shift of the financial and banking practices towards investments based on environmental performance underlying indices. At the biophysical level D5.2 aims at assessing the environmental lifecycle impact of RA or RA-CA mixed practices on ecosystem services as part of the local natural capital high environmental value. In this context ESs are a form of *Store of Value* (SoV) [5], embodying an incentive for the commercial deployment of RA practices, should the lifecycle impact of RA on them be assessed, compared to the respective impact of CA and eventually monetized [6]. ESs comprise part of this monetization as the EU GD suggests. Via the utilization of data from three selected CSs in WP4 and with a “farm to fork” approach, the lifecycle environmental impacts are assessed with the PEF as an EU-27 “umbrella” LCA framework for achieving transparency of corporate and national accounts, as well as for consumers’ information [7], following international standards (e.g. ISO 14040/44) and the rationale of the SEEA.

The value-added of the SIRAM D5.2 consists in six dimensions: **(1)** Benefits deriving from the SIRAM consortium synergies that increased the “knowledge stock” on the environmental impact at lifecycle of RA practices and its comparison to CA practices by enriching the related scientific literature [8,9]; **(2)** The enrichment of an ongoing *Regenerative Agriculture Economics* (RAE) database with first data and assessments on RA full cost accounting at lifecycle; **(3)** The post-SIRAM commercial potential, as the FCBA framework developed can be applied in CSs with already identified potential outside the consortium and be further *upscaled* based on tangible monetary values; **(4)** The incorporation of the lifecycle environmental costs and benefits of various agricultural practices in the REGENA function, **(5)** The compatibility of SIRAM’s quantitative economic framework with the ongoing EU directions towards the EU GD, the EU SFT, and the *Circular Economy* (CE) as integral elements of the *Common Agricultural Policy* (CAP) for all EU member-states and **(6)** the proposal for a RA labeling user-friendly system as part of the ongoing legal framework for certified carbon removals in agriculture [10].

2. Scope and Objectives of Deliverable 5.2

D5.2 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. Environmental impact assessments at lifecycle and their monetary translation

is a prerequisite for financial institutions to 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 D5.2 addresses both the current scientific goals of SIRAM and the conditions for the future commercial utilization of its results. Specifically, we may identify the relation of D5.2 with the following SIRAM SOs:

SO1: Lifecycle environmental impact approaches as a basis to monetize the cost of RA practices as able to address climate change, desertification, ecosystems' pollution and low-income issues into a coherent evaluation framework that reveals their true value. These approaches will be commercially applicable even to individual small farms in the Mediterranean area.

SO2: The ability of LCA and specifically the PEF method to depict the energetic effect of chemicals' and the economic value of reducing their use, their substitution by organic fertilizers, biostimulants, organic waste biomasses and the deriving restoration and regeneration of soil health via the growth of beneficial microorganisms' species and populations, as well as the use of resistant local varieties and adoption of agronomical practices, such as no-tillage and cover crops.

SO7: The ability of the PEF method to comprise an *underlying index* of ecological finance instruments tailored by financial institutions to assess the FCBA of RA small-farms in the Mediterranean and the establishment of respective payoffs (as examined in D5.3) based on tangible measurements.

In addition, in Table 1 below we assess the relation of D5.2 background works and findings to the six pillars of the EU SFT, in terms of scientific, dissemination and commercial potential:

Table 1. Relevance of D5.2 works to the pillars of the EU SFT.

EU SFT Pillar	Relevance (1-5 Scale)	Comment
Climate Change Mitigation	5	The PEF assesses the GWP of various agricultural practices in a comparable way to select the optimal.
Climate Change Adaptation	4	The PEF as a lifecycle method allows the identification of GWP "hotspots" and targeted improvements.
Sustainable Water and Marine Resources	3	The PEF includes the impact on water as a dimension. Marine resources are outside the scope of SIRAM.
Transition to a Circular Economy	3	The PEF includes the EoL stage in regard to Biomass in SIRAM and potentially CE actions beyond the lifecycle.
Pollution Prevention and Control	4	The PEF includes eutrophication (e.g. by N, P) as a dimension in terms of GWP.
Biodiversity and Ecosystems	5	The PEF includes 6 out of 15 dimensions on ecosystems that can group many ESs found in the CICES v5.1.

From Table 1, as in previous reports (D5.1) we observe an unequal distribution of the issues covered in relation to the EU SFT. For the PEF as lifecycle approach we may see that pillars 1 and 6 have the strongest relation to D5.2 due to the fact that **(a)** most LCA methods reduce environmental impacts to *Global Warming Potential* (GWP) and **(b)** pillar 6 of the EU SFT essentially relates to ecosystems degradation as part of the FCBA by the 2000/60 WFD. Pillars 2 and 5 follow in terms of relation with the PEF as they comprise a normative approach (adaptation and prevention/control respectively) for which LCA approaches are a prerequisite. In any case though, all SIRAM pillars are either directly or indirectly related to the EU SFT. For instance, no-till and cover crops for mitigating soil degradation in SIRAM are related to pillar 2 of the EU SFT; using resistant varieties and beneficial microorganisms is highly related to pillar 6, while the crowding-out of conventional fertilizers and increase of water

retention capacity is related to pillar 4. The relation of pillars 3 and 4 of the EU SFT is reduced as the part of marine resources is outside the scope of SIRAM and will be assessed by proxy data as part of the PEF variables, while CE actions in the PEF method is only partially incorporated as an obligatory study of the *End of Life* (EoL) stage, with any other measure beyond it being optional.

3. Features of selected SIRAM Case Studies

The basic information of this chapter for all CSs is contained in the M5.1 report. In D5.2, we include selected updates regarding (a) the classification of the selected three CSs for the PEF assessment, (b) the available data classification and transformation into GWP equivalents and (c) the PEF assessment steps. In the following parts, we present the features of the three selected CSs. The composition of SIRAM pillars is highly related to the PEF performance. Although currently due to the diversification of CSs significant uncertainty is incorporated in the PEF results, the adoption of an EU-wide accepted LCA methodology, the selection of RA constituents for the optimal output, as well as farm income SDGs and ESG compliance are tasks of pivotal importance for SIRAM results' commercialization.

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 Case Study.

SIRAM Pillars	CS 1 (UCSC)	CS 4 (ARC)	CS 6 (IRTA)
A Agronomical Practices	1	0	1
B Biomasses	1	1	1
M Micro-organisms	1	1	0
R Resistant Varieties	0	1	1
Examined SIRAM Pillars	3	3	3

According to Table 2, SIRAM CSs will examine 3 SIRAM pillars, which is also the maximum number of pillars examined in any SIRAM CS. CSs 1,4 and 6 also achieve the maximum diversification, as besides their individual pillars' overlaps, each one examines a unique combination. The descriptive statistics of SIRAM Pillars examined with higher frequency by the three CSs is presented in Table 3:

Table 3. Frequency of SIRAM Pillars in the selected CSs for the PEF assessment.

SIRAM Pillar	A	B	M	R
Examination Frequency	0.66	1.00	0.66	0.66

According to Table 3, the SIRAM Pillar examined in the three selected CSs with the higher frequency (100%) is **B** = Biomasses, which is examined in all CSs with all other pillars being equally distributed with frequency 66,6% with combinations of pairs of CSs that allows us to compare the performance of the examined pillars in the PEF assessments.

Table 4. Number of SIRAM Pillars examined in the selected CSs for the PEF assessment.

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

In both D5.2 versions we selected among CSs with 3 SIRAM Pillars, as shown in Table 4, to maximize available information on RA impacts and their comparability to CA practices. The PEF can potentially include all 4 SIRAM Pillars and any pillar not examined by a CS is substituted with a CA reference value, as for these cases we assume that a CA-RA practices mix is applied in the hypothetical farm.

3.2 Selected Case Studies' Groups

Following Table 4, we examine the combinations of selected SIRAM Pillars in the three selected CSs, based on the initial grouping of all 8 CSs presented in the M5.1 and D5.1 reports. Table 5 presents the classification of the three selected CSs in the initial groups.

Table 5. Classification of the three selected SIRAM CSs in Groups, as initially presented in D5.1.

Group	Case Studies	Branches	Case Studies	Features
A	CS 1 (UCSC) CS 4 (ARC) CS 6 (IRTA)	A-1	CS 4 (ARC)	CS4 has Pillar B in common with CS1, CS6; Pillar M in common with CS1 and Pillar R in common with CS6.
		A-2	CS 1 (UCSC)	CS1 has Pillar B in common with CS4, CS6; Pillar A in common with CS6 and Pillar M in common with CS4.
		A-3	CS 6 (IRTA)	CS6 has Pillar B in common with CS1, CS4; Pillar A in common with CS1 and Pillar R in common with CS4.

As we observe in Table 5, all three CSs belong to Group A, as they examined 3 SIRAM pillars, with the exception of CS7 that in the initial grouping was classified into sub-group A-1 as closer to CS4. While CSs 4 and 7 would comprise an interesting case for higher comparability of PEF assessments due to their similarity in SIRAM pillars and climate conditions, we prioritized the diversity of the CSs sample.

4. The Product Environmental Footprint (PEF) Method

The PEF belonging to the family of LCA methods addresses to companies aiming at the certification of their products to the final consumers of EU markets, with the maximum reporting transparency of their environmental impacts at all stages and for all international suppliers. Besides dealing with the issue of informing reliably EU consumers on the environmental impacts of a product's processes, it deals with the issue of "greenwashing" prevention, as the transfer of environmental costs to areas with inadequate environmental legislation allowed highly aggravating manufacturing processes that were difficult to trace to take place outside the EU, the EU import of their final products and their promotion in EU markets as environmentally friendly [11]. This is considered both as unethical and illegal, as it sets the background for illicit international competition and crowding out corporations that follow strict environmental legislation and incorporate the related production costs.

4.1 PEF stages, variables and treatment in SIRAM

The sum of the environmental impacts at all lifecycle stages of all products yields the *Organization Environmental Footprint* (OEF), which is an overall lifecycle environmental impact index of the whole company. The purpose of PEF and OEF information is to enable the transparent information of the environmental impacts of goods and services, monetize these impacts, calculate them into the total cost, incorporate these total costs into the final price and eventually motivate with tangible metrics the reduction of these impacts via investments in new processes and product designs. Besides the production processes the PEF method takes into account international supply chains in order to take

into account the embodied environmental footprint that took place in foreign countries to foster the compliance of global suppliers (as source of Scope 3 emissions) to EU standards. Both purposes are based on detailed requirements for reporting flows of energy, materials, as well as *embodied* GhG emissions (Scope 3) and waste streams deriving from a product across its whole economic life.

The transition towards an EU PEF method began in 2011, when for the first two years until 2013 its experimental foundations were built. The pilot phase took place for the period 2013-2018 when 27 different pilots from 8 different sectors were investigated. From these 27 pilots, 2 did not continue at all, while 3 were discontinued. From the 25 pilots that initially kicked-off, 11 were directly related to the agri-food sector. From these 11 pilots, 1 is directly related to SIRAM (olive oil). Since 2019, the PEF method is under transition after the classification of collected data, where in 2021 the EU issued the Recommendation 2021/2279 [7] as the second major legal document for the harmonization of LCA reporting under PEF guidelines.

As for all LCA methods, there are typically 4 stages for assessing an environmental impact for each dimension, classified from the extraction of raw materials, through manufacturing and/or industrial processing, its use from the consumer to the final waste generation and its management. In some cases, the stage of “Transportation” is chosen to be separated from the Manufacturing/Processing stage, which in the case of SIRAM is considered to be a more reliable option as although RA products are in most cases locally produced, their demand is global; hence embodied environmental impacts from (in many cases global maritime) transportation are not negligible. In the updated D5.1 report we also examine the *national* scenario, where the main assumption is that the reference product for both CA and RA (potato) is consumed domestically. This new scenario clarifies the contribution of transportation to environmental lifecycle impacts. The lifecycle stages in the PEF method, adjusted for SIRAM products are the following:

Stage A: Raw materials’ extraction and use for cultivation (e.g. petrochemical fertilizers, metals).

Stage B: Manufacturing and packaging of grown products (e.g. in industrial facilities).

Stage C: Transportation of packaged products to the consumer (e.g. in cities via trucks or maritime).

Stage D: Consumption of the product from the final consumer (e.g. household consumption).

Stage E: End of Life (EoL) management (e.g. composting biomass residuals, recycling of packaging).

From the above, it is clearly understood that significant working assumptions and conventions are incorporated to deal with the uncertainties on both the actual sequence of the PEF stages and the reduction of impacts into kg CO₂eq. For instance, it is possible that the transportation stage B could take place either after the collection of the crop to the factory for picking and packaging or after it if the processing unit is next to the farm or even split into stages B1 and B2 if transportation is needed for both the product’s arrival to the processing unit and its distribution to the consumers. In respect, such a case could be identified for stage E, with E1 depicting biomass recycling after cropping to be used as fertilizer (as it is a SIRAM pillar as well) and E2 depicting the composting of the RA product’s biomass residuals that may or may not be used as organic fertilizer in the RA in which it was initially grown. This issue will be examined as part of D5.3 on the establishment of RA business models, such as *Bio-Leasing* (BioL). Numerous other complexities like the above can be derived; however, as they require knowledge of the specifics that are unavailable at a high degree in our case (as we structure two hypothetical CA and RA farms), we assume the simplest possible lifecycle sequence. In general,

since one SIRAM pillar concerns the use of *biomasses* (B) as an alternative composition of nutrients for RA fields, we follow a *Cradle to Grave* (CtG) approach that includes as much as possible detailed environmental impact assessments for stage E (EoL) that deal with the use of the residual material after the end of its technically and economically useful life. For the case of RA though, the material is by default eligible to serve again an input purpose with potential benefits for *microorganisms* (M) that have been modeled in the REGENA function; hence reducing significantly related environmental impacts. Indeed, in regard to the EoL stage for the *national* scenario, the updated D5.2 assumptions include a higher fraction of residual biomasses used as organic fertilizer than in the global scenario. Specifically, as the monitoring and tracking of reused residual biomass can be safely assumed to be more reliable at EU-level or nationally than globally (e.g. the reuse of biomass and/or food packaging can be verified more easily when the materials stay within the geographical limits of Italy and Spain at EoL than when the products is exported and consumed in a foreign country with no obligation to report such information).

Respectively, the SIRAM classification of PEF variables, taking into consideration the 2000/60 WFD and the grouping of the above variables into its categories (depletion of resources and ecosystems' degradation, including human health impacts) are the following fifteen (15):

A. Resources' Depletion

1. Land Use (Total)
2. Resource Depletion | Water
3. Resource Depletion | Earth

B. Ecosystems' Degradation

4. Climate Change (atmospheric concentration of Greenhouse Gases)
5. Ozone Depletion
6. Photochemical Oxidant Formation
7. Human Toxicity | Cancer
8. Human Toxicity | Non-Cancer
9. Particulate Matter Formation
10. Ecosystems' Toxicity
11. Ionizing Radiation
12. Terrestrial Acidification
13. Eutrophication | Earth
14. Eutrophication | Marine
15. Eutrophication | Freshwater

From the above we may conclude that the majority (80%) of the dimensions assessing PEF impacts concern ecosystems' degradation from which 2 are directly related to human health, while only 20% concerns resource depletion. Of course, there are numerous alternative approaches to classify the

above dimensions (e.g. several Group B dimensions could be modeled in resource depletion terms), however, in our case we aim at harmonizing with the FCBA rationale of the 2000/60 WFD.

4.2 Scope 1, 2 and 3 GhG Emissions and supply chain dependence

An issue frequently pointed out in lifecycle analyses is the difficulty to comprehend adequately the impact of externally supplied materials in a production unit (whether industrial or agricultural) that respectively makes the unit dependent on the embodied lifecycle impacts of the external supplier. In this context we may frequently observe the paradox of highly environmental-friendly production processes incorporating a much lower lifecycle performance than anticipated; especially when we adopt *Cradle to Grave* approaches that include the EoL impacts instead of *Cradle to Gate* approaches that include impacts only up to Stage B (manufacturing). Specifically for RA, a typical question is why lifecycle impacts: **(a)** appear to be quite higher although the production process is one of the most ecologically friendly and **(b)** they include embodied impacts that seem completely unrelated to RA (e.g. human toxicity or particulate matter formation). The answer nests in the *embodied* impacts of externally supplied infrastructure and specifically Scope 2 and 3 emissions.

According to the GhG Protocol, emissions are classified by *Scope 1* that concern energy and material inputs that are fully controlled by the production unit (e.g. in-house produced biomass for heating, photovoltaic electricity generation but not the embodied emissions across its assembly stage), *Scope 2* that concern the energy supplied externally (e.g. the grid as a whole or a specific power company that does not generate exclusively renewable energy) and *Scope 3* that concerns externally supplied infrastructure and/or materials (e.g. building with concrete, critical materials for IT). The PEF method has standard impact categories that measure the impacts across the whole value chain, in relation to Scope 1, 2 and 3 aspects as the GhG Protocol framework suggests. Hence, for instance, with 5 life-cycle stages in the PEF method, although the methods of RA cultivation may have minimum or even zero impacts (in terms of CO₂ eq. emissions by a mid-point approach), infrastructure used, such as photovoltaic panels, building materials and machinery etc. that are supplied by an external supplier from countries with questionable production processes and without transparent tracking or lifecycle certification [11], embody these impacts across the raw materials mining and manufacturing stage, even if they are not directly responsible for them as *producers*. However, they are responsible for using these materials -hence their embodied impacts- as final *users*. Such impacts are accounted for as part of Scope 3. In overall, the PEF method -and other lifecycle accounting methods in general- highlights the dependence of even the most environmental-friendly production processes on global supply chains and provides a first signal for shifting towards collaborations with alternative suppliers with lower embodied impacts.

4.3 PEF and water resource use

In regard to dimension A-2 (Resource Depletion | Water), as it comprises a significant variable of the REGENA function as well (see D5.1) related to the use of machinery for tillage that in turn affects the retaining of water in the soil, we further highlight the differentiation of the two water types and the three potential water effects (depletion of surface water, groundwater, pollution from wastewater) in compliance to the *Extended Producer's Responsibility* (EPR) and *Polluter Pays Principle* (PPP):

- For surface water and groundwater, as two potentially alternative and competitive sources of irrigation water, the environmental impact heavily depends on renewability rates. Specifically, since from a natural resource economics standpoint groundwater reservoirs are treated as near-

depletable resources with much lower replenishment rate than surface water, the depletion effect between both is diversified and accounted by the *Scarcity Rent* (SR) in terms of GWP that can be further monetized in the FCBA and charged to the polluter according to the EPR and PPP.

- For wastewater, the PEF aims at imprinting in an EPR system the cost of environmental pollution for which the polluter (here the farm) is responsible during the product's cultivation and growth stage (Stage A). The pollution of this kind is assumed to increase depletion of water resources for irrigation. All other impacts from wastewater pollution (e.g. wastewater containing fertilizers and pesticides) are assessed as different categories (e.g. B-15 Eutrophication | Freshwater).

4.4 Extender Producer's Responsibility (EPR) and the Polluter Pays Principle (PPP)

Taking into consideration the EU Recommendation 2021/2279 [7] on the corporate harmonization of lifecycle analyses under the PEF as an EU methodological umbrella and the increasing maturity of EU legislation on sustainable supply chains and responsible resourcing as integral parts of the EU SFT, the SIRAM PEF method attempts a preliminary unification of *midpoint* and *endpoint* approaches via the reduction of assessed impacts into kg CO₂ equivalents. Although this effort incorporates many uncertainties due to the assumptions on intermediate environmental processes taking place before the final impact is manifested, it can be combined to the *Principle of Maximum Safety Limits* (PMSL) (i.e. the lowest possible and most strict carrying capacity limits); thus, allowing higher comparability between alternative and competitive solutions. At the economic level this would translate into the potential to standardize a straightforward EPR system for optimal allocation of payments for each producer by the PPP at any farm size with the use of a midpoint LCA approach.

A related issue to D5.2 is to investigate the feasibility of establishing an EPR system in regard to the production of RA products and their respective labeling for their easy and direct identification by the consumer. The major extensions of this issue analysis are: **(1)** How can the quantitative information generated with the PEF method be utilized to structure a consistent EPR system that standardizes the payments of a producer in compliance to the PPP and the environmental impact information to consumers as part of their market preferences? **(2)** The structuring of financial instruments to fund capital and/or operational costs of producers with low lifecycle environmental impacts as a reward for their integrated production approach and as a price signal to less efficient producers to motivate them towards corporate structural changes. These issues are addressed in Chapter 6 in more detail.

In addition, considering that the PEF method assesses supply chains as well, an emerging vital issue is to structure an EPR system that is conceptually clear by defining accurately the “producer” at any stage of the supply chain (and -hence- the product's impacts at any stage of its lifecycle), as well as operationally efficient for all counterparties in it. Furthermore, the EPR and labelling system should be compatible to the EU GD, the EU SFT, as well as to *Environment, Society and Governance* (ESG) criteria to motivating producers and intermediate suppliers towards more environmentally friendly processes.

Taking into consideration the sequence of works in SIRAM D5.2, the design of an EPR and labelling system for RA products accounts for the following aspects:

- **Definition of the “Producer”**, within the PEF. A distinction between the “primary producer” as the one who cultivates and grows the RA product in the farm and “intermediate producers” that

are involved in the supply network of the former is a necessary step to allocate accurately both the number and responsibilities for each one across the product's lifecycle.

- **EPR system costs**, since new services will have to be created to collect many kinds of data, such as certified environmental footprints by all suppliers, contracts, prices, labeling, maintenance of complex digital databases for authority inspections etc. for which the small RA farmer may not be able to support; hence, an alternative business model or centralized service may be required.
- **Administrative burdens**, concerning risks that may completely prevent the establishment of an EPR system -irrespective of its implementation costs- or disrupt its continuation should a critical intermediate producer demonstrate discontinuity in its transparency practices.
- **EPR benefits for RA farmers**, essentially answering how an EPR and labeling system can become a “value multiplier” for the farmer in the market, attracting both the preferences of consumers and financial capital from the banking sector for the expansion of its operations and increase of its scientific knowledge (as modeled in the REGENA function in D5.1) among a high availability of environmental finance instruments backed by the EU GD, EU SFT and ESG.

4.5 PEF monetization and its relation to FCBA

The PEF comprises the technical background for an EU legislation-compatible FCBA framework as defined in the 2000/60 WFD and the SEEA 2014 [4] in order to be applied as a straightforward and accurate lifecycle impact accounting standard that allows EU-scale comparability of the monetization of conventional economic (e.g. capital, operations, administration), as well environmental costs and benefits by any interested producer or stakeholder at life-cycle level. In practice, the monetization of lifecycle impacts essentially aims at translating PEF dimensions into economic costs and benefits at each lifecycle stage for the establishment of an RA EPR and labelling standards with tangible metrics utilized as environmental performance underlying indices within the *Sustainable Development Goals* (SDGs), EU GD, EU SFT and ESG contexts and environmental finance instruments for capital funding.

Monetization of lifecycle environmental impacts of production processes (irrespective of method) has been at the core of natural resource economics discussion since the theoretical beginnings of global-scale climate change impacts' assessment [12] that essentially inspired the 2000/60 WFD and the various SEEA versions. At the structural part, the PEF-based FCBA consists of two parts; (1) the *Conventional* costs and benefits (e.g. capital expenses, operational expenses, administration) that are directly related to the producer's legal establishment, initial investment and operations; (2) the *Environmental* costs and benefits, further classified into (a) *costs* of resource depletion and *benefits* of virgin resources savings from materials' reuse and (b) *costs* of ecosystem services' degradation (from various emissions and discharges) and *benefits* from any practice of pollution avoidance. The FCBA categories (a) and (b) can be further monetized at lifecycle level following the PEF 3.0 method [13] as an EU LCA umbrella framework. As agriculture is highly energy-intensive since the *Industrial Revolution* [14] the PEF method is also compatible with the identification of Scope 1 and 2 emissions' definitions, as well as established reporting standards on supply chain impacts concerning Scope 3. The value-added of the PEF method is nested in that it allows the identification of any inequalities in the distribution of environmental impacts (hence, related environmental costs and benefits) across the lifecycle stages; thus, recommend targeted interventions to farmers. Regarding the impacts on ESs, the most widely accepted classification framework is the *Common International Classification of Ecosystem Services* (CICES) v5.1 (2018). Currently, an ongoing SIRAM work concerns the charting and

estimation of RA-generated ESs from each of the 8 CSs in the M5.2, contributing to PEF assessment in the updated D5.2. However, as the CICES v5.1 contains more than 80 different ESs species that are classified in three main categories (Provisional, Maintenance and Cultural), we choose for simplicity to incorporate them into the PEF 3.0 examined variables B4-15.

4.6 FCBA elements analysis for RA farms

As mentioned, the *conventional costs* are related to the legal establishment and operations of any type of farm, whether CA, RA or CA-RA mix. Essentially, the conventional economic cost is a building block model, further enhanced by the environmental cost. The price of a RA product is expected to cover this part as it is classified in the following main categories:

- **Capital Expenses (CAPEX)**, concerning the investment costs for the farm's foundation, facilities and infrastructure. CAPEX may either be tangible (e.g. machinery) or intangible (e.g. Intellectual Property | IP rights) assets that are subject to depreciation.
- **Operational Expenses (OPEX)**, concerning a farm's operations and production volume, including machinery maintenance costs, software costs, manual labor costs, electricity costs, purchase of fertilizers, fuels, pesticides, experimentation etc.
- **Administration Expenses (ADEX)**, including a farm's expenses for corporate management (e.g. Board of Directors), salaries and other non-monetary benefits. This cost category is considered negligible for small-scale RA farms; although for large agricultural corporations with possession of large areas of land and industrial sites should be calculated separately.

Complementary to the conventional costs are the *environmental costs*, related to the environmental impacts of a farm. The first major differentiation is that each crop production method or technology may have different environmental impacts. For instance, a very advanced farm monitoring system for micro-organisms or biomass decay and use optimization may impose higher conventional costs on a RA farmer. However, this monitoring system can generate lifecycle environmental benefits (e.g. pollution avoidance) due to its high environmental performance that if accounted and monetized can partially or fully offset the previous conventional cost increase. Following this methodology, the environmental economic costs and benefits are classified as:

- **Resource Costs and Benefits**, related to the intensity of using virgin resources. Hence, the use of virgin resources intensifies depletion in the PEF categories A1-3, while using recycled materials or *Renewable Energy Sources* (RES) in the energy mix generates a *resource depletion avoidance effect* that translates into lower GWP equivalents.
- **Ecosystem Services Costs and Benefits**, related to the impact of each crop production method and related technology on the output and value of ESs. For assessing the environmental benefits of RA, we will compare its performance to a benchmark CA value. Hence, for GWP values lower than the benchmark we assume a *net environmental benefit*, while for higher GWP values a *net environmental cost*.

5. Estimated PEF values for each selected SIRAM Case Study

In this section we present the results of the PEF assessment, based on the assumptions presented in the methodological part of sections 4.1-4.3. As mentioned, all values are reduced in GPWs as kg CO₂ eq. as updated on the *Assessment Report 6* (AR6) of the Intergovernmental Panel on Climate Change

(IPCC) [15]. The AR6 GWPs for assessed *Greenhouse Gases* (GhGs) yields higher values than previous estimations, which has been taken into consideration in the PEF assessment.

5.1 Endpoint vs. Midpoint approaches

Another aspect of the current PEF assessment concerns the level of causal relationships that in the LCA literature translates as the selection between *midpoint* and *endpoint* approaches. In short, the main difference relates to whether the complete sequence from the beginning of a specific emission or discharge and its final environmental impact is charted (in endpoint approaches) or it is assessed according to a safety maximum limit that is assumed to cause a variety of impacts; hence it should be overshoot (in midpoint approaches). In D5.2, it is preferred to adopt a midpoint approach as the complete charting of each environmental impact for each ecosystem at each geographical location is practically impossible. Instead, without focusing on the specific environmental impacts in each of the three CSs, we adopt for convenience the PMSL as an upper pollution budget.

5.2 Global and National scenarios

Table 6a shows the total PEF performance for the benchmark CA farm along with the RA of the three selected CSs as fraction of the benchmark CA farm for the *global* scenario, where the products are distributed in global markets.

Table 6a. Total PEF (in kg CO₂ eq./kg) for the CA farm and selected RA CSs for the *global* scenario.

Case Study	PEF (CO ₂ eq./kg)	PEF as % of Benchmark	Top 5 PEF Hotspots
CA (Benchmark)	0.8964	100.00%	1. Climate Change 2. Resource Depletion Earth 3. Resource Depletion Water 4. Eutrophication Freshwater 5. Human Toxicity Cancer
RA CS1 (UCSC)	0.6677	74.49%	1. Climate Change 2. Resource Depletion Earth 3. Resource Depletion Water 4. Human Toxicity Cancer 5. Eutrophication Marine
RA CS4 (ARC)	0.7446	83.07%	1. Climate Change 2. Resource Depletion Earth 3. Resource Depletion Water 4. Human Toxicity Cancer 5. Eutrophication Marine
RA CS6 (IRTA)	0.6799	75.85%	1. Climate Change 2. Resource Depletion Earth 3. Resource Depletion Water 4. Human Toxicity Cancer 5. Eutrophication Marine

The results of the top 5 hotspots show the phenomenal paradox of marine eutrophication being a part of the list in all selected SIRAM CSs. However, this is due to the fact that for the 3 intermediate PEF stages (Manufacturing, Transportation and Use) the values of the CA scenario were assumed, as the hypothesis was that RA products are packaged and distributed in the same way as CA products to the end consumer. This is a typical case of Scope 3 impacts that although not controlled by the RA farm they affect its performance indirectly through the infrastructure and materials produced and

distributed by global suppliers. In addition, such materials embody an additional impact across the Transportation stage (C) with the involvement of global maritime as GhG emissions-intensive.

Table 6b shows the total PEF performance for the benchmark CA farm along with the RA of the three selected CSs as fraction of the benchmark CA farm for the *national* scenario, where the products are distributed exclusively in the markets of the production country. As already highlighted, the major change from assuming only national consumption concerns the lifecycle impact on the *Transport* (C) and *EoL* (E) stages. The former impacts are reduced due to smaller vehicle distances, while the latter are reduced due to the utilization of biomass residuals either across the cultivation and harvesting stages or after consumption (as collected food wastes) that are assumed to provide a higher fraction of renewable energy (biogas or biofuels impacting on the manufacturing stage) and organic fertilizer from the dry secondary residual (after the production of biogas/biofuels).

Table 6b. Total PEF (in kg CO₂ eq./kg) for the CA farm and selected RA CSs for the *national* scenario.

Case Study	PEF (CO ₂ eq./kg)	PEF as % of Benchmark	Top 5 PEF Hotspots
CA (Benchmark)	0.7983	100.00%	1. Climate Change 2. Resource Depletion Earth 3. Resource Depletion Water 4. Eutrophication Freshwater 5. Human Toxicity Cancer
RA CS1 (UCSC)	0.5220	65,39%	1. Resource Depletion Earth 2. Climate Change 3. Resource Depletion Water 4. Human Toxicity Cancer 5. Eutrophication Marine
RA CS4 (ARC)	0.6208	77.77%	1. Climate Change 2. Resource Depletion Earth 3. Resource Depletion Water 4. Human Toxicity Cancer 5. Eutrophication Marine
RA CS6 (IRTA)	0.5369	67.26%	1. Resource Depletion Earth 2. Climate Change 3. Resource Depletion Water 4. Human Toxicity Cancer 5. Eutrophication Marine

It should be denoted though that the 5 top “hotspots” for both the global and the national scenarios were identified via the percent (%) contribution of each PEF variable to the total PEF as the simplest method out of many potential calculation methods. Such an approach can be affected by numerous factors, with the most important being related to Scope 3 impacts. Indicatively, Climate Change (B1) impacts comprise the most important hotspot for the CA and all RA CSs for the global scenario with a range between 30%-34% as they highly depend on Scope 2 and 3 emissions. For CA the B1 impact can be explained as the embodied emissions from petroleum extraction, distillation and production of its byproducts, such as petrochemical fertilizers that comprise a significant input. However, even if in all three RA CSs the B1 impact is low at stage A (with petrochemical fertilizers having a minimum direct contribution to the cumulative impact) its contribution to stages B and C remains significant as we assume that RA products are processed and packaged in industrial units that cover their energy needs from the country’s electricity grid -that in turn depends on the country’s energy mix, where

fossil fuels are dominant (Scope 2)- and distributed globally via emissions-intensive global maritime. In addition, the assumption that the majority of produced quantities is exported and consumed in a foreign country in the global scenario induces environmental impacts in stage E as well (EoL), as the verification of residual biomass and packaging recycling cannot be verified.

Respective conclusions can be postulated via looking the lifecycle impacts' structure by stage. For both the global and the national scenarios, we observe the prevalent contribution of stages A and B that are directly related to Scope 2 and 3 emissions. Specifically, in the global scenario we observe a contribution range of stages A and B between ~58% and ~65%, suggesting that the majority share of total lifecycle impacts depend on factors that the RA farms cannot control directly. A respective view can be identified in the national scenario with the contribution of stages A and B ranging between ~64% and ~68%. That structure primarily signifies the need for substituting fossil fuels in the energy mix of countries with RES and collaborating with alternative suppliers. As we present in Chapter 6, alternative transparent suppliers comprise a major part of RA labeling philosophy and schemes. The PEF results for the global and national scenarios are presented for comparison in Figure 1 below.

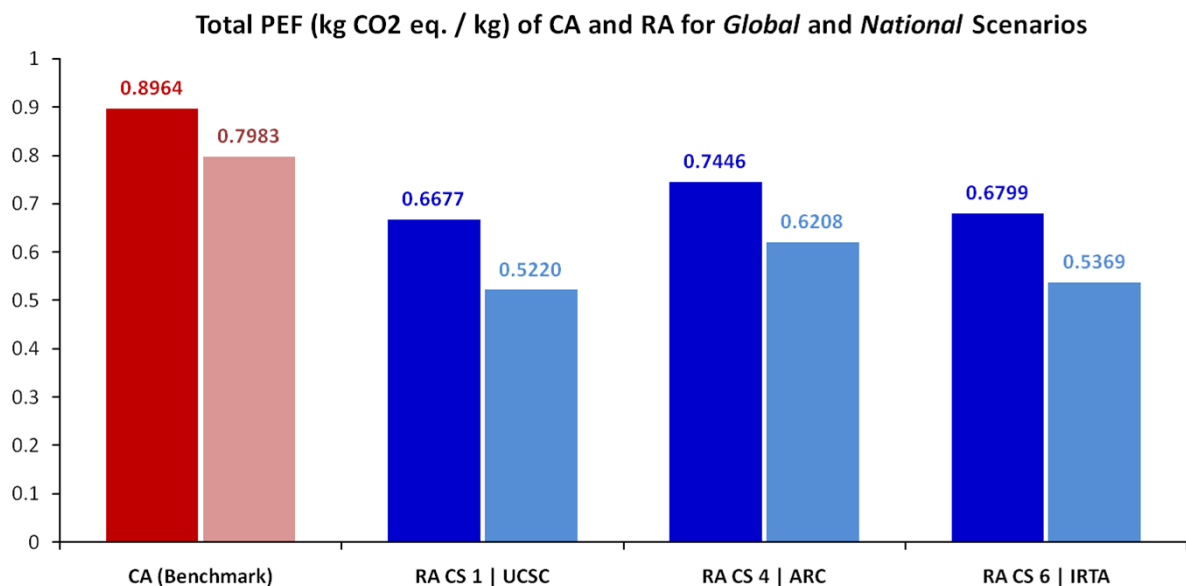


Figure 1: Overall PEF performance of a benchmark CA farm and SIRAM CS-based standardized RA farms for the *global* and *national* scenarios.

The percent (%) increase contribution of stages A and B to the total environmental impacts in the national scenario for the CA and RA farms is explained via the reduction of the percent contribution of stages C (Transportation) and E (EoL). As distances are reduced and a higher fraction of packaging materials and residual biomasses is assumed to be recycled, the impact of these stages is reduced. With the contribution of stages A and B reducing marginally, their share in the total PEF increases for the national scenario. Finally, an interesting result is that the PEF of the three RA CSs as fraction of the CA is also reduced in the national scenario, in comparison to the global scenario. This implies a downscaling effect when the geographical scale of production and trade is reduced and vice versa. The analytical PEF calculations for both scenarios for the CA and the three RA CSs are presented in Tables 7-10 below.

Table 7a. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Conventional Agriculture (CA).**Product Environmental Footprint (PEF): Conventional Agriculture (CA) | Global Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total PEF by Variable	Total PEF by Variable fraction
Resource Depletion							
Land Use	1.28E-02	5.00E-04	2.00E-04	1.00E-04	1.10E-03	1.47E-02	0.0164
Resource Depletion Earth	9.34E-02	9.11E-02	3.24E-02	2.00E-04	9.00E-04	2.18E-01	0.2432
Resource Depletion Water	1.10E-01	1.71E-02	1.13E-02	3.50E-03	1.30E-03	1.44E-01	0.1601
Ecosystem's Degradation							
Climate change	4.14E-02	9.67E-02	7.39E-02	2.00E-04	6.32E-02	2.75E-01	0.3072
Ozone Depletion	3.10E-03	7.90E-03	5.50E-03	1.00E-04	3.70E-03	2.03E-02	0.0226
Photochemical Oxidant Formation	2.70E-03	4.20E-03	3.10E-03	1.00E-04	2.30E-03	1.24E-02	0.0138
Human Toxicity Cancer	3.41E-02	5.70E-03	1.80E-03	1.30E-03	9.00E-04	4.38E-02	0.0489
Human Toxicity Non-Cancer	1.20E-03	1.90E-03	1.30E-03	1.10E-03	1.10E-03	6.60E-03	0.0074
Particulate Matter Formation	2.10E-03	2.70E-03	1.40E-03	1.00E-04	2.90E-03	9.20E-03	0.0103
Ecosystem's Toxicity	3.80E-03	4.90E-03	3.20E-03	1.00E-04	2.70E-03	1.47E-02	0.0164
Ionizing Radiation	1.00E-04	2.40E-03	2.00E-04	1.00E-04	1.00E-04	2.90E-03	0.0032
Terrestrial Acidification	2.90E-03	3.40E-03	6.00E-04	1.70E-03	2.80E-03	1.14E-02	0.0127
Eutrophication Earth	9.00E-04	4.00E-04	2.00E-04	8.70E-03	2.37E-02	3.39E-02	0.0378
Eutrophication Marine	1.10E-03	6.00E-04	1.20E-03	9.90E-03	1.91E-02	3.19E-02	0.0356
Eutrophication Freshwater	1.70E-03	8.00E-04	6.00E-04	7.30E-03	4.73E-02	5.77E-02	0.0644
Total PEF by Stage	3.12E-01	2.40E-01	1.37E-01	3.45E-02	1.73E-01	8.96E-01	
Total PEF by Stage fraction	0.3476	0.2681	0.1527	0.0385	0.1931	1.0000	

Table 7b. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Conventional Agriculture (CA).**Product Environmental Footprint (PEF): Conventional Agriculture (CA) | National Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total by PEF Variable	Total by PEF Variable fraction
Resource Depletion							
Land Use	1.28E-02	5.00E-04	2.00E-04	1.00E-04	1.10E-03	1.47E-02	0.0184
Resource Depletion Earth	8.59E-02	8.93E-02	2.24E-02	2.00E-04	7.50E-04	1.99E-01	0.2487
Resource Depletion Water	1.10E-01	1.65E-02	1.01E-02	3.20E-03	1.10E-03	1.41E-01	0.1769
Ecosystem's Degradation							
Climate change	3.79E-02	7.89E-02	5.39E-02	2.00E-04	6.25E-02	2.33E-01	0.2924
Ozone Depletion	3.10E-03	7.20E-03	5.10E-03	1.00E-04	3.30E-03	1.88E-02	0.0236
Photochemical Oxidant Formation	2.40E-03	3.70E-03	2.80E-03	1.00E-04	2.10E-03	1.11E-02	0.0139
Human Toxicity Cancer	3.02E-02	5.30E-03	1.60E-03	1.30E-03	9.00E-04	3.93E-02	0.0492
Human Toxicity Non-Cancer	1.20E-03	1.70E-03	1.20E-03	1.10E-03	1.10E-03	6.30E-03	0.0079
Particulate Matter Formation	2.10E-03	2.40E-03	1.10E-03	1.00E-04	2.50E-03	8.20E-03	0.0103
Ecosystem's Toxicity	3.60E-03	3.80E-03	2.80E-03	1.00E-04	2.40E-03	1.27E-02	0.0159
Ionizing Radiation	1.00E-04	2.20E-03	2.00E-04	1.00E-04	1.00E-04	2.70E-03	0.0034
Terrestrial Acidification	2.10E-03	3.00E-03	6.00E-04	1.70E-03	2.10E-03	9.50E-03	0.0119
Eutrophication Earth	6.00E-04	4.00E-04	2.00E-04	8.70E-03	2.07E-02	3.06E-02	0.0383
Eutrophication Marine	1.10E-03	6.00E-04	1.20E-03	9.90E-03	1.23E-02	2.51E-02	0.0314
Eutrophication Freshwater	1.20E-03	8.00E-04	6.00E-04	7.30E-03	3.62E-02	4.61E-02	0.0578
Total by PEF Stage	2.95E-01	2.16E-01	1.04E-01	3.42E-02	1.49E-01	7.98E-01	
Total by PEF Stage fraction	0.3691	0.2710	0.1303	0.0428	0.1868	1.0000	

Table 8a. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Regenerative Agriculture (RA) in CS1 (UCSC).**Product Environmental Footprint (PEF): Regenerative Agriculture (RA) | CS1 | UCSC | Global Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total PEF by Variable	Total PEF by Variable fraction
Resource Depletion							
Land Use	9.80E-03	5.00E-04	2.00E-04	1.00E-04	6.00E-04	1.12E-02	0.0168
Resource Depletion Earth	6.57E-02	9.11E-02	3.24E-02	2.00E-04	7.00E-04	1.90E-01	0.2847
Resource Depletion Water	7.01E-02	1.71E-02	1.13E-02	3.50E-03	1.10E-03	1.03E-01	0.1544
Ecosystem's Degradation							
Climate change	1.05E-02	9.67E-02	7.39E-02	2.00E-04	3.96E-02	2.21E-01	0.3308
Ozone Depletion	2.40E-03	7.90E-03	5.50E-03	1.00E-04	2.30E-03	1.82E-02	0.0273
Photochemical Oxidant Formation	1.40E-03	4.20E-03	3.10E-03	1.00E-04	1.60E-03	1.04E-02	0.0156
Human Toxicity Cancer	1.70E-02	5.70E-03	1.80E-03	1.30E-03	7.00E-04	2.65E-02	0.0397
Human Toxicity Non-Cancer	8.00E-04	1.90E-03	1.30E-03	1.10E-03	8.00E-04	5.90E-03	0.0088
Particulate Matter Formation	1.30E-03	2.70E-03	1.40E-03	1.00E-04	1.20E-03	6.70E-03	0.0100
Ecosystem's Toxicity	3.00E-04	4.90E-03	3.20E-03	1.00E-04	1.30E-03	9.80E-03	0.0147
Ionizing Radiation	1.00E-04	2.40E-03	2.00E-04	1.00E-04	1.00E-04	2.90E-03	0.0043
Terrestrial Acidification	1.00E-04	3.40E-03	6.00E-04	1.70E-03	7.00E-04	6.50E-03	0.0097
Eutrophication Earth	3.00E-04	4.00E-04	2.00E-04	8.70E-03	1.04E-02	2.00E-02	0.0300
Eutrophication Marine	2.00E-04	6.00E-04	1.20E-03	9.90E-03	8.30E-03	2.02E-02	0.0303
Eutrophication Freshwater	4.00E-04	8.00E-04	6.00E-04	7.30E-03	6.20E-03	1.53E-02	0.0229
Total PEF by Stage	1.80E-01	2.40E-01	1.37E-01	3.45E-02	7.56E-02	6.68E-01	
Total PEF by Stage fraction	0.2702	0.3599	0.2050	0.0517	0.1132	1.0000	

Table 8b. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Regenerative Agriculture (RA) in CS1 (UCSC).**Product Environmental Footprint (PEF): Regenerative Agriculture (RA) | CS 1 | UCSC | National Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total by PEF Variable	Total by PEF Variable fraction
Resource Depletion							
Land Use	8.60E-03	4.00E-04	1.00E-04	1.00E-04	5.00E-04	9.70E-03	0.0186
Resource Depletion Earth	5.14E-02	8.62E-02	1.78E-02	2.00E-04	5.00E-04	1.56E-01	0.2991
Resource Depletion Water	6.22E-02	1.43E-02	8.40E-03	2.90E-03	9.00E-04	8.87E-02	0.1699
Ecosystem's Degradation							
Climate change	9.70E-03	7.54E-02	5.01E-02	2.00E-04	1.98E-02	1.55E-01	0.2973
Ozone Depletion	2.10E-03	6.80E-03	5.50E-03	1.00E-04	1.70E-03	1.62E-02	0.0310
Photochemical Oxidant Formation	1.20E-03	3.30E-03	2.10E-03	1.00E-04	1.20E-03	7.90E-03	0.0151
Human Toxicity Cancer	1.01E-02	4.80E-03	1.40E-03	1.30E-03	6.00E-04	1.82E-02	0.0349
Human Toxicity Non-Cancer	7.00E-04	1.60E-03	1.00E-03	1.10E-03	5.00E-04	4.90E-03	0.0094
Particulate Matter Formation	1.30E-03	2.10E-03	1.10E-03	1.00E-04	9.00E-04	5.50E-03	0.0105
Ecosystem's Toxicity	2.00E-04	2.90E-03	2.50E-03	1.00E-04	8.50E-04	6.55E-03	0.0125
Ionizing Radiation	1.00E-04	2.20E-03	2.00E-04	1.00E-04	1.00E-04	2.70E-03	0.0052
Terrestrial Acidification	1.00E-04	3.00E-03	6.00E-04	1.70E-03	5.00E-04	5.90E-03	0.0113
Eutrophication Earth	2.00E-04	4.00E-04	2.00E-04	8.70E-03	5.30E-03	1.48E-02	0.0284
Eutrophication Marine	2.00E-04	6.00E-04	1.20E-03	9.90E-03	4.90E-03	1.68E-02	0.0322
Eutrophication Freshwater	3.00E-04	8.00E-04	6.00E-04	7.30E-03	3.80E-03	1.28E-02	0.0245
Total by PEF Stage	1.48E-01	2.05E-01	9.28E-02	3.39E-02	4.21E-02	5.22E-01	
Total by PEF Stage fraction	0.2843	0.3924	0.1778	0.0649	0.0806	1.0000	

Table 9a. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Regenerative Agriculture (RA) in CS4 (ARC).**Product Environmental Footprint (PEF): Regenerative Agriculture (RA) | CS4 | ARC | Global Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total PEF by Variable	Total PEF by Variable fraction
Resource Depletion							
Land Use	1.15E-02	5.00E-04	2.00E-04	1.00E-04	7.00E-04	1.30E-02	0.0175
Resource Depletion Earth	8.94E-02	9.11E-02	3.24E-02	2.00E-04	1.00E-03	2.14E-01	0.2875
Resource Depletion Water	1.02E-01	1.71E-02	1.13E-02	3.50E-03	1.20E-03	1.35E-01	0.1814
Ecosystem's Degradation							
Climate change	1.11E-02	9.67E-02	7.39E-02	2.00E-04	4.98E-02	2.32E-01	0.3112
Ozone Depletion	2.60E-03	7.90E-03	5.50E-03	1.00E-04	2.30E-03	1.84E-02	0.0247
Photochemical Oxidant Formation	1.70E-03	4.20E-03	3.10E-03	1.00E-04	1.60E-03	1.07E-02	0.0144
Human Toxicity Cancer	1.80E-02	5.70E-03	1.80E-03	1.30E-03	7.00E-04	2.75E-02	0.0369
Human Toxicity Non-Cancer	8.00E-04	1.90E-03	1.30E-03	1.10E-03	8.00E-04	5.90E-03	0.0079
Particulate Matter Formation	1.30E-03	2.70E-03	1.40E-03	1.00E-04	1.20E-03	6.70E-03	0.0090
Ecosystem's Toxicity	3.00E-04	4.90E-03	3.20E-03	1.00E-04	1.90E-03	1.04E-02	0.0140
Ionizing Radiation	1.00E-04	2.40E-03	2.00E-04	1.00E-04	1.00E-04	2.90E-03	0.0039
Terrestrial Acidification	5.00E-04	3.40E-03	6.00E-04	1.70E-03	1.10E-03	7.30E-03	0.0098
Eutrophication Earth	1.10E-03	4.00E-04	2.00E-04	8.70E-03	1.09E-02	2.13E-02	0.0286
Eutrophication Marine	6.00E-04	6.00E-04	1.20E-03	9.90E-03	9.80E-03	2.21E-02	0.0297
Eutrophication Freshwater	1.20E-03	8.00E-04	6.00E-04	7.30E-03	7.60E-03	1.75E-02	0.0235
Total PEF by Stage	2.42E-01	2.40E-01	1.37E-01	3.45E-02	9.07E-02	7.45E-01	
Total PEF by Stage fraction	0.3253	0.3227	0.1839	0.0463	0.1218	1.0000	

Table 9a. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Regenerative Agriculture (RA) in CS4 (ARC).**Product Environmental Footprint (PEF): Regenerative Agriculture (RA) | CS 4 | ARC | National Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total by PEF Variable	Total by PEF Variable fraction
Resource Depletion							
Land Use	9.10E-03	4.60E-04	1.80E-04	1.00E-04	6.00E-04	1.04E-02	0.0168
Resource Depletion Earth	6.11E-02	8.79E-02	2.26E-02	2.00E-04	7.00E-04	1.73E-01	0.2779
Resource Depletion Water	9.80E-02	1.51E-02	1.01E-02	3.30E-03	9.00E-04	1.27E-01	0.2052
Ecosystem's Degradation							
Climate change	1.03E-02	8.03E-02	6.69E-02	2.00E-04	2.07E-02	1.78E-01	0.2874
Ozone Depletion	2.50E-03	7.30E-03	5.50E-03	1.00E-04	1.70E-03	1.71E-02	0.0275
Photochemical Oxidant Formation	1.60E-03	3.60E-03	2.40E-03	1.00E-04	1.30E-03	9.00E-03	0.0145
Human Toxicity Cancer	1.50E-02	5.20E-03	1.60E-03	1.30E-03	6.00E-04	2.37E-02	0.0382
Human Toxicity Non-Cancer	7.00E-04	1.60E-03	1.00E-03	1.10E-03	5.00E-04	4.90E-03	0.0079
Particulate Matter Formation	1.00E-03	2.30E-03	1.20E-03	1.00E-04	1.00E-03	5.60E-03	0.0090
Ecosystem's Toxicity	2.00E-04	3.30E-03	2.80E-03	1.00E-04	9.20E-04	7.32E-03	0.0118
Ionizing Radiation	1.00E-04	2.20E-03	2.00E-04	1.00E-04	1.00E-04	2.70E-03	0.0043
Terrestrial Acidification	3.00E-04	3.10E-03	6.00E-04	1.70E-03	8.00E-04	6.50E-03	0.0105
Eutrophication Earth	9.00E-04	4.00E-04	2.00E-04	8.70E-03	8.90E-03	1.91E-02	0.0308
Eutrophication Marine	4.00E-04	6.00E-04	1.20E-03	9.90E-03	7.60E-03	1.97E-02	0.0317
Eutrophication Freshwater	9.00E-04	8.00E-04	6.00E-04	7.30E-03	6.80E-03	1.64E-02	0.0264
Total by PEF Stage	2.02E-01	2.14E-01	1.17E-01	3.43E-02	5.31E-02	6.21E-01	
Total by PEF Stage fraction	0.3256	0.3450	0.1886	0.0553	0.0856	1.0000	

Table 10a. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Regenerative Agriculture (RA) in CS6 (IRTA).**Product Environmental Footprint (PEF): Regenerative Agriculture (RA) | CS6 | IRTA | Global Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total PEF by Variable	Total PEF by Variable fraction
Resource Depletion							
Land Use	8.40E-03	5.00E-04	2.00E-04	1.00E-04	8.00E-04	1.00E-02	0.0147
Resource Depletion Earth	6.34E-02	9.11E-02	3.24E-02	2.00E-04	1.20E-03	1.88E-01	0.2770
Resource Depletion Water	5.02E-02	1.71E-02	1.13E-02	3.50E-03	1.60E-03	8.37E-02	0.1231
Ecosystem's Degradation							
Climate change	9.90E-03	9.67E-02	7.39E-02	2.00E-04	5.18E-02	2.33E-01	0.3420
Ozone Depletion	1.90E-03	7.90E-03	5.50E-03	1.00E-04	2.30E-03	1.77E-02	0.0260
Photochemical Oxidant Formation	2.20E-03	4.20E-03	3.10E-03	1.00E-04	2.10E-03	1.17E-02	0.0172
Human Toxicity Cancer	1.70E-02	5.70E-03	1.80E-03	1.30E-03	7.00E-04	2.65E-02	0.0390
Human Toxicity Non-Cancer	8.00E-04	1.90E-03	1.30E-03	1.10E-03	8.00E-04	5.90E-03	0.0087
Particulate Matter Formation	2.40E-03	2.70E-03	1.40E-03	1.00E-04	1.80E-03	8.40E-03	0.0124
Ecosystem's Toxicity	1.20E-03	4.90E-03	3.20E-03	1.00E-04	1.70E-03	1.11E-02	0.0163
Ionizing Radiation	1.00E-04	2.40E-03	2.00E-04	1.00E-04	1.00E-04	2.90E-03	0.0043
Terrestrial Acidification	1.30E-03	3.40E-03	6.00E-04	1.70E-03	1.12E-02	1.82E-02	0.0268
Eutrophication Earth	1.40E-03	4.00E-04	2.00E-04	8.70E-03	1.11E-02	2.18E-02	0.0321
Eutrophication Marine	7.00E-04	6.00E-04	1.20E-03	9.90E-03	1.09E-02	2.33E-02	0.0343
Eutrophication Freshwater	1.60E-03	8.00E-04	6.00E-04	7.30E-03	7.60E-03	1.79E-02	0.0263
Total PEF by Stage	1.63E-01	2.40E-01	1.37E-01	3.45E-02	1.06E-01	6.80E-01	
Total PEF by Stage fraction	0.2390	0.3534	0.2014	0.0507	0.1555	1.0000	

Table 10b. PEF assessment in terms of GWP by IPCC-AR6 in terms of kg of CO₂ eq. per kg of product and land use of 1,000m² for Regenerative Agriculture (RA) in CS6 (IRTA).**Product Environmental Footprint (PEF): Regenerative Agriculture (RA) | CS 6 | IRTA | National Scenario**Impacts as GWP by AR6 in terms of kg of CO₂ eq. per kg of Product for Land Use of 1,000m²

PEF Variables / Stages	Raw Materials	Manufacturing	Transportation	Use/Consumption	End of Life (EoL)	Total by PEF Variable	Total by PEF Variable fraction
Resource Depletion							
Land Use	8.30E-03	4.13E-04	1.20E-04	1.00E-04	5.00E-04	9.43E-03	0.0176
Resource Depletion Earth	6.02E-02	8.66E-02	1.83E-02	2.00E-04	5.50E-04	1.66E-01	0.3089
Resource Depletion Water	4.96E-02	1.47E-02	9.40E-03	3.05E-03	9.00E-04	7.77E-02	0.1447
Ecosystem's Degradation							
Climate change	9.10E-03	7.67E-02	5.27E-02	2.00E-04	2.01E-02	1.59E-01	0.2958
Ozone Depletion	1.87E-03	6.91E-03	5.50E-03	1.00E-04	1.70E-03	1.61E-02	0.0300
Photochemical Oxidant Formation	1.93E-03	3.60E-03	2.23E-03	1.00E-04	1.23E-03	9.09E-03	0.0169
Human Toxicity Cancer	1.54E-02	4.90E-03	1.47E-03	1.30E-03	6.00E-04	2.37E-02	0.0441
Human Toxicity Non-Cancer	7.00E-04	1.60E-03	1.00E-03	1.10E-03	5.00E-04	4.90E-03	0.0091
Particulate Matter Formation	2.01E-03	2.10E-03	1.12E-03	1.00E-04	9.60E-04	6.29E-03	0.0117
Ecosystem's Toxicity	8.00E-04	3.00E-03	2.62E-03	1.00E-04	8.70E-04	7.39E-03	0.0138
Ionizing Radiation	1.00E-04	2.20E-03	2.00E-04	1.00E-04	1.00E-04	2.70E-03	0.0050
Terrestrial Acidification	7.00E-04	3.00E-03	6.00E-04	1.70E-03	5.90E-04	6.59E-03	0.0123
Eutrophication Earth	1.00E-03	4.00E-04	2.00E-04	8.70E-03	6.40E-03	1.67E-02	0.0311
Eutrophication Marine	5.00E-04	6.00E-04	1.20E-03	9.90E-03	5.30E-03	1.75E-02	0.0326
Eutrophication Freshwater	1.30E-03	8.00E-04	6.00E-04	7.30E-03	4.20E-03	1.42E-02	0.0264
Total by PEF Stage	1.54E-01	2.08E-01	9.73E-02	3.41E-02	4.45E-02	5.37E-01	
Total by PEF Stage fraction	0.2859	0.3866	0.1812	0.0634	0.0829	1.0000	

5.1 Data Synthesis

The estimations of the above tables incorporate significant uncertainty due to lack of geographically specific baseline values. In addition, the intermediate PEF stages (Manufacturing, Transportation, Use/Consumption) are considered identical for both CA and RA in the *global* scenario. However, it should be taken into account that RA products could have different distribution networks and more local consumption with alternative business models that are tailored for certified/labeled products. This issue of lower local impacts is addressed in the examination of the *national* PEF scenario, with database estimations from the CSs on alternative packaging and distribution channels that will be utilized in D5.3 where tailored business models for RA will be developed. Respectively, a proposal for a labeling system is described thoroughly in Chapter 6.

For data that were not produced directly by the SIRAM CSs, we made rational assumptions according to available databases, following the general approach of business lifecycle certifications (e.g. EPD or Cradle to Cradle). This is a necessary approach until production units in the EU are obliged to keep analytical records of their materials and production processes to assess embodied and operational emissions [10]. Currently, there are more than 400 LCA standards that cover various lifecycle stages (e.g. Cradle to Gate instead of Cradle to Grave performed in D5.2). However, the most reliable, EU acceptable but challenging LCA method is the PEF.

Regarding the data sources, the CA benchmark was estimated for a mono-culture field of 1,000m² of potatoes with standard embodied environmental impact values based on estimates of the *Food and Agriculture Organization* (FAO) in combination to the *Ecoinvent 3.10* database. These data sources were in turn translated into GWPs by the IPCC AR6. For infrastructures of the hypothetical fields, the databases of special software packages were utilized in a tailored way. For instance, for buildings' materials the *One Click LCA* software databases were used, while for transportation infrastructures we used the *Sima Pro* databases. The above data were combined to data generated and published across the PEF pilot phase by the European Commission (EC) and affiliated counterparties. For the RA hypothetical farms the data received by SIRAM CSs in M5.1 for all SIRAM pillars (those examined by each CS) and five common economic data classes, such as the energy mix related to Scope 1 and 2 emissions, surface and groundwater use, the use of conventional fertilizers as production factors with embodied GhGs that are competitive to micro-organisms and derived ESs, as well as climate time series data, such as temperature, precipitation, soil pH and Evapotranspiration (ET). The data received were translated into respective resource uses to assess the PEF in comparison to CA.

6. Regenerative Agriculture Certification and Labeling (RACL)

A major challenge for consumers' information and the qualitative market classification of products by the FCBA concerns the accurate and user-friendly labeling in packaging. Product labeling aims at establishing the highest possible classification via an integrated approach to RA as a reward beyond the exclusive consideration of environmental performances. This approach is compliant to the EU SFT and ESG criteria and highlights that RA farms have an overall socio-economic impact besides the high environmental performance.

In this context, the revenue streams of RA farms should satisfy a number of multiple criteria in order to receive the labeling reward. The label should depict their differentiation from conventional farms, through the establishment of transparent supply chains and commercial relations with certified eco-friendly producers, balance in the access of scientific knowledge and practices that -as presented in

D5.1- define a large part of the endogenous growth potential of an RA farm for both genders, trade networks that pay fair prices to counterparties without exercising their market power, decent labor conditions and salaries, social contributions to local communities in which they operate, as well as several other aspects. Indeed, it would be quite difficult and ethically challenging to consider a farm as eligible for RA labeling with exclusive criterion its lifecycle environmental performance, but with several moral issues in other aspects of its business activity. Of course, it could be argued that a very strict environmental lifecycle certification would be a preventive factor against other malpractices as it imposes a minimum level of transparency to the business. However, even the most transparent and coherent Scope 2 and 3 reports are unable to provide meaningful information on the supplier's business practices (e.g. child labor) -other than its environmental performance. Hence, even though a farm may achieve high environmental performance, it would not be accepted as RA if specific SDG-related *Fair Trade* (FT) elements were missing [16].

6.1 The PEF universal classification

To establish a consistent RACL system as an upgrade of the PEF, it is necessary to comprehend the *universal* PEF 5-grade coloring classification that is essentially a user-friendly coding of the complex underlying lifecycle impact calculations. The 5-grade coloring PEF system is established for any kind of environmental performance classification in the EU (e.g. energy performance of buildings); hence it comprises a benchmark to which any other performance classification system must be compliant. A theoretical example of an olive oil product is presented schematically in Figure 2 below.

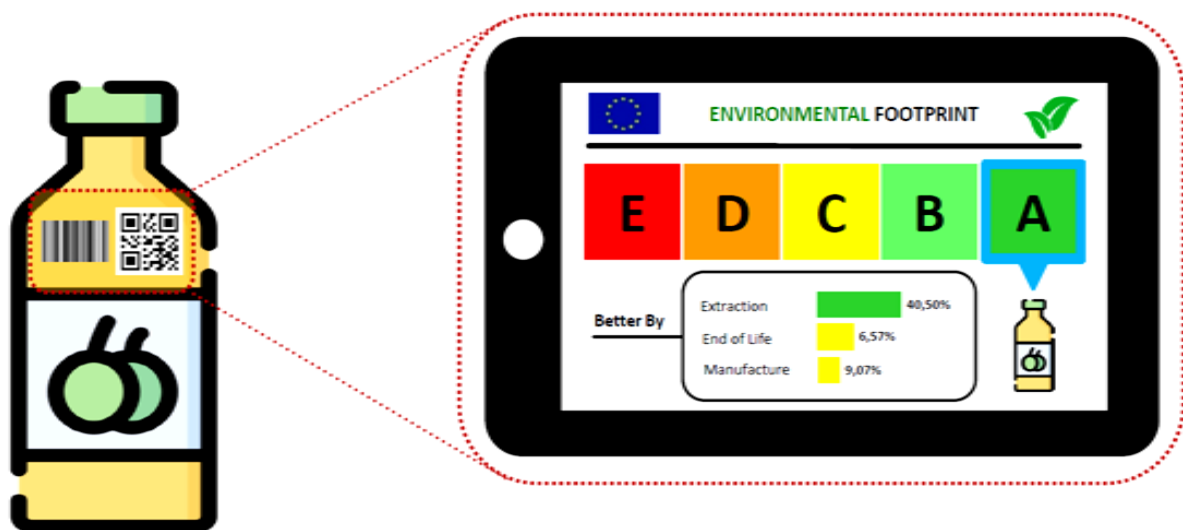


Figure 2: Schematic depiction of the EU universal 5-grade coloring of an agricultural product's EF performance revealed by scanning over a bar or Quick Response (QR) code. The three (3) PEF stages for which the product achieves better performance in relation to the alternatives can be included as optional information; however, this requires additional digital infrastructures that will be available after 2028 [10].

The color classification system is accompanied by respective letters that declare the environmental state achieved. The 5-level grading also serves as an easy way to establish a Median value exactly in the middle of the color spectrum with symmetrical edges (two from left and right) without the need to describe it with complex mathematical formulation. The median value is expressed by letter "C" with the yellow color. In short, the brief explanation of environmental states by colors and letters is as following:

A (Dark Green): Improves environmental state significantly from the baseline value.

B (Light Green): Improves environmental state marginally from the baseline value.

C (Yellow): Maintains environmental state at the baseline value (neither improves or worsens).

D (Orange): Deteriorates environmental state marginally from the baseline value.

E (Red): Deteriorates environmental state significantly from the baseline value.

The baseline value (Yellow, C) in our study case would be the CA farm for each scenario (global and national), following practices that deteriorate the natural environment from its virgin natural state. However, as CA has become the dominant agricultural practice since the Industrial Revolution it is considered to be the baseline. Any alternative agricultural practice (e.g. RA) is assessed according to how better it performs in relation to the baseline. This approach has been adopted in the global and national scenarios, where RA farms perform better in comparison to the CA as their lifecycle impacts are only a fraction of the CA impacts. In addition, the baseline value can be geographically-specific (different at every location).

6.2 SDGs, Fair Trade Principles and the RACL rationale

As developed in the previous sections, RA farms embody significant socio-economic dimensions. As the core argument for the agricultural shift towards nature-based or bio-based solutions -with RA being a major representative of this current- such farms should reflect the regenerative character of the new agro-economic paradigm in society. Besides the ethical issues, there is a practical utility for such an approach as a case where a farm would achieve high environmental performance but at the cost of extreme economic inequality, competition suppression via the use of monopoly or oligopoly power, as well as child labor to suppress production costs would be in direct conflict with definitions of sustainable development that focus on the balance between environment, society and economy with *intergenerational equity*. Hence, the assessment of RA farms should extend to socio-economic criteria. The most indicative framework to reflect this context is the 10-principles FT framework [16] that further specifies several SDGs as following:

P1: Creating Opportunities for Economically Disadvantaged Producers | SDGs 1, 8, 10, 17.

P2: Transparency and Accountability | SDGs 10, 12, 16.

P3: Fair Trading Practices | SDGs 1, 8, 9, 10, 12, 16, 17.

P4: Payment of a Fair Price | SDGs 1, 2, 8, 10.

P5: Ensuring no Child Labor and Forced Labor | SDGs 4, 8, 10, 16.

P6: Commitment to Non Discrimination, Gender Equity and Women's Economic Empowerment and Freedom of Association | SDGs 4, 5, 8, 10.

P7: Ensuring Good Working Conditions | SDGs 1, 2, 8, 10.

P8: Providing Capacity Building | SDGs 4, 8, 9, 11.

P9: Promoting Fair Trade | SDGs 1, 2, 8, 9, 10, 12, 16, 17.

P10: Respect for the Environment | SDGs 3, 6, 7, 9, 11, 12, 13, 14, 15.

The above principles cover all SDGs at least once, although they focus on the socio-economic goals in their majority, describing at a more special level the dimensions of the related SDGs (e.g. P5 on child labor prevention via securing quality education, decent work that could include young apprentices, reduce inequalities between countries to prevent the use of children as cheap hard labor force for otherwise “green” technologies and the strengthening of institutions protecting the social relations of people). In overall, if the revenue streams of the RA farm are defined by both environmental and socio-economic criteria, the rationale of a respective labeling should depict this 3-variable balance. Such a classification must be compliant to the existing EU universal labeling principles and reflect the “one step further” of RA farms.

6.3 RACL universal classification

As in principle the RA farm revenue streams should reflect the balance between environmental and socio-economic aspects, the RACL metrics should respectively facilitate an overall index measuring the deviation between its dimensions. Specifically, the RACL metrics’ pillars are the following:

1. The potential to use weighting for criteria defining environmental and socio-economic impacts, as the priorities and pressures may significantly changing per geographical location.
2. The potential to use the *Min(C)* function as the *minimum acceptable level of performance for each dimension* in order to be eligible to be evaluated as RA farm. Some of the most demanding systems on the CE (e.g. Cradle to Cradle labels) set a minimum performance as a baseline to even declare an economic unit as eligible to be assessed at a more specific level and get a classification grade. After the minimum performance is verified, the RA farm is assessed by the score achieved in each one of its dimensions.
3. The potential to use *information entropy* metrics [6,14] to define the RA farm’s specific score after securing the minimum acceptable score for each dimension in order to belong to the family of RA farms (“Pass” state) that further positions it within the family (e.g. top 5%, 25% etc.). This ranking can be available to consumers and investors in order to stimulate RA farms to further innovate and grow via minimizing their PEF and following FT principles.

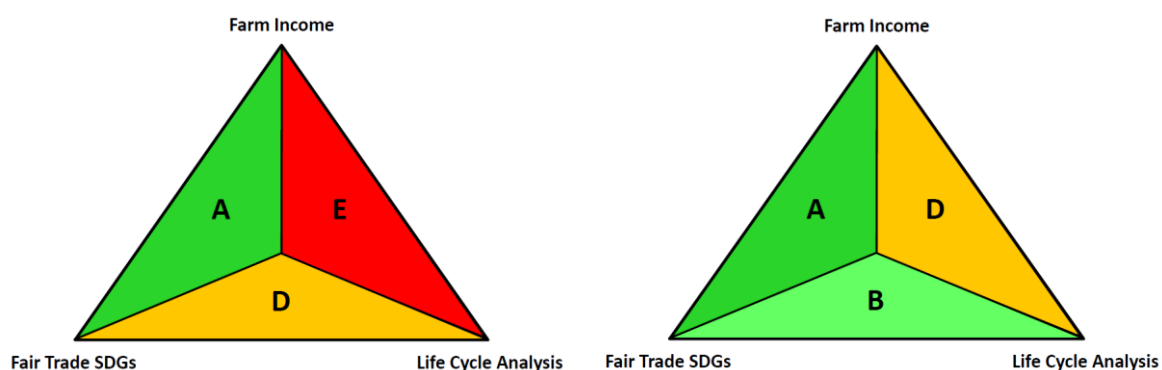


Figure 3: Schematic depiction of the additional RA labeling following the EU universal 5-grade coloring by three (3) additional dimensions. For a product to be eligible to be labeled as RA its *minimum* performance in *every* dimension must be at least of level “C”. The above cases present product that *fail* the RA certification.

Whatever the selected metrics are, the RA farm must have secured a “Pass” for *every* criterion that is equivalent to the “C” (yellow color) in the EU universal classification system. State “C” represents the baseline state for proceeding to the farm’s RACL assessment that is the descriptive equivalent to

“no substantial change the baseline state caused by the applied solution”. Typical graphic examples of the RACL certification are presented below in Figures 3 and 4.

The baseline state concerns both the environmental and socio-economic part of the assessment. The environmental state is already assessed by the PEF, where (as shown in the global and the national scenarios, RA farms achieve a better performance than the CA as baseline). The complementary part of the PEF is the SDGs FT on the socio-economic aspects as described in Section 6.2. In this context, Figure 3 depicts the universal 5-grade coloring scheme for the RA labeling assessment. The top edge of the triangle represents the farm’s income size, as the annual turnover. The annual turnover is a quick and representative index of the size of the farm and its share in the whole sector for a selected geographical area (local, regional, national, international). This is a useful index reflecting also the market power of the farm; meaning that a farm with high market share (and power) would signify on the one hand the preference of consumers for its products, while on the other hand its higher socio-economic weight, responsibility and difficulty to be transparent. The right lower edge represents the farm’s environmental performance in PEF terms, while the lower left edge represents the SDGs FT performance.

Hence, according to the above, in overall, the RACL triangle represents primarily the performance of the farm’s revenue constituents separately (how well does the PEF and the SDGs FT contribute to the farm’s income separately), as well as the relation between these constituents (e.g. how much does the PEF performance contribute to the SDGs FT performance). The separate internal triangles reflect these paired relationships. According to the rules set in the previous sections, Figure 3 depicts a theoretical case where a farm is primarily assessed with a “Fail” grade by the $\text{Min}(C)$ function, as in both cases it fails to acquire the “C” level as minimum in every criterion (in the first case (left) it fails to acquire the “C” level for the PEF-FT and PEF-income contribution, while in the second case (right) it fails to acquire the “C” level for the PEF-income contribution even if it achieves high scores in the other two constituents).

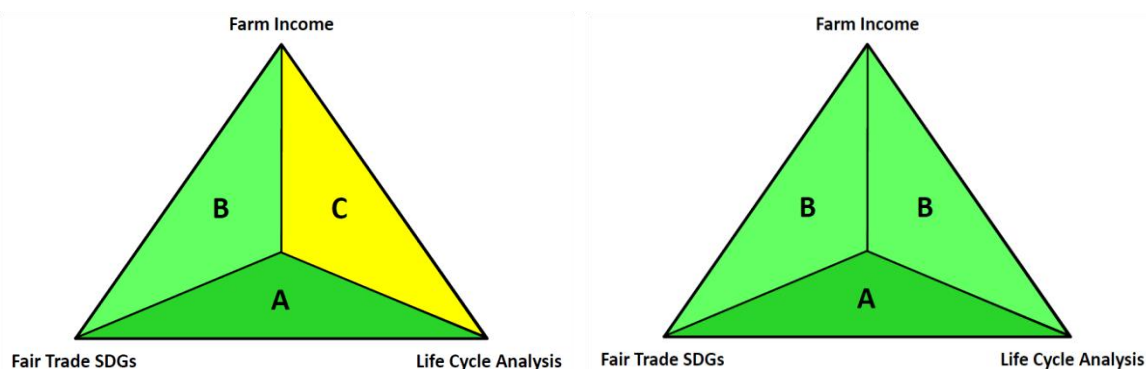


Figure 4: Schematic depiction of the additional RA labeling following the EU universal 5-grade coloring by three (3) additional dimensions. For a product to be eligible to be labeled as RA its *minimum* performance in *every* dimension must be at least of level “C”. The above cases present product that *pass* the RA certification.

In contrast, with the same rationale, Figure 4 depicts cases where a farm is primarily assessed with a “Pass” grade by the $\text{Min}(C)$ function; hence, it is considered to belong in the RA farming family and further be assessed for its score within it. For instance, the first case (left) can be considered to be a farm that achieves a baseline environmental performance by its PEF (and it is important to denote again here that this may be due to numerous factors, such as the high dependence of Scope 2 and 3 emissions with global impact although it may be performing exceptionally in terms of ES generation

locally), while it may be performing exceptionally in terms of how it manages to translate its PEF into value for all or specific aspects of its SDGs FT that in turn contributes with a high performance in the farm's income. The second case (right) is more straightforward, as it depicts a *Pareto Improvement* in relation to the first case (same performance in the FT-Income and PEF-FT contribution but better in the PEF-Income contribution), which essentially would classify it at a better rank within family of certified RA farms. Finally, it is important to denote that this approach focuses mainly on the RACL semantics and the general approach of the classification system whatever metrics are selected for use. The issue of mathematical formulation for assessing such performances comprises a major issue in the literature with enormous commercial significance after 2028 with the obligatory registration of baseline carbon assessments [10] that will further establish a future market of carbon credits (as well as other pollutants). In addition, identifying inter and intra-correlations and causalities between the selected variables (e.g. the economic mechanism by which the PEF and FT contribute to income, as well as between them) will comprise one of the most challenging field of econometrics.

7. State of the Deliverable 5.2 Update

From the updated PEF analysis we may conclude the existence of significant uncertainties, although these uncertainties derive from the special features of the hypothetical farms' location. In addition, it can be easily understood that the CA and RA scenarios are assessed by a single reference crop that is assumed to be produced with the same methods, except for the differences in their pillars for the RA farms and the hydroclimatic conditions in each country. This is an uncertainty deriving from all midpoint LCA approaches that prioritize the homogenization and comparability of data. However, it should be kept in mind that in the future attempt to monetize the lifecycle environmental benefits and impacts, endpoint methods may be more appropriate; provided that a common EU ecological valuation system as vital part of the EU GD is established, taking into account the special conditions of Southern Mediterranean ecosystems [17]. With "Climate Change" and "Earth Resource Depletion" impacts shown in the PEF assessments as the first "hotspot" for all CA and RA scenarios, the role of RA as temporary net carbon storage should be considered for areas threatened with desertification, including the use of resistant varieties for its mitigation [18]. In addition, we can fairly assume that with a tailored approach for each RA CS the PEF would probably yield a significantly lower lifecycle impact that adds monetary value to RA practices. This issue will be partially covered in D5.3 as well.

Additional uncertainties of the updated PEF assessment are the following:

1. What different results would the PEF assessment yield in terms of GWP per land use instead of per unit of crop output?
2. The current PEF assessment assumed a relatively small cultivated area of 1,000m². What would be the effect of economies of scale on the PEF across the (linear) increase of land of CA and RA?
3. What would be the PEF-normalized value by including the fallow periods for CA in the long-term with the PEF estimated as a weighted average of many subsequent years?
4. What would be the geographical implications for the comparison between CA and RA scenarios, since not a "universal standard" of a benchmark CA farm would apply for comparing the yield of all CSs? This is an issue to be standardized in the EU from 2028 [10].
5. The enrichment of existing LCA databases with baseline data for RA for higher accuracy of results with the inclusion of benefits from increased carbon storage.

6. How could we combine economic analyses to highlight the value of natural capital and the true cost of depletion and degradation effects at a local scale more accurately?

8. Conclusions and next steps

With the objectives of the first version of D5.2 achieved and the progress of WP5 considered above satisfactory, the next scheduled steps are the following:

- The WP5 Leader will collaborate with the responsible partners of critical deliverables in WP3 to assess microbial performance and elaborate the REGENA function.
- The WP5 Leader investigates the potential of a WP5-side work on the *Economics of Micro-biodiversity* in collaboration to a SIRAM letter supporter that has declared interest.
- Publication of a paper to an open access peer-reviewed journal with the methodology and results of the REGENA function by the end of the project (M36).
- Publication of a paper to an open access peer-reviewed journal on how PEF assessments can be utilized for structuring contracts for RA finance by the end of the project (M36).
- Dissemination of the PEF preliminary results and their relation to the REGENA function by WP6 and inclusion of the model to the training workshops.

9. Extensions of D5.2 beyond SIRAM

From the collaboration with the partners of the SIRAM consortium and the integration of agronomic and economic methods, we have already identified commercial breakthrough extensions for which our current work is the foundation. In this chapter we focus exclusively on economic utilizations that are a results' exploitation target during the post-SIRAM era, as for now they are beyond the scope of our current research objectives and can only be discussed.

It is expected that the establishment of EPR and labeling systems for RA would be catalytic for the large-scale deployment of RA solutions, as it will allow a tangible assessment by financial institutions with reliable and investable metrics. Based on that prospect, we may state the following indicative, however non-exhaustive, post-SIRAM issues to be investigated:

- How would an EPR/labeling system based on the PEF, impact on the global demand for RA products?
- How can the combined EPR/labeling system based on the PEF, attract financial capital from commercial banks and investment funds (in relation to the results of D5.3)?
- What can the PEF reveal on the potential of RA to upscale the output of legumes for cattle feed and substitute international imports on which the EU depends by ~80%?

As mentioned, the above issues are only indicative and WP5 of SIRAM will set the foundations via the next deliverables (D5.3) along with the collaboration with stakeholders and project supporters for continuing the research towards this direction.

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