Conceptual and Analytical Framework for Climate Smart Agriculture Research

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Author(s):
Guy Ziv & Judith Ford, University of Leeds
Ellen Bulten & Emma Knol, Wageningen Research

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Authors	**Guy Ziv, Judith Ford (ULeeds)** **Ellen Bulten, Emma Knol (WR)**
Reviewer	**Herman Schoorlemmer, Arwen van der Gugten (WR)**
Contact	**Prof. Guy Ziv (g.ziv@leeds.ac.uk)**
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Disclaimer

List of Abbreviations

AKIS	Agricultural Knowledge and Innovation System
ClimAP(s)	Climate Action Plan(s)
CSA	Climate Smart Advisors project
CFD	Climate Farm Demo project
CSR	Climate Smart Research
DEC	Dissemination, Exploitation and Communication
ERS	Experimental Research Station(s)
GHG	Greenhouse Gas
HEI	Higher Education Institution
InnovatERS	Innovating Experimental Research Stations
LCA	Life Cycle Analysis
MAA	Multi Actor Approach
PioneERS	Systemic Pioneering Experimental Research Stations
R&I	Research & Innovation
WP	Work Package

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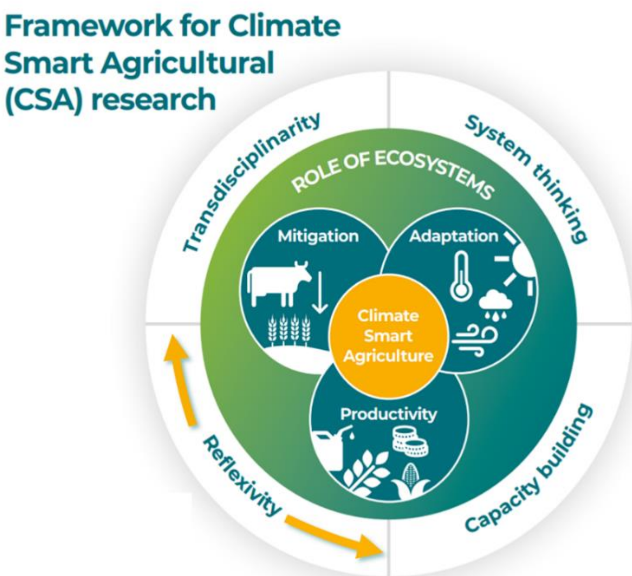
Abstract

The Climate Smart Research (CSR) project aims to accelerate the transition to climate neutral agriculture and contribute to EU climate goals by developing new Climate Smart Agriculture knowledge and innovations, connecting 29 agricultural Experimental Research Stations (ERS). Contemporary research on Climate Smart Agriculture tends to focus on individual solutions, missing a holistic whole-farm perspective that includes pedoclimatic context, interactions, synergies and trade-offs. This holistic approach is even lacking on many agricultural ERS across the EU. This limits our understanding of what effective Climate Smart Agriculture systems look like and how to effectively research Climate Smart Agriculture systems. As part of the CSR project, we therefore developed a conceptual framework for *conducting* climate-smart agricultural research, aiming for maximum impact.

This deliverable presents a Conceptual and Analytical Framework for Climate Smart Agriculture Research. The aim of this framework is to 1) introduce, clarify and align key concepts for conducting climate-smart agricultural research; and 2) ensure alignment of methods, data and impact, as well as creating a common language within the CSR project. The framework consists of two parts: a conceptual framework and a research framework. The conceptual framework describes *what we know* about Climate Smart Agriculture and doing Climate Smart Agriculture research, identifying and defining key concepts. The research framework describes *where we go with this* by defining research questions around the core concepts.



The Conceptual Framework describes six core concepts for Climate Smart Agricultural research:

1. Climate Smart Agriculture in 'real conditions'
    a. Mitigation,
    b. Adaptation,
    c. Productivity
2. Role of ecosystems supported and/or impacted by Climate Smart Agriculture
3. System thinking

4. Capacity building
5. Reflexivity
6. Transdisciplinarity

For each of the concepts in the Conceptual Framework, we developed a short primer which outlines;

- Definition
- Role of the concept in the project
- Examples, challenges and opportunities
- Operationalisation
- Implementation

To be able to streamline methods, protocols, and data across the project, we created a Research Framework. The Research Framework uses a lens-based approach and is structured as a matrix, intersecting four themes with six research lenses. The four themes explored in the Research Framework are:

1. Defining Climate Smart Farming practices and measuring success;
2. What Climate Smart practices work and why?
3. Enabling the transition to climate neutral agriculture by farmers;
4. Building capacity for Climate Smart Agriculture research.

These four themes are explored in the 6 CSR Work Packages (WPs) using six lenses:

- Literature
- Experimental research
- Researchers' expert knowledge
- Practitioners' local knowledge
- Simulations and tools
- Policy and business

In a matrix where these themes and lenses intersect, we formulated research questions for the CSR project. This matrix approach ensures that no research question is answered in isolation. By triangulating data from literature, experimental trials, practitioner experience, and modelling tools, CSR ensures that the knowledge generated is not only scientifically robust but also practically applicable and scalable across the diverse pedo-climatic zones of the European Union.

1. Introduction

The European Green Deal offers an ambitious set of initiatives towards a climate neutral European economy solution, as reducing agricultural GHG emissions (CO_2, CH_4, N_2O) plays a significant role in mitigating climate change, while sequestering atmospheric CO_2 into soils and biomass is among the cheapest options for 'negative emissions. Climate Smart Agriculture is an often-suggested framework to address climate change challenges in agriculture, by 2050. The "Fit for 55" package was adopted to respond to the requirements in the EU Climate Law, aiming to meet the target of reducing GHG emissions by at least 55% by 2030 compared with 1990, and achieve climate neutrality by 2050. Agriculture plays a dual and critical role in the climate challenge; it is both a contributor to climate change while also being one of the sectors most vulnerable to its impacts. Climate Smart Agriculture Research offers an integrative, whole-farming system approach to respond effectively to climate change, since "it integrates the three dimensions of sustainable development (economic, social and environmental) by: 1) sustainably increasing agricultural productivity and incomes; 2) adapting and building resilience to climate change; and 3) reducing and/or removing greenhouse gas (GHG) emissions, where possible."[1] The Climate Smart Research (CSR) project aims to accelerate the transition to climate neutral agriculture and contribute to EU climate goals by developing new Climate Smart Agriculture knowledge and innovations, connecting 29 agricultural Experimental Research Stations (ERS).

Contemporary research on Climate Smart Agriculture tends to focus on individual solutions, e.g. a specific crop and/or adaptation/mitigation solution, missing a holistic whole-farm perspective that includes pedoclimatic context, interactions, synergies and trade-offs at farm scale. This holistic approach is even lacking on many agricultural ERS across the EU. This limits our understanding of what effective Climate Smart Agriculture systems look like and how to effectively research Climate Smart Agriculture systems. As part of the CSR project, we therefore developed a conceptual framework for *conducting* climate-smart agricultural research, aiming for maximum impact - thinking about the entire research process, its components, and how they interact, to achieve meaningful outcomes.

Conceptual framework workshops

To develop the conceptual framework and ensure alignment of methods, data and impact, as well as creating a common language, we organised two workshops with consortium partners. The objective of the first workshop was to explore a shared theoretical framework by introducing, clarifying and aligning key concepts for conducting climate-smart agricultural research. The workshop aimed to

[1] FAO (2013). Climate-Smart Agriculture Sourcebook Executive Summary. Food and Agriculture Organization of the United Nations

synthesise these insights into a shared framework, agree on steps for operationalisation, and map (conceptual) pathways towards the transition to net-zero emissions agriculture.

The second workshop focused on assessing the first draft of the conceptual framework, which was developed based on the outcomes of the first workshop. In addition, we aimed to create an overview of project activities and identify how and where different WPs contribute to the key concepts within the framework. This workshop resulted in a refined framework, agreed-upon definitions, and a mapping of relevant activities across the project.

Following these broader workshops, targeted workshops with focus on finetuning the frameworks took place with WP3 (including PioneERS, split into two events), WP2 (WP co-/lead and task leaders), WP4 (WP co-/lead and task leaders) and WP5 (WP co-/lead and task leaders).

Reading guide

In this chapter, we first introduce the core principles of Climate Smart Research and an overall visualisation showing *what* we research in CSR and *how* we research in CSR. This overall framework is split into two parts: a conceptual framework (Chapter 2) and a research framework (Chapter 3). The conceptual framework describes *what we know* about Climate Smart Agriculture and doing Climate Smart Agriculture research. In Chapter 2, we introduce key concepts of climate smart agricultural research. We introduce these key concepts through primers; short notes defining each concept and how the concept will be operationalised in CSR. The research framework in Chapter 3 describes *where we go with this* by defining, in collaboration with all CSR WP leaders, the research questions around the core concepts.

Principles for Climate Smart Research

The Climate Smart Research framework builds on the work of Rossing et al. (2021), Fazey at al. (2018) and Thornton et al. (2018), we formulate core principles for Climate Smart Agricultural Research. Starting from the work of Fazey et al. (2018), their work assists in setting the scene and epistemological logic of what 'good' research in the context of climate smart agriculture looks like. Building on the work of Rossing et al. (2021) we operationalise this logic in a co-creative approach for climate smart agricultural research. Finally, the work of Thornton et al. (2018) assists in prioritising research activities specifically for climate smart agriculture research given available resources.

'Good' research for climate smart agriculture

Fazey et al. (2018) argue that "the most critical question for climate research is no longer about the problem, but about how to facilitate the transformative changes necessary to avoid catastrophic climate-induced change". To achieve this, Climate Smart Research needs to be adaptive, reflexive, collaborative and impact-oriented, and enable research to enhance the capacity to respond to the climate challenge.

Co-creative approach

Rossing et al. show that significant contributions to sustainability transitions, such as the transition to climate neutral agriculture, require 1) in-depth project preparation, 2) focus on farm-level rather than field or crop level, 3) connection to regional actors and 4) frequent exchange among project actors. They also highlight the need to move from linear cause-effect relations to systems thinking, learning and reflexivity.

Priorities

Lastly, Thornton et al. stress that priority setting activities for climate smart agricultural research need a mix of quantitative and qualitative methods, which need to address actions spanning spatial and temporal scales. In practice, this means to leave room to address urgent and immediate climate related farming problems but simultaneously enable conditions for long-term change.

Translating these insights, we formulate the following core principles for Climate Smart Research:

1. Focus on 'how to' knowledge for climate smart agriculture…
2. … covering the three pillars of mitigation, adaptation and productivity…
3. … from a systems and long-term perspective…
4. … through participation and co-creation: research *with* and not just *for* stakeholders…
5. … fostering biodiversity and ecosystem services considering impact of agricultural activities on ecosystems and vice versa the potential to manage ecosystems to help farming practices; and …
6. … adopting an iterative, reflexive approach to research design and collective learning.

2. Conceptual Framework

The core principles described in Chapter 1 translate into six core concepts for Climate Smart Agricultural research, as also visualised in Figure 1. We make a distinction between *what* we research and *how* we research in CSR.

What we research:

1. Climate Smart Agriculture in 'real conditions'
   - Mitigation,
   - Adaptation,
   - Productivity
2. Role of ecosystems supported and/or impacted by Climate Smart Agriculture

How we research:

3. System thinking
4. Capacity building
5. Reflexivity
6. Transdisciplinarity

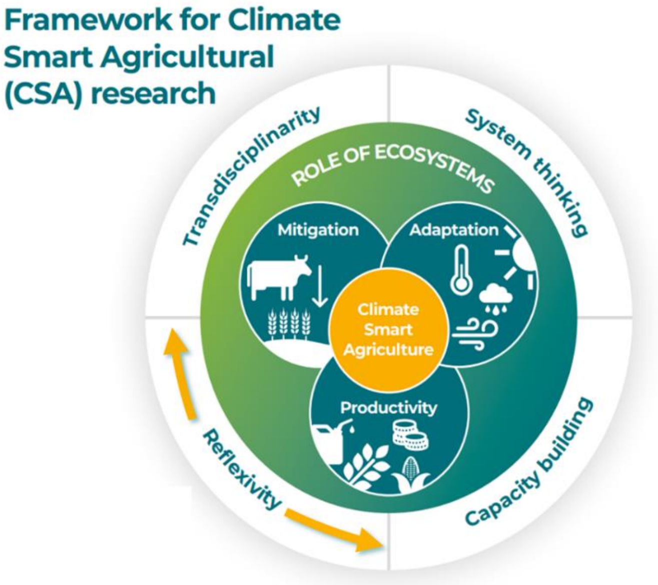


Figure 1. Principles for Climate Smart Agriculture research. What we research is the centre of the framework. How we research is the outer layer of the framework.

To support a shared understanding of the key concepts within the CSR project's conceptual framework, we have developed a set of primers. These primers provide concise and accessible introductions to the concepts central to our approach.

Structure of primers

For each of the concepts in the Conceptual Framework, we developed a short primer which outlines:

1. **Definition:** based on existing terminology or definitions in the literature or practice community, we adopted the most relevant option for CSR.
2. **Role of the concept in the project**: it is important to give some context to why this concept is included in the framework, which is given in this section.
3. **Examples, challenges and opportunities:** lists some specific examples or highlights why there are opposing views or possibly conflicting options which CSR need to consider when developing the project workplan in the context of that concept.
4. **Operationalisation:** this section lists the CSR viewpoint, stand or decisions in respect to the specific concept. This section is written intentionally as a general text, not tied to any specific WP or Task – it is there for the WP and Tasks of CSR to *reflect* on and design their own operational guidelines/protocols/activities in a way that is consistent with those project-wide decisions or views, so CSR as a whole maintains a cohesive and unified framing especially for some of the more challenging topics such as climate adaptation.
5. **Implementation:** these are examples for WP/task specific actions and how they will be implementing/embedding/considering the operationalization decisions in the previous section in the details of their action protocols/activities. While we attempted to be exhaustive as possible, developing those examples in multiple workshops with CSR partners, this section is mainly illustrative and not replacing the Grant Agreement as the sole authoritative description of WP/Tasks in the project.

With the use of these primers, we want to ensure that all project partners, regardless of disciplinary background, work from a common foundation. They also promote consistency across WPs and serve as a reference for stakeholders who engage with the project throughout its duration.

In the next section, the following primers, outlining the key concepts for conducting climate smart agricultural research, are elaborated: 1) climate smart agricultural research in 'real conditions', 2) climate adaptation, 3) climate mitigation, 4) productivity, 5) the role of ecosystems in climate smart agriculture, 6) capacity building, 7) reflexivity, 8) systems thinking, and 9) transdisciplinary research.

Climate Smart Agricultural research in 'real conditions'

Definition

Climate Smart Agriculture integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. It is composed of three main pillars:

1. sustainably increasing agricultural productivity and incomes,
2. adapting and building resilience to climate change,
3. reducing and/or removing GHG emissions, where possible[2].

When considering 'real conditions', CSR refers to research that is relevant to commercial farms within particular regions or sectors and reflecting the actual context in which farmers operate every day.

Role in CSR project

The objective of CSR is to research practices which would enable Climate Smart Agriculture goals in the commercial sector, bringing practices/systems from low TRL to higher TRL suitable for upscaling/adoption by the commercial sector. While the network of ERS involved has, in some cases, been operating part or all of their experimental station as a commercially viable business, this is not true in all ERS. It is also likely that the trials of CSR will, within the current regulatory/business environment (including levels of subsidies and private investment opportunities) be more costly than alternative 'business-as-usual' farming (otherwise those practices/systems would already see much higher adoption, notwithstanding issues of knowledge gaps, infrastructure and social inertia).

It is important to emphasise that real-world conditions vary considerably across Europe, including pedo-climatic factors, agricultural sectors, and socio-economic contexts. By establishing a network of ERS throughout Europe, we can better account for all diversity and incorporate local differences into CSR's analysis and recommendations.

[2] FAO (2013). "Climate-Smart Agriculture Sourcebook." from https://openknowledge.fao.org/server/api/core/bitstreams/b21f2087-f398-4718-8461-b92afc82e617/content.

CSR will need to work within the constraint that ERS cannot commit (financially) to changes which will be detrimental to their financial stability – as the funding of CSR cannot cover large losses of income. Therefore, most trials by ERS will be at plot/sub-plot/field scale and not whole farm system changes.

Challenges and opportunities

Most experimental research stations use plot experiments, which do not necessarily scale up to field level, nor capture the interactions and possibly trade-offs that appear when system-change is implemented at farm scale (e.g. the need for an expensive new drill or new storage silos).

The second challenge is that ERS are managed, in many cases, by academics or people with farming experience but working within a research-focused (often progressive) environment. This may be not representative of commercial farmers.

Finally, there is an understandable gap between the level of TRL of solutions that need empirical research by ERS, and the practices than even the most pioneering farmers are implementing on commercial scale/settings. It is also challenging to expect farmers to do a whole-farm transformation or significantly change their production mix without evidence on the impact, efficacy, risks and costs. CSR should aim to interact with the real farming systems at multiple levels – considering different TRL levels and system changes.

Operationalisation

CSR will consider a unit of 'real farm' rather than plot/field scale. When research data or research activities take place on a unit smaller than a full farm, a 'model farm' approach will be taken, and researchers will *systematically* consider the whole-farm interactions that are missing from the experimental system. Whenever possible, data from plots will be considered only if big enough to use commercially relevant equipment and reliably extrapolate practices, e.g. application rates, to field and farm scale.

For the consideration of upscale/uptake, and to prioritise practices that commercial farmers will consider, CSR will involve farmers and farm advisors across multiple levels, in Farmer and Stakeholder Groups and in our sister projects Climate Farm Demo (CFD) and Climate Smart Advisors (CSA).

CSR will explore 3 levels of practice change *compared with typical farms within your region*:

1. Optimisation – doing things better within the existing system (e.g. improving fertiliser application, implementation of cover crops, changing first calving age);
2. Innovation – adopting clearly novel elements and cutting-edge solutions within the same system (e.g. importing FYM into arable only rotation, new feed additives, introducing agroforestry);
3. Transformation – fundamental change to the system with a different way of producing, organising etc. (e.g. shift from dairy to meat production).

The focus of CSR will differ between different WPs - In WP3 we should test cutting edge solutions of an innovative or transformative type. WP4 will be more focused on practices, focusing within the current system (optimisation, innovation).

Implementation

The concept of Climate Smart Agriculture in real conditions will be implemented in the following ways:

- Setting up various activities to connect researchers, farmers and advisors (WP2). Through these activities we want to gain insight into the perspectives of the various actors on the question: which practices contribute to climate-smart agriculture that are tested at the ERS are not necessarily adopted by farmers, just as emerging practices on farms might not be adopted by researchers. By interacting with advisors and farmers, we can gain a better understanding of how 'real conditions' influence applicability in practice.
- Exploring the research-practice gap by developing surveys to understand how researchers collaborate with real farmers and advisors (WP2). The outcomes of the surveys will lead to capacity-building activities exchange visits to bring together research ERS actors, farmers and advisors from both sister projects CFD and CSA.
  A baseline will be defined for each PioneERS using available agricultural statistic to characterise a typical farm operating within the same farming system, country, and conditions in 1990. This reference year aligns with the objective of reducing climate impact of the PioneERS by at least 55% from 1990 levels. The PioneERS will also define a baseline at the beginning of the project by applying the same Life Cycle Analysis (LCA) methodology that will be used in subsequent years to monitor the implementation and performance of the various selected solutions on PioneERS level. The selection of solutions and results will be validated and reviewed by the groups of farmer and stakeholders, who will meet at least once a year to monitor progress and help steer decision-making within the PioneERS.
- Performing empirical research at the PioneERS (in WP3) in real conditions – i.e. within open fields, complex ecosystem, and influenced by weather. Their ClimAP will be reviewed by WP lead to encourage PioneERS to test innovative and transformative solutions (considering funding constraints), as much as possible – however CSR will avoid 'cataloguing' solutions as 'optimization' vs. 'innovation' vs 'transformative' as that depends on local context. The initial ClimAP and annual assessment (T3.3) will for a full farm or, if trials are carried out at plot or single field scale, a 'model farm' approach will be used. Even if the PioneERS itself changed size from 1990 to 2025, the 'model farm' approach will ensure the analysis is carried out on a consistent sized commercially relevant/typical farming unit and will capture *trade off/synergies* at farm level. The involvement of farmers (in the Farmer Group) and industry professionals (as part of the Stakeholders Group) will ensure the trials reflect what commercial farmers are considering, identify the development needed to increase the TRL to a level suitable for adoption, or highlight the policy or business model changes that could make those solutions financially viable.
- Validation of emerging practices will not only include the potential for mitigation or adaptation, but trade-offs that can come up during implementation at farm-level (WP4). If possible, experiences from farm-level implementation can be included.
- Developing business models for solutions that are not only scientifically sound, but also economically viable and operationally feasible for farmers (WP5). This includes addressing operational feasibility, economic implications, scalability, and interactions at farm level, rather than isolated plot-scale effects. These business models will consider farm economics, investment needs, risks, and existing policy and incentive frameworks, prioritising solutions with a clear market fit and/or interest from relevant industry actors. Where results originate from plot-scale research, communications to potential end-users will be designed to clearly explain how findings can be extrapolated to whole-farm application and integrated into viable farm management strategies.

Climate Adaptation

Definition

Climate adaptation means taking action to prepare for, and adjust to, the current and projected impacts of climate change[3].

Role in CSR project

Climate Adaptation, together with climate mitigation and productivity, is one of the three core pillars of Climate Smart Agriculture and therefore central to the CSR project. Adaptation solutions can create synergies or trade-offs with mitigation, and productivity strategies and may impact (or be impacted by) ecosystems. Climate adaptation is closely tied to *risk* (specifically risk reduction) arising from climatic extremes/variability, which is a main concern in commercial sectors.

Examples

Adaptation actions can reduce the risk of the impact of climate change on a farm business and environment, for example:

- The impact of drought or flooding can be reduced by water management,
- Crop and livestock breeding can improve resilience to excessive heat or disease, and
- Integrating hedges and trees into farms can improve soil health and resilience and provide shade for livestock as well as sequestering carbon.

Challenges and opportunities

There are many ways to monitor or measure climate adaptation. Measuring the efficacy of climate adaptation solutions is not straightforward and cannot be easily calculated in the way that mitigation effects can be either measured or can be estimated from emissions factors. We need to define how to measure the degree of protection that a solution provides, and how the implementation of adaptation solutions is to be monitored over time.

The effect of an adaptation solution could be assessed by monitoring the impact of climate changes, such as a season of extreme heat or drought, on crop yield and quality, and on livestock mortality, fertility, and feed conversion. However, these events are not predictable so modelling of outcomes may be needed, or longer term (e.g. 5 or 10 year) averages must be used.

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[3] Global Centre on Adaptation (2025). "What is climate adaptation?". from https://gca.org/what-is-climate-adaptation/.

Another common approach is to build proxies/measured indicators that are intermediate between actions and impacts – for example level of soil organic carbon in soil. These should not be dependent on weather and have low inter-annual variance – but often the trade-off is slow response of the indicator to practice change and issues with traceability and/or causality between these indicators and impact of climate change of the farm. As a convenient starting point, the CFD and CSA projects suggested a relevant proxy/indicator in their list of Climate Smart Agriculture solutions.

A third approach is to monitor the level of implementation of climate adaptation solutions (an activity-based metric). These will depend on the specific farm context, which solutions you include in your list of solutions, how to account for solutions that cannot be implemented at the same time/in the same place.

As an example – consider a farm facing problems with waterlogging due to compaction. One can approach that farm 'climate adaptation' monitoring in 3 different approaches:

1. Implementation or activity-based records of the solutions implemented on the farm e.g. control farming traffic, IoT based controlled drainage, planting deep-rooted cover crops or planting strips of trees;
2. Proxies or indicators, e.g. how much of a field shows compaction measured with penetrometer, how many km of drains are installed, what is the surface infiltration rate measured using infiltrometer test), what is the saturated hydrological conductivity (ksat) of a soil core tested in a lab, or how many trees have been planted;
3. Direct climatic effects, e.g. the number of days in last 5 years when the field was workable by conventional machinery, or the average yield loss over last 10 years.

Operationalisation

CSR will define adaptation solutions as practices whose goal is to reduce the impact of climate extremes or climate shift on agricultural systems, excluding those focused on emission reduction or carbon removal. Adaptation solutions must be relevant to the pedoclimate and context of a farm, as well as to the current and future projected climate change challenges facing farms in that specific region of Europe (or NZ). Both detrimental and beneficial impacts of climate change will be considered e.g. warmer winters mean more wintering plants can be cultivated.

As CSR does not include process-based modelling, the most realistic approach for establishing a baseline and monitoring climate adaptation within the project is to assess the level of adoption of climate adaptation solutions, and (where implemented) system changes/transformation trials.

The selection of adaptation practices should be tailored to the specific farm, taking into account local climate challenges, farming systems, and feasibility constraints. The selection should first consider current and foreseen (based on e.g. climate scenarios) climate change impacts on the farm (e.g. a PioneERS) and then assess potential adaptation solutions. Rather than relying on a historical baseline, the CSR approach focuses on comparing the level of adoption between an 'average farm' and the ERS (i.e. taking a space-for-time approach) at the start of the project, and on tracking progress over the course of the project. When possible, comparing to climate change risks in other commercial farms within the same system and country will help identify the uptake potential of such climate adaptation solutions.

This adaptation monitoring approach can be further strengthened through exchange and alignment with existing initiatives, in particular the CFD network and the LIFE European Farm Adaptation to Climate Change project. The framework will initially build on a qualitative assessment, following the proposed ClimAP methodology, and can be further refined as experience and data availability increase.

In addition, CSR will develop an outcome-oriented (direct effects) monitoring framework for each PioneERS (e.g. measurable metrics e.g. number of workable days per year in an arable field, irrigation demand etc.). These will be assessed as a baseline at the first year of the project. While these are unlikely to change significantly (in a *statistical* sense) during the project, they can be compared with an 'average farm' in the same context of the ERS (as many ERS already implement long-term solutions). For some quick to respond metrics – to be defined by WP3 – there may be significant changes recorded between the start and end of the project. Where quantitative data is unattainable, CSR will build on expert views / qualitative assessment from ERS managers.

Implementation

The concept of adaptation will be implemented in the following way:

- A rapid evidence review to explore synergies and trade-offs between adaptation, mitigation and production solutions. This rapid evidence review (T1.2) will identify relevant systems per adaptation solution and mutual compatibility between them. In addition, T1.2 will consolidate proxy-based and/or outcome-based metrics proposed by other projects (e.g. CFD/CSA, UNDERPIN, CLIMAAX, pathways2resilience, European Mission on Adaptation).
- Providing CSR feedback from the CFD and CSA consortia on the use of specific solutions (also for mitigation) and potential proxy/indicators to monitor those (WP2).
- Evaluating climate adaptation solutions (pros, cons and risks) by making use of a Climate Action Plan (ClimAP) (WP3). The ClimAP will first evaluate/identify the climatic risks (also involving Farmers or Stakeholders Groups) specific to the context of the ERS. Then, quantitative outcomes-based data (e.g. farm records on livestock mortality during heat waves, satellite data derived drought indices), or if this is not possible, farm managers expert views/qualitative assessment, will be used as a Baseline. The listed solutions will aim to mitigate those specific risks (present or upcoming), as well as reduce farm emissions to 55% (or more) below 1990 baseline. From those solutions, a list of proxy indicators (using the CFD and CSA list as a start) will be included in the annual assessments by each PioneERS. At the end of the project, quantitative data on the same outcomes/effects metrics collated in the baseline will be compared, and farm managers will also be asked to assess changes (if no statistically significant impact is seen in data). Results of trials will help improve 'model farm' modelling for future outlook after the end of WP3.
- When considering upscaling potential in WP3, CSR must take into account supply-chain pressures as restrictions on optimal climate adaptation choices e.g. harvest dates being optimised for supply-chain logic resulting in soil structure damage or the demand for specific breeds. PioneERS are advised to include supply chain actors in Stakeholders Group for such discussions.
- Integrating adaptation relevant metadata (e.g. adaptation solutions used by PioneERS) into the repository to enable researchers to replicate climate-adaptation experiments (WP4, T4.1). The meta-data schema will reflect the type of proposed indicators in the operationalization section, namely focus on quantitative metrics of implementation, and indicators of climate impact (outcome based) when available.
- Considering adaptation, mitigation and productivity aspects in the evaluation of emerging practices and highlighting specific knowledge gaps in the three scopes (T4.4) beyond what is state-of-art (T1.2). The evaluation of those emerging practices will look at metrics to quantify implementation progress and impact.

- Dissemination of best and emerging practices regarding adaptation via practice abstracts and/or factsheets, together with the progressive development and implementation of 10 tailor-made mini-dissemination, -exploitation, and -communication (DEC) plans for generating impact from each of the PioneERS (T5.3). Practice abstracts will translate selected, context-specific adaptation solutions (tested or analysed within CSR) into short, clear and farm-relevant messages. Through the mini-DEC plans developed for each PioneERS, adaptation solutions reflecting local pedo-climatic challenges and farming systems will be communicated in a targeted way, supporting understanding, demonstrating relevance and enhancing the potential for uptake by local stakeholders. The abstracts will include recommendations for implementation-based and outcome-based metrics, as described above. If space data is available (e.g. comparing PioneERS with commercial farms or control fields in the same ERS), figures showing how such practices change those outcome-based metrics will be included.
- Lessons learned on indicators for monitoring climate adaptation will be part of the Policy Briefs, Roadmap, and the DEC Plan, aligned with EU climate and CAP priorities, and will support exploitable results, industry player engagement, and the development of tailored business models.

Climate Mitigation

Definition

Climate change mitigation refers to actions or activities that limit emissions of GHGs from entering the atmosphere and/or reduce their levels in the atmosphere[4].

Role in CSR project

Together with climate adaptation and productivity, Climate Mitigation is one of the three core pillars of the CSR project. Mitigation actions can create synergies or trade-offs with adaptation, and productivity strategies and may impact ecosystems.

Examples

Mitigation actions to reduce the emissions from farming include:

- Improving slurry and manure management to reduce methane emissions,
- Installing anaerobic digestion to reduce emissions and generate renewable energy,
- Using precision application of fertiliser and,
- Improving animal health to reduce emissions per kg of product.

Mitigation solutions also include carbon sequestration e.g.:

- Planting hedges, woodland, and agroforestry, and
- Using cover crops and spreading FYM on fields.

Challenges and opportunities

By the end of 2025, the ClieNFarms project produced a catalogue of solutions[5] and data sheets for over 40 climate solutions which have reliable scientific evidence for their effectiveness. The CSA project will also produce materials on adaptation and mitigation solutions.

When considering mitigation at farm level, there are many decisions that need to be made and kept consistent between baseline and follow-up, and between case studies to allow comparison (list below from *under review* ClieNFarms paper titled “Climate-neutral farms: meaning and implications”):

a. Spatial scale and system boundaries,
b. Temporal scale – from growing season to multi-decadal,
c. Budget unit – tCO_2 eq. per farm, per unit of production, per unit area,
d. Inclusion of all CO_2, all GHG, carbon removals, also albedo and energy partitioning,

[4] IPCC (2022), Climate Change 2022 Frequently Asked Questions, From www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FAQs_Compiled.pdf.
[5] https://clienfarms.eu/solutions/

e. Import and export of carbon in seed, produce, residue (e.g. hay/straw sold or exchanged), FYM, biochar etc. This does NOT include embedded or embodied emissions associated with the manufacture, production, and transport of these inputs – which go into Scope 3 accounts,
f. Inclusion of all direct activities (Scope 1), energy/heat (Scope 2) and indirect climate impacts (Scope 3, e.g. embedded emissions in manufacturing, producing and transporting inputs to farm gate such as seeds or mineral fertiliser, land use change impact from soy production),
g. Using either a 'static baseline' (measured once then assumed constant over time while activities change the system in study) or a 'dynamic baseline' (either a control plot that monitor change over time with BAU practice, or a modelled dynamic baseline),
h. Offset by other exports – e.g. energy export to grid from on farm solar/AD,
i. Carbon leakage (using LCA) due to changing production intensity and production mix – accounting for (assumed) constant food/feed/fibre/biomaterial demand,
j. Future casting production level and extreme events impact – affecting emission per unit of production (if production will be reduced)
k. Future casting demand level – if accounting for carbon leakage using LCA.

Operationalisation

The concept of mitigation will be implemented in the following way:

- Considering the whole farm (actual or 'model farm') as a system boundary, with a temporal window of ca. 5 - 10 years as Baseline, 5 years of CSR project, up to 2050 as a policy-relevant time scale, and to an ecologically meaningful time horizon (e.g. 100 years for tree planting) depending on solutions implemented.
- Reporting all units tCO_2 eq. per farm, per unit of production (e.g. per kg), and per unit area (e.g. per hectare)
- Including all GHG emissions (at least CO_2, N_2O, CH_4) and carbon removals (e.g. sequestration in soil). Specific indicators will be developed for PioneERS in WP3.
- Including carbon exchange in all materials bought/delivered/exported at commercial scale e.g. of Farmyard Manure (FYM).
- Considering scopes 1, 2 and 3 emissions and systematically looking at solutions by addressing all three. Solutions that reduce emissions, sequester carbon, use carbon-neutral energy/heat, or improve efficiency (e.g. produce the same with less mineral fertiliser) are examples focused on each Scope.
- Using a dynamic baseline, ideally with control plot.
- CSR will acknowledge but will **NOT** (generally) consider changes in biogeophysical cycles e.g. albedo, export of energy (e.g. using LCA approach), or carbon leakage/liability/offset due to change in production level or production mix impacting import/land use elsewhere.

Any deviation from these will need to be documented in the appropriate reporting/assessment and minimized as much as feasible with support of CSR expertise in other partners.

To avoid confusion, the <u>CSR project aims to demonstrate a reduction of -55% compared with 1990 baseline *at farm level*</u> corrected to the same area farm / herd size (if PioneERS changed size/livestock units) and for carbon leakage/liability (due to change in production intensity or mix) between 2025 (or start of CSR) and 2030 (end of project). This is line with current European policy objectives.

Implementation

To their best effort, CSR will implement this concept by conducting the following:

- Rapid evidence reviewing to explore synergies and trade-offs between adaptation, mitigation and production. This rapid evidence review (T1.2) will aim to cover all aspects highlighted in Operationalization – and highlight where the literature is lacking in adhering to those principles.
- Defining and monitoring a set of indicators to be used to evaluate mitigation and the trend towards climate neutrality, defined in CSR as zero net emissions considering the full range of factors explained in Operationalization section above (WP3). PioneERS will follow the operationalization details (scope, gases breakdown, carbon removal, etc.) when doing annual assessment and monitoring. Each PioneERS will be assessed with an LCA Scope 3 approach at the beginning, middle and end of the project to monitor the implementation and the effect of the tested solutions. Whenever possible, PioneERS will directly measure that data (e.g. energy use, N_2O through mass balance, Nitrogen/Nitrogen Use Efficiency, soil moisture, weather data, soil carbon stocks through sampling or proximate sensing) and report change (and significance) over time for the 5-year duration of CSR.
- in T4.2, the impact of practices adopted by the PioneERS on soil carbon sequestration will be assessed, combined baseline measurements with modelling approaches.
- Comparing and testing the digital toolkit and services for assessing farm-level GHG balances and performance in T4.3. This will potentially be done through systematic reviews and meta-analysis. As part of this research, we will examine whether the selected tools capture key aspects of whole-farm GHG assessments, including all major GHGs, emission scopes, embodied emissions, carbon removals and consider potential carbon leakage.
- In Task 4.4, the evaluation of emerging practices will look at climate mitigation metrics following the operationalization principles, e.g. all scopes, all GHGs, reporting on tCO2eq at different units etc.
- Within WP5, CSR will translate the selected whole-farm mitigation solutions, aligned with the elements described in the operationalisation paragraph, into short, clear, and farm-relevant messages in the form of practice abstracts. Through the mini-DEC plans developed for each PioneERS, mitigation solutions will be communicated in a targeted way, supporting understanding, demonstrating relevance and enhancing the potential for uptake by local stakeholders. The data from CSR, and lessons learned from covering multiple gases, scopes and units, will support generating coherent, evidence-based policy recommendations taking advantage of relevant “windows of opportunity” during the lifetime of the CSR project for influencing policy-making decisions at EU, national and regional levels (T5.4).

Productivity

Definition

Productivity is a measure of economic or business performance that indicates how efficiently people, companies, industries and whole economies convert inputs, such as labour and capital, into outputs, such as goods or services.[6] Productivity is not the same as profitability, which refers to the degree to which a farm makes a financial gain from delivering goods and services after all expenses of doing so have been taken into consideration[7].

Role in CSR project

Together with climate adaptation and mitigation, productivity/incomes are one of the three core pillars of Climate Smart Agriculture and the CSR project. Productivity solutions can create synergies or trade-offs with adaptation, and mitigation solutions, and may impact on ecosystems.

Examples

Productivity actions include:

- Using more efficient machinery which will also reduce GHG emissions;
- Planting higher yielding crops;
- Improving animal health and reproduction rates through genetics and husbandry; to reduce emissions per kg of product;
- Optimising fertiliser use.

Challenges and opportunities

Productivity (output per unit of input) is easier to predict than profitability and farm incomes. We will need to consider both productivity and profitability in assessing the impacts of climate smart solutions. It is also important to correct for the quality of product, as well as aggregating over whole farm (given some Climate Smart Agriculture solutions change the production mix). To contextualise production and consider elements of profitability and socio-economic impact of Climate Smart Agriculture, complementary metrics (e.g. inputs, labour) will also be needed.

Operationalisation

CSR evaluates farm productivity using a variety of metrics aligned with climate risks, categorised into four main approaches:

- Total Volume: Measuring the gross annual output (e.g., total tonnes of crop, litres of milk, or kg of meat),

[6] UNFAO, 2024 AGROVOC Multilingual Thesaurus, From https://agrovoc.fao.org/browse/agrovoc/en/page/c_6210
[7] Adapted from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Profitability

- Intensity: Measuring yield per specific unit, either by land area (per hectare) or by animal (per head),
- Quality-Adjusted: adjusting production figures to account for quality, such as fat/protein content in milk, moisture levels in crops, or usable carcass weight in meat, and
- Mixed System Aggregates: Assessing farms with diverse outputs (crops and livestock) by calculating the total Economic value (€) or Nutritional value (protein/calories) produced per hectare.

To assess the net productivity and resource efficiency, CSR will measure the specific inputs required to generate the production outputs defined above. These include:

- Nutrient Intensity: Total kg of active Nitrogen, Phosphorous, and Potassium (N-P-K) applied and removed (balance) per hectare (differentiating between mineral fertiliser and organic manure). Efficiency indicators e.g. yield per kg applied Nitrogen,
- Energy Intensity: Total consumption of fossil fuels (litres) and electricity (kWh), allowing for the calculation of energy-use efficiency (MJ input/ MJ output),
- Labour Inputs: Total human capital required, measured in Annual Work Units (AWU) to align with EU standards,
- Economic Inputs: Total Variable Costs (€) associated with crop/animal management e.g. mineral fertiliser costs, to contextualise the profitability of climate-smart interventions, and
- Land Use: total agricultural area used in farm production.

Whenever CSR consider solutions demonstrated at scale smaller than field/farm and not using commercial equipment/typical farming labour, either standard economic data will be used, or adjustments will be made based on feedback from the Farmer Group. Any indicators will be assessed over multiple years (e.g. 5 years) to avoid influence of weather and market fluctuations.

For profitability, there are many local differences between countries and contexts, because of different financial incentives and subsidies provided by countries. CSR will only consider profitability within the context of economic output and input costs. To allow local context/prices to be considered by stakeholders e.g. farmers via dissemination/outputs, CSR will provide the outputs and inputs quantities so that others can make that calculation themselves. CSR will also explore solutions that are (currently) not economically viable/profitable without changes in policy/business models – especially where there are trade-offs between climate adaptation, mitigation and productivity/profitability.

Implementation

Given that productivity is one of the core principles of CSR, the project will implement this concept in the following way:

- Rapid evidence reviewing to explore synergies and trade-offs between adaptation, mitigation and productivity. This rapid evidence review (T1.2) will gather data regarding the impact on productivity changes by implementing adaptation and mitigation solutions, e.g. via qualitative data or Likert-scales. As far as possible, different metrics of productivity will be included in the analysis.
- In WP3, PioneERS will list and monitor productivity (using data as well as various LCA tools) covering as many dimensions as feasible. CSR will also acknowledge (but will not calculate) carbon leakage risk when there is a change of commodities produced by the PioneERS. Productivity will be monitored throughout the project (in Annual Assessments T3.3) on each

PioneERS while profitability will be discussed with the farmers group for each PioneERS and described in new factsheets for the solutions implemented.

- Considering a Monte-Carlo approach for propagating productivity uncertainty into economic uncertainty in some PioneERS (NZ, who developed the approach in Spaans et al.[8]; others based on capacity).
- Capturing productivity variables e.g. yields, intensities, resource use efficiency etc the in the Farming4Climate repository to allow other researchers to analyse trade-offs between productivity and climate outcomes (T4.1).
- Looking at as many productivity measures as feasible following the operationalisation principles (T4.4) in the evaluation of emerging practices.
- Including productivity changes in the WP5 practice abstracts and/or factsheets, together with the development and implementation of 10 tailor-made mini-DEC (Dissemination, Exploitation, Communication) plans for generating impact from each of the PioneERS (T5.3). The mini-DEC plans developed for each PioneERS will ensure that the productivity aspects are clearly articulated and targeted to the appropriate stakeholders, thereby supporting the uptake of project findings by practitioners (particularly commercial farmers).

[8] Spaans, O. K., Macdonald, K. A., Neal, M., Auldist, M. J., Lancaster, J. A. S., Bryant, A. M., ... & Roche, J. R. (2019). A quantitative case study assessment of biophysical and economic effects from altering season of calving in temperate pasture-based dairy systems. Journal of dairy science, 102(12), 11523-11535.

The Role of Ecosystems in Climate Smart Agriculture

Definition

An agro-ecosystem is a managed ecosystem in which agricultural production is embedded within ecological processes, including nutrient cycling, water regulation, and biodiversity dynamics, and which is influenced by climate and management decisions[9]. Ecosystems in Climate Smart Agriculture should therefore be considered as a dynamic interplay. Healthy agro-ecosystems are the foundation upon which climate-resilient and productive agriculture is built, while well-designed Climate Smart Agricultural systems have the potential to restore and enhance the very ecosystems they rely on for their success[10]. Moreover, ecosystem management can be seen as an overarching requirement for the conceptualisation and implementation of Climate Smart Agriculture.

Role in CSR project

Ecosystems play a central role in Climate Smart Agricultural research, both as a precondition for Climate Smart Agricultural research and as an active lever for action, particularly through their capacity to store carbon and to prevent, or reduce, climatic impacts. Within the project, ecosystems are not only considered as systems that can enhance resilience and sustainability, but also as a boundary condition that must be safeguarded in the design and implementation of Climate Smart Agriculture. Therefore, the relationship between farms and ecosystems is approached in a dual way. On the one hand, Climate Smart Agriculture is embedded within broader ecosystems and, through appropriate management, can actively contribute to maintaining and enhancing ecosystem functioning. On the other hand, ecosystem functions at farm level can be strengthened to reduce the vulnerability of agricultural production. In addition, carbon storage can be seen as a key ecosystem service in the project in which we explore the potential of leveraging carbon storage in the Climate Smart Agriculture design.

Examples

Examples of how ecosystems' contributions are incorporated into Climate Smart Agriculture research include:

- Promoting or preserving biodiversity: supporting wild biodiversity that has a neutral or positive effect on agricultural production[11], for example by mimicking natural ecological structures by planting trees or grasses.

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[9] http://Biodiversity.europa.eu
[10] Akamani, K. (2021). An ecosystem-based approach to climate-smart agriculture with some considerations for social equity. *Agronomy*, *11*(8), 1564.
[11] Scherr, S. J., & McNeely, J. A. (2008). Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 477-494.

- Improving soil health: Ecosystem services such as nutrient cycling, soil organic carbon sequestration, and water retention are essential for maintaining agricultural productivity and resilience. Soil organisms play a key role in maintaining healthy soils by enhancing nutrient availability, improving soil structure, and supporting plant growth. Practices such as cover cropping, reduced tillage, compost application, and agroforestry can strengthen these soil-based ecosystem services[12].
- Water management: natural vegetation or wetlands can help retain water, reduce runoff, and regulate floods. Climate Smart Agriculture interventions, such as installing buffer strips or promoting rainwater infiltration can be implemented to maintain the ecosystems' hydrological benefits[13].

Challenges and opportunities

Incorporating ecosystems into Climate Smart Agricultural research presents both challenges and opportunities. The complexity of ecological interactions, limited data availability, trade-offs between productivity and conservation, and context-specific variability can complicate research. However, healthy ecosystems enhance resilience to climate extremes, support sustainable productivity and promote multifunctional landscapes that balance environment and agricultural objectives. From an operational perspective, inclusion of biodiversity impact into e.g. LCA is emerging[14] but still in its infancy.

Operationalisation

Ecosystems are operationalised by translating ecological concepts into measurable variables and practical interventions that can be assessed and acted upon. This involves defining ecosystem components (such as soils, water, biodiversity, and nutrient cycles), identifying key ecosystem services relevant to agriculture, and linking these to management practices and outcomes in the CSR ERS.

In CSR we focus on three specific elements of ecosystems:

1. High diversity landscape features (as defined in Nature Restoration Law, this indicator being one of the policy objectives);
2. Ecosystem sequestering carbon (hedges, agroforestry, soils in fields – SOC in mineral soils being another Nature Restoration Law indicator);
3. Natural capital supporting natural disaster risk reduction – these will be specific to different locations and linked to local climate change impacts and risk (e.g. extreme flooding, drought,

[12] Handayani, I. P., & Hale, C. (2022). Healthy soils for productivity and sustainable development in agriculture. In *IOP conference series: earth and environmental science* (Vol. 1018, No. 1, p. 012038). IOP Publishing.
[13] Patle, G. T., Kumar, M., & Khanna, M. (2020). Climate-smart water technologies for sustainable agriculture: A review. *Journal of Water and Climate Change*, *11*(4), 1455-1466.
[14] Knudsen, M. T., Hermansen, J. E., Cederberg, C., Herzog, F., Vale, J., Jeanneret, P., ... & Dennis, P. (2017). Characterization factors for land use impacts on biodiversity in life cycle assessment based on direct measures of plant species richness in European farmland in the 'Temperate Broadleaf and Mixed Forest' biome. *Science of the Total Environment*, *580*, 358-366.

wind, frost etc.). The specifics of these will need discussion with Farmers or Stakeholders Groups.

The data for monitoring ecosystems will primarily be that used for reporting by farmers as part of Common Agricultural Policy requirements. This includes e.g. crop diversity, areas of landscape features. Depending on the site and available resources, specific indicators will be considered e.g. composition of species in grassland etc.

CSR will look at how agricultural practices implemented for climate adaptation or mitigation are affected by the presence/conditions of ecosystems (high diversity landscape features, ecosystems sequestering/storing carbon, natural capital reducing disaster risk). If not explicitly monitored, CSR will take a 'do no harm' approach to the same ecosystems.

Implementation

The role of ecosystems will be implemented in the following way:

- The rapid evidence reviewing to review and explore synergies and trade-offs between adaptation, mitigation and production and take into account the role of ecosystems – both impacting and being impacted by solutions (T1.2). When not considered, this will be highlighted by gap analysis, and will support the CSR second round of ClimAPs or future research applications.
- Integrating the guiding principle for ecosystems' contributions in Climate Smart Agriculture in the development of the ClimAPs (WP3). Specifically, quantitative metrics on the area and condition of high-diversity landscape features, carbon sequestering ecosystems and natural capital mitigating natural disasters will be quantified by the PioneERS, be considered as potential solutions and any direct or indirect impact on them via other solutions will be assessed.
- Focussing on the impact of solutions on carbon sequestration in particular, with an emphasis on soils and using a modelling approach (T4.2).
- Looking at synergies/trade-offs between emerging practices and listed classes of ecosystems in and around the farm for the evaluation of emerging practices (T4.4), following the Operationalisation section approach.
- Learnings from WP3 and WP4 on the importance of ecosystems and impact on them will be part of the Policy Briefs and Practice Abstracts template developed in WP5.
- Consider business models that include ecosystem services provisioning e.g. carbon farming, allowing fields to store floodwater, etc. (WP5).

Capacity Building

Definition

In CSR, we define capacity as the specific knowledge, attitudes and skills that researchers need to conduct Climate Smart Agricultural research and Research and Innovation (R&I) design, in such a way that it contributes to closing the research-practice gap and the transition to climate neutral agricultural production with reliable yields.

Capacities for climate research and R&I design include the ‘how we work’ concepts of the CSR conceptual framework (transdisciplinarity, systems thinking and reflexivity).

Role in CSR project

Capacity building on Climate Smart Research, climate R&I processes, synchronised methods, data exchange and collaboration is a core aim of the CSR project. CSR will work on capacity building of agricultural research stations across the Europe and in New Zealand, building a network of 29 ERS.

Capacity building efforts within the CSR project target multiple stakeholder groups. For researchers, CSR focuses on strengthening their capacity on methodological competencies for improving climate-impact assessment, and on reducing the research-practice gap through co-creation and shared learning. For farmers and advisors, CSR enhances knowledge uptake and enhances practical application of Climate Smart Agriculture insights, enabling more informed and resilient farm management decisions. For the ERS, the project aims to build capacity to effectively participate in the national Agricultural Knowledge and Innovation System (AKIS) and to conduct high-quality Climate Smart Agriculture research.

Examples

Examples of capacity building for climate smart agricultural research include:

- Research training on methods and tools for effective research on climate smart agriculture, for example taking into account all concepts presented in this framework;
- Developing inter- and transdisciplinary research skills to bridge the gap between research and practice implementation and vice versa (the research-practice gap);
- Collective learning to collectively address and advance understanding of the ‘wicked’ problem of transitioning to Climate Smart Agriculture.

Challenges and opportunities

The CSR project covers 26 countries and involves 33 partners. This offers opportunities for capacity building across Europe and New Zealand, accelerating research and action for climate smart agriculture at a broad scale. However, this diversity also brings challenges. Inevitably, there will be different needs for capacity building across project partners and countries. How do we tailor capacity building to different needs? Another challenge is that while the CSR project involves 33 partners across 26 countries, only a small group of all researchers working on climate smart agriculture across Europe will be involved. Therefore, capacity building activities only directly reach a relatively small group of researchers. A challenge is to reach researchers beyond those involved in the project.

Operationalisation

Capacities include knowledge, attitudes and skills. In CSR, capacity building is operationalised as:

- Understand and apply the three pillars of Climate Smart Agriculture; adaptation, mitigation and productivity[15]. For example, sharing protocols for measuring indicators for Climate Smart Agriculture on the experimental research stations.
- Understand and make explicit trade-offs between adaptation, mitigation and productivity, including equity concerns; when win-win solutions are not possible, who or what benefits and who or what does not[16]?
- Adopt transdisciplinary ways of working, using co-creation and participatory approaches[17, 18] and social learning, answering the questions how to set up research design, how to develop the research process in a transdisciplinary way, bridging the research practice gap[19].
- Adopt systems thinking, including considering the whole farm.
- Adopt a reflexive attitude as a transformative capacity.
- Knowledge of and ability to relate research design and results to ‘real farm conditions;
- Creating actionable, ‘how-to’ knowledge[12, 20] for Climate Smart Agriculture and translating research results into actionable, practice-oriented outputs and realistic uptake pathways
- Tailor communication of research results to different target groups.

CSR will also build on the work of the “Premier” Horizon project, which aims to strengthen the multi-actor approach. They developed a toolbox CSR can use to improve six multi-actor skills relevant to the CSR project[21]:

1. Supporting the balance of the needs of the ERS, the consortium and the AKISs in which they operate;
2. Supporting the ERS and the consortium to gain experience with multi-actor methods or practical engagements;
3. Supporting transparent communication about expectations and outcomes of researchers, farmers and other stakeholders;
4. Supporting the ERS to work with a diversity of professional backgrounds, their limitations and strengths;
5. Supporting a safe, open, and cohesive culture in the CSR project consortium and in collaboration with stakeholders;

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[15] FAO (2013). *Clilmate-Smart Agriculture Sourcebook*. Food and Agriculture Organization of the United Nations
[16] Taylor, M. (2018). Climate-smart agriculture: what is it good for? *The Journal of Peasant Studies*, *45*(1), 89-107.
[17] Carter, S., Arts, B., Giller, K. E., Golcher, C. S., Kok, K., De Koning, J., ... & Herold, M. (2018). Climate-smart land use requires local solutions, transdisciplinary research, policy coherence and transparency. *Carbon Management*, *9*(3), 291-301.
[18] Rossing, W. A., Albicette, M. M., Aguerre, V., Leoni, C., Ruggia, A., & Dogliotti, S. (2021). Crafting actionable knowledge on ecological intensification: lessons from co-innovation approaches in Uruguay and Europe. *Agricultural Systems*, *190*, 103103.
[19] Biesbroek, G. R., & Wals, A. E. (2017). The interplay between social learning and adaptive capacity in climate change adaptation: A systematic review. *NJAS-Wageningen Journal of Life Sciences*, *82*, 1-9.
[20] Fazey, I., Schäpke, N., Caniglia, G., Patterson, J., Hultman, J., Van Mierlo, B., ... & Wyborn, C. (2018). Ten essentials for action-oriented and second order energy transitions, transformations and climate change research. *Energy Research & Social Science*, *40*, 54-70.
[21] https://toolbox.premiere-multiactor.eu/

6. Supporting active participation of and focus on the end users such as other researchers and farmers.

Implementation

Capacity building will be implemented as follows:

- Facilitating exchanges between ERS in WP2. This includes 20 exchange visits and 12 online masterclasses, which focus on effective climate research design. Understanding the current state of play of Climate Smart Research across Europe, to identify gaps and needs among the research community for effective climate research and innovation design.
- Supporting the ERS to become an integral part of the national AKIS (T1.4 & 2.4) by bringing together researchers, farmers, advisors and other AKIS actors, co-defining ClimAPs, and develop roadmaps for (better) integration of the ERS into the national AKIS.
- Organising capacity building activities that focus on how to close the research-practice gap via masterclasses and exchange visits (T2.3). Moreover, training will be organised on methods and protocols that improve skills and capacity for research within the ERS and the (early career) researchers involved in this research.
- Identifying toolkits for enhancing farmer and researcher use of climate tools and awareness of Climate Smart Agriculture strategies (T4.3).
- Putting emerging practices in the perspective of EU emissions. CSR should agree on a common approach EU-level emission inventory (T4.4).

Reflexivity

Definition

Reflexivity is about critically examining one's own assumptions, values, and positionality (*doing the right things*), as well as methods and impacts (*doing things right*), to understand how these assumptions shape outcomes. This means reflexivity happens both at a personal and a methodological level[22]. Banister et al. describe reflexivity as "acknowledging the central position of the researcher in the construction of knowledge" [23]. Reflexivity is then not just the act of reflecting itself, but the *actions and change* resulting from such reflection.

Reflexivity as a (transformative) capacity[24] is necessary for navigating challenges and contributing to the transition towards climate neutral and climate resilient agricultural systems. Lazurno and colleagues define reflexivity in this context as "the capacity to nurture a dynamic, embedded, and collective process of self-scrutiny and mutual learning in service of transformative change, which manifests through interacting boundary processes-boundary delineation, interaction, and transformation".

Role in CSR project

Reflexivity needs to be part of the whole project, as it is as much an attitude as an action. The goal of reflexive action and attitude is to continuously improve our way of working and increase the impact of systems changes leading towards climate neutral agriculture. Iteration provides space for reflection, improvement and changing course of action, and for example, this iterative approach is a part of the ClimAPs.

Examples

Examples of reflexivity include:

- Reflexive questioning, for example: whose knowledge are we including or excluding in our research? What outcomes would count as 'success' for farmers and are they the same as ours? What is my role as a researcher in the ERS and should anything change?
- Re-evaluating stakeholder involvement. Reflecting on who does *not participate* and, if needed, changing invitation strategies.

[22] Finlay, L. (1998). Reflexivity: an essential component for all research?. *British Journal of occupational therapy*, *61*(10), 453-456.
[23] Banister P, Burman E, Parker I, Taylor M, Tindall C (1994) Qualitative methods in psychology: a research guide. Buckingham: Open University Press.
[24] Lazurko, A., Moore, M. L., Haider, L. J., West, S., & McCarthy, D. D. (2025). Reflexivity as a transformative capacity for sustainability science: Introducing a critical systems approach. *Global Sustainability*, *8*, e1.

- Reflexive, collective learning, monitoring and exchange, for example about specific climate smart practices, about synergies and trade-offs or about how different ERS implement a systems approach in their research design.

Challenges and opportunities

Including reflexivity in the CSR project provides the project with the important opportunity to keep our goals in mind and adjust course wherever necessary, thereby maximising scientific as well as societal impact. While we recognise that reflexivity is an important capacity for climate smart agricultural research, we also recognise that there are limited resources to implement, for example, an extensive reflexive monitoring and learning approach. The involvement of the farmer and stakeholder groups, evaluations of the ClimAPs, as well as the knowledge exchange sessions provide opportunities and spaces to explicitly introduce and implement reflexivity.

Operationalisation

In CSR, reflexivity is operationalised as a continuous component of the research process. We will involve farmers and other relevant stakeholders in the initial framing of research questions and research design on the ERS (see also transdisciplinarity). Reflexivity will also be introduced in the CSR project as a whole, both in in-person and online consortium meetings, within the ExCom and as part of internal review of deliverables before submission.

Implementation

To the best of our efforts, CSR will implement reflexivity in the following way:

- Reflecting, as a project, on our progress and direction in joint meetings with sister projects CFD and CSA. Moreover, during all (online) meetings with the full consortium, sessions with elements of reflection, learning and peer-to-peer mentoring will be organised.
  In T1.4, we will organise interviews and reflection sessions with InnovatERS and PioneERS to promote collective learning and theory building in the CSR network.
- Reducing the research-practice gap is approached as a dynamic and ongoing reflective process. The work builds on an existing research-practice framework, which serves as the conceptual basis for surveys conducted among InnovatERS and PioneERS (T2.1 & 2.2). These surveys, scheduled for spring 2026, aim to explore how the research-practice gap is conceptualised and which factors contribute to it at different levels, including researchers, ERS, farmers, advisors and the broader external environment. Focus group activities will be developed to address identified barriers and opportunities. Insights, feedback, and questions emerging from these activities will in turn be used to further refine the research-practice framework, inform subsequent capacity-building efforts, and adapt the survey approach. Through this iterative process, pathways for bridging the research-practice gap will be progressively identified and strengthened.
- Monitoring and evaluating exchange visits will generate insights from the firsts round these visits, specifically regarding elements that were effective, challenges that were encountered, and aspects that were lacking (T2.2). A guideline for the exchange visits will be developed, incorporating a structured monitoring and evaluation (M&E) framework. The outcomes of the M&E process will be systematically used to inform, organise and optimise the second round of exchange visits.
- Working in WP3, collaboration with the PioneERS' farmers and stakeholder groups focuses on the development of a farm-level ClimAP. These plans will be evaluated annually (T2.2),

together with the farmer and stakeholder groups. Specific attention will also be given to reflecting on how engagement with these groups is organised (WP2). This includes reflecting on who is involved, the structure and frequency of interactions, and the level and form of participation. The combined evaluation of both the ClimAPs and the engagement process will provide opportunities to adjust the course of action where necessary.

- Iterating and refining the repository structure through several feedback rounds with WP leaders and ERS to critically adjust data requirements as the CSR project evolves (T4.1).
- Reflecting on the necessary information from the research approaches we envisage for the collection and evaluation of emerging practices. We will try to get information on different perspectives between CFD, CSA and the CSR projects on potential emerging practices in T4.4.
- Involving an external expert advisory board (EEAB) and ethical advisor in the CSR project. The EEAB will advise consortium members regarding their decision-making about how to work towards the project goals while taking into consideration core ethical and legal principles regarding animal well-being, environments and biodiversity, privacy and data ownership. During the project he will report 4 times to the Commission on the ethics performance of CSR (WP7). Board members will be invited to reflect on and provide advice regarding the project's approaches, progress, and results during 4–5 online meetings. Feedback, suggestions, and connections provided by the EEAB will be discussed within the Executive Committee and fed back to the EEAB in subsequent meetings.
- Closing the research-practice gap with the use of an iterative process. An initial research-practice framework will guide the first surveys, and the resulting insights will inform the design of capacity-building activities. Feedback and questions arising from these activities will then be used to refine the framework, update future activities, and revise the surveys. Through this continuous cycle of reflection and adjustment, WP2 will progressively identify pathways for bridging the research-practice gap. As a potential final output, WP2 aims to develop an online self-assessment tool enabling researchers to reflect on their performance in bridging this gap.
- Continuous monitoring and evaluation of DEC activities (WP5). Insights from KPI tracking and partner feedback will feed into the update of the DEC Plan, ensuring it remains aligned with project needs, ambitions, and emerging communication opportunities and trends. WP5 will regularly reflect on whether DEC activities effectively support the project's envisioned impacts, and will adapt messages, tools, channels and exploitation pathways where needed to maximise the uptake, relevance and long-term impact of CSR results.

Systems Thinking

Definition

Systems thinking facilitates understanding of the complexity, interdependence and interactions of a system as a whole, rather than judging a system as an accumulation of its constituent parts. It considers interdependent relationships, viewing a problem as a dynamic, interdependent, and ongoing process[25]. In the case of CSR, this means recognising the simultaneous change needed at multiple levels (agronomic, socio-economic, scientific, etc.) in the transformation to climate neutral and resilient agriculture in Europe. Systems thinking includes three core activities: understanding inter-relationships, engaging with multiple perspectives, and reflecting on boundary judgements [26,27].

Role in CSR project

Systems thinking in CSR will be used to make sense of the complex realities of food production, recognising and taking into account interdependencies but also synergies and trade-offs between adaptation, mitigation and productivity in climate neutral and climate resilient farming systems. Systems thinking recognises that there is no single solution for climate risks. Instead, climate related problems in agriculture need to be tackled at multiple scales in space (e.g. plot, farm, landscape) and time (long term versus short term impacts) and at multiple levels (e.g. agronomic, economic, technological, social, governance, scientific).

Examples

An example of systems thinking and systemic research in agricultural research is studying how different Climate Smart Agriculture solutions are interacting with each other either creating synergies or trade-offs with other farm activities or ecosystem services. For example, considering the emissions from slurry management and fertiliser-use highlights the need for looking at emissions from a whole chain of activities rather than just reducing emissions from one process and causing an increase from a later process (aka ‘pollution swapping’).

Challenges and opportunities

Systems thinking in systemic research offers both significant opportunities and challenges when aiming for true system change. Its main strength lies in its ability to capture complexity by recognising interdependencies, feedback loops, and non-linear dynamics across ecological, social, economic, and

[25] Richmond, B. (1993). Systems thinking: critical thinking skills for the 1990s and beyond. *System dynamics review*, *9*(2), 113-133.
[26] Reynolds, M., & Holwell, S. (Eds.). (2020). *Systems approaches to making change: A practical guide* (Vol. 2). London: Springer London.
[27] Jagustović, R., Zougmoré, R. B., Kessler, A., Ritsema, C. J., Keesstra, S., & Reynolds, M. (2019). Contribution of systems thinking and complex adaptive system attributes to sustainable food production: Example from a climate-smart village. *Agricultural systems*, *171*, 65-75.

institutional domains, thereby enabling more holistic and resilient solutions. At the same time, this complexity poses challenges: system boundaries are difficult to define, causal relationships are often uncertain, and outcomes may emerge only over long time-horizons, complicating evaluation and decision-making. Navigating this complexity requires balancing analytical thoroughness with practical relevance, accepting uncertainty, and working iteratively across disciplines and stakeholder perspectives.

Operationalisation

Systems thinking is operationalised in CSR most prominently in the research done at the PioneERS, where a systemic perspective will be adopted to design and research agricultural systems that meet climate adaptation and mitigation goals. Defining system boundaries is part of this research, where it should consider change needed at multiple levels (agronomic, socio-economic, governance, etc.) and pay attention to synergies and trade-offs between different components of the agricultural system. CSR's transdisciplinary and interdisciplinary approach allows integration of different perspectives in identifying trade-offs and synergies between farming practices. Where sister projects CFD and CSA focus on single practices, CSR focusses on integrating practises in a systems approach. On the PioneERS, this translates for example in adopting a whole farm approach, considering landscape scale impact (e.g. water quality/groundwater), and looking at potential synergies and trade-offs between practices of adaptation, mitigation and productivity.

Implementation

System thinking and system research will be implemented in the following way:

- Highlighting, throughout the project but specifically in WP3, that the impact of adopting multiple solutions is greater than the sum of individual parts; adopt a whole farm approach, extending to local region or value chain if necessary.
- Considering a whole range of stakeholders in the AKIS, also including knowledge brokers, NGOs, and supply chain contacts that go beyond farmers and advisors (T1.3, 2.3, 2.4 & 3.1). Exchanging knowledge between these stakeholders will give insight into interconnections between elements of the farming system and the impact on climate change.
- Emphasising the importance of pedoclimate and farm context, recognising any two farms are not the same, while at the same time seek general and scalable/ transferable answers to key research questions (WP3 & 4). Therefore, project results will be upscaled to EU level and needs to include system thinking for agronomy, socio economy and science.
- Defining the ClimAPs considering the farming system as a whole (T3.1). A list of indicators at farm level will be provided to evaluate research in the farm context (T3.3). We try to connect system thinking, farm scale and research through empirical experimentation in WP3.
- Considering system thinking as a way to report on impact on the farm scale, although a whole farm system experiment may not have been conducted.
- Recognising interdependencies between farming systems, society, stakeholders, etc. and involving stakeholders to explore societal impacts.
- Evaluating emerging climate smart agriculture practices and their system impact in WP4.
- Connecting project findings to wider project impacts in WP5. Key to the systems thinking dimension will be the consideration of the different policies (and necessary policy mixes) contributing to the creation of a "favourable enabling environment" for the necessary behavioural change amongst farmers to adopt the best/emergent practices for mitigation, adaptation and productivity. This involves looking at policies across different areas beyond just CAP, as well as the influence of different business actors.

- Studying the research-practice gap at multiple levels: researcher, research organisation, institutional level and interactions between those, as well as integrating perspectives from practice (farmers and advisors) (WP2).
- Developing and/or using different types of tools to facilitate systems thinking, such as theory of change, stakeholder mapping, root cause diagrams, crop and farm-level models or Life Cycle Analyses. Part of our CSR output could be a toolbox or guidelines with recommended tools to implement a systems approach in the design of climate smart agriculture research.

Transdisciplinary Research

Definition

The CSR project adopts a Multi-Actor Approach (MAA). MAA "aims to make the R&I process more co-creative and inclusive, and thereby its outcomes are more co-owned, reliable, demand-driven and relevant to society[28]". Adopting a MAA ensures involvement of relevant AKIS actors in the CSR project. In MAA, this involvement goes beyond dissemination or consultation, instead MAA is about co-creation. In the Sustainability Science field, stakeholder involvement is part of a transdisciplinary research approach. Sustainability challenges such as the transition towards climate resilient agricultural systems require new ways of knowledge production and decision-making. Transdisciplinary research is such an approach. In transdisciplinary approaches, knowledge is co-created by integrating academic and non-academic knowledge[29]. The aim of transdisciplinary research is to address complex, real-world problems, integrating different types of knowledge and prioritising collaboration and problem solving, crossing disciplinary boundaries[30]. The outcomes of transdisciplinary research are action-oriented[31], aimed at 'how-to' knowledge for climate smart agriculture.

Role in CSR project

In CSR, transdisciplinary research is about co-creating knowledge and action for climate smart agriculture together with farmers and other relevant stakeholders (e.g. advisors). A multi-actor, transdisciplinary approach is applied throughout the whole project and at different stages of the research process (i.e. design, implementation, evaluation). By creating a core group of researchers, farmers and other AKIS actors from the start of the project, CSR facilitates a reciprocal and co-creative relationships between relevant stakeholders throughout the projects' lifespan. The goal of adopting a transdisciplinary approach in CSR is to adequately address the complex problem of dealing with the effects of climate change on agriculture and developing outcomes that are co-owned and relevant to both science and society.

Examples

Examples of shaping transdisciplinary collaboration:

- Co-defining the research problem and experimental farm design in a collaboration between farmers, researchers and other AKIS actors;

[28] Horizon Europe - Work Programme 2026-2027

[29] Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., ... & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability science*, *7*(Suppl 1), 25-43.

[30] Hadorn, G. H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., ... & Zemp, E. (Eds.). (2008). *Handbook of transdisciplinary research* (Vol. 10, pp. 978-1). Dordrecht: Springer.

[31] Fazey, I., Schäpke, N., Caniglia, G., Patterson, J., Hultman, J., Mierlo, B. van, Säwe, F., Wiek, A., Wittmayer, J., Aldunce, P., Al, H., Battacharya, N., Bradbury, H., Carmen, E., Colvin, J., Cvitanovic, C., Souza, M. D., Gopel, M., Goldstein, B., Hämäläinen, T, Harper, G. … Wyborn, C. (2018). Energy research & social science ten essentials for action-oriented and second order energy transitions, transformations and climate change research. Energy Research & Social Science, 40, 54–70.

- Doing field trials or tests on farmers' land;
- Organising exchange sessions and cross-visits where researchers, farmers and other AKIS actors learn from each other's experiences.

Challenges and opportunities

For CSR as a project, adopting a transdisciplinary way of working provides the opportunity to produce actionable knowledge that addresses real-world problems and contributes to the transition to climate neutral agriculture. However, working in a transdisciplinary way also comes with challenges. For example, when different actors define the problem differently, when there are conflicting goals or unequal power relations. Reflexivity is introduced in the project to at least be aware, but also to deal with such challenges in a reflexive manner.

Operationalisation

Transdisciplinarity is a way of working, in CSR operationalised through active collaboration and co-creation with the Farmer and Stakeholder groups, through facilitated exchange sessions and brokering events. Collaboration with the sister project CFD and CSA further strengthens collaboration between researchers, farmers and advisors. Furthermore, the CSR project aims to involve stakeholders as active participants in co-creating e.g. the PioneERS' research design and the ClimAPs.

The CSR project will implement the MAA requirements as outlined by Horizon Europe[25]:

1. Target the needs of the end-users (i.e. climate smart agricultural researchers, farmers, advisors, other relevant AKIS actors) of CSR project results;
2. Include both scientific and practical knowledge and skills in the design, implementation and evaluation of Climate Smart agricultural systems by including farmers and other relevant AKIS actors in the ERS;
3. Cross-fertilisation and co-creation between researchers and non-academic actors through high-quality knowledge exchange activities;
4. Facilitate multi-actor engagement throughout the whole project's lifespan, e.g. through the Farmer and Stakeholder Groups, knowledge exchange and brokerage events;
5. Demonstrate the added value of CSR for researchers, farmers and agricultural advisors;
6. Produce practice-oriented and ready-to-use Climate Smart knowledge, tools and solutions;
7. Widely and effectively disseminate CSR results that are ready-for-practice.

Implementation

The concept of transdisciplinarity will be implemented in the following way:

- Exploring the role of InnovatERS and PioneERS in their national AKIS (T1.3) through surveys, focus groups, and road mapping. CSR will engage extensively with farmers (via CFD, farmers group in PioneERS), advisors (via CSA) (T3.4 & 3.5) and AKIS stakeholders (via stakeholder groups, external advisory board and in events). Engagement will be focused (be clear about what we want), reciprocal (give as much as we get), and respectful (value everyone's time).
- Consulting and involving farmer and stakeholder groups within CSR's research activities and the shaping of the ClimAPs (T3.1). CSR aims to involve stakeholders in ERS problem framing, research design and exploring actions and impacts.

- Including social sciences on behavioural change for the upscaling and adoption of Climate Smart Agriculture practices. WP2 works with stakeholders to co-design specific "pathways" for bridging the research-practice gap, providing insights into how brokerage events and networking contribute to mid- and long-term implementation outcomes.
- Co-designing the repository structure and survey together with stakeholder groups (T4.1).
- Aligning research questions with knowledge needs from farmers (WP4), as identified in CFD and CSA, incorporating transdisciplinary input where feasible during the selection of emerging practices.
- Integrating the perspective of farmers (CFD) and advisors (CSA) in identifying climate smart practices (T2.3).
- Organising two shared brokering events together with the CSA and CFD projects (T2.3).

3. Research framework

To be able to streamline methods, protocols, and data on ERS across four pedoclimatic zones, we created a research framework. The research framework was formed through collective theory building and leads to recommendations for effectively conducting Climate Smart Research. 'Collective theory building' refers to a collaborative research process where CSR researchers from all WPs, and with diverse backgrounds and disciplines, worked together to develop, refine, or expand the conceptual framework into a research framework.

A lens-based approach

Introduction to the Matrix Approach

The transition to Climate Smart Agriculture represents one of the most complex challenges facing European agriculture today. It is a "wicked problem" characterised by biological complexity, regional heterogeneity, and competing socio-economic demands. To accelerate the transition to climate-neutral agriculture, the CSR project must move beyond linear, uni-dimensional research methods. A purely agronomic perspective might identify a practice that reduces emissions but fails economically; a purely economic perspective might identify a profitable practice that degrades soil health or lacks social acceptance.

To address this complexity, this Deliverable presents a comprehensive Multi-Lens Research Framework. This framework is structured as a matrix (Figure 2), intersecting four Grand Challenges (Themes), representing the *goals* of our inquiry, with six research lenses, representing the *modes* of inquiry and sources of knowledge.

This matrix approach ensures that no research question is answered in isolation. By triangulating data from literature, experimental trials, practitioner experience, and modelling tools, CSR ensures that the knowledge generated is not only scientifically robust but also practically applicable and scalable across the diverse pedo-climatic zones of the European Union.

Rationale: Why a Multi-Lens Perspective?

The justification for adopting a multi-lens perspective is rooted in the project's ambition to bridge the persistent gap between scientific research and on-farm implementation. Traditionally, agricultural research has prioritised "Experimental Research" and "Scientific Literature" as the primary sources of truth. While these are foundational, they often fail to capture the tacit knowledge of farmers, the regulatory constraints of policy, or the predictive power of simulation tools necessary for upscaling.

For the CSR project, specifically, the multi-lens approach serves three critical functions:

1. **Operationalizing the Multi-Actor Approach (MAA):** The CSR Grant Agreement explicitly commits to co-creation. By formally elevating *Practitioners' Local Knowledge* and *Policy and Business* to the status of distinct research lenses, we institutionally embed the MAA into the

scientific methodology. It ensures that the insights from the 10 PioneERS' Farmer and Stakeholder Groups are treated with the same analytical rigor as data from e.g. soil testing.

2. **Handling Systemic Complexity:** Climate Smart Agriculture involves intricate synergies and trade-offs (e.g., between productivity and mitigation). A single lens cannot capture the full picture. For instance, *Simulations and Tools* might predict high carbon sequestration for a specific practice, but *Practitioners' Local Knowledge* might reveal operational barriers that make that practice unfeasible. Only by looking through both lenses can we derive a valid conclusion.
3. **Facilitating Upscaling and Harmonisation:** With 29 ERS involved as either PioneERS or InnovatERS, different levels of resourcing and engagement are expected. To bring the different parts together, harmonisation is key. A multi-lens framework provides a common scaffolding that allows lessons from a dairy farm in New Zealand to be triangulated with knowledge based in a mixed farm in Poland, despite their vast differences. It provides a standardized structure for inquiry that transcends national borders.

Figure 2. Research framework: a lens-based approach. This includes six lenses to research four different themes.

The Four Grand Challenges (Research Themes)

The framework organises the project's scientific inquiry around four Grand Challenges. These themes have been selected because they represent the logical progression from defining a concept to implementing it at scale.

Theme 1: Defining Climate Smart Agricultural practices and measuring success

Why this theme?
Before we can improve Climate Smart Agriculture, we must agree on what constitutes success. Currently, metrics for productivity, adaptation, and mitigation are often fragmented. There is a lack of consensus on system boundaries (farm gate vs. lifecycle), baselines, and trade-off acceptability.
In the CSR Context:
This theme addresses the Standardisation challenge. It involves establishing the protocols for the

ClimAP developed in WP3. It asks: How do we measure climate neutrality? What key performance indicators (KPIs) allow us to compare a high-input system in the Netherlands with an extensive system in Spain? This theme focuses on operationalizing concepts into measurable variables.

Theme 2: What Climate Smart Agriculture practices work where and why?

Why this theme?
Agriculture is context dependent. A practice that is climate smart in the Nordic zone (e.g., specific tillage practices) might be detrimental or ineffective in the Mediterranean zone due to differences in soil moisture and temperature.
In the CSR Context:
This theme addresses the core scientific investigation of the project. It focuses on the contextual efficacy of solutions. It is about unpacking the 'black box' of causality. It is not enough to know *that* a practice reduces emissions; we must understand the pedo-climatic mechanisms (the *why*) to predict where else it might work. This theme is crucial for guiding the work of the 19 InnovatERS as they validate emerging practices from sister projects (CFD and CSA) across different environments.

Theme 3: Enabling the transition to Climate Smart Agriculture by farmers

Why this theme?
The availability of a technology does not guarantee its adoption. This theme shifts focus from the *biophysical* to the *socio-technical*. It addresses the implementation gap. Barriers to adoption are rarely purely technical; they are often financial, behavioural, cultural, or logistical.
In the CSR Context:
This theme explores the human and systemic dimensions of change. It connects directly to the project's ambition to foster adoption among 'average farms', not just front runner farmers. It investigates upscaling barriers, financial models, and policy options to promote Climate Smart Agriculture. It asks how we can de-risk the transition for the primary producers or commercial agriculture sector as a whole.

Theme 4: Building capacity for Climate Smart Agriculture research

Why this theme?
Research stations themselves must evolve. The traditional one-way linear model of technology transfer (from station to farmer) is insufficient to tackle the complex problem of transitioning to Climate Smart Agriculture. In order to effectively contribute to change in the agricultural sector, ERS must become innovation hubs that facilitate co-design. However, capacities vary significantly across the EU AKIS.
In the CSR Context:
This theme addresses the long-term sustainability of the network (WP2 & 5). It is about researching the research. It seeks to identify the skills, infrastructures, and methodologies required to make ERS effective agents of change. It aims to harmonise the capabilities of the 10 PioneERS and the 19 InnovatERS, ensuring that the legacy of the CSR project is a robust, interconnected European research infrastructure capable of tackling future climate challenges.

The six research lenses

To address the four themes CSR employs six distinct 'lenses'. These represent the different methodological angles from which each theme will be interrogated. By applying multiple lenses to a single theme, we achieve triangulation, increasing the validity and robustness of our findings.

Lens 1: Literature

Definition: This lens encompasses the synthesis of existing academic and grey literature. It involves systematic reviews, meta-analyses, and the review of results from previous and ongoing EU projects (e.g., EJP SOIL, ClieNFarms).

Importance:

As the starting point for WP1 (Foundations), this lens establishes the State-of-the-Art (SOTA). It helps us identify 'emerging practices' and define the 'theoretical maximum' of mitigation potential for specific practices and identifies gaps in current knowledge (e.g., regarding trade-offs) that the CSR project must fill through experimentation.

Lens 2: Practitioners' Local Knowledge

Definition: This lens captures the tacit, experiential, and context-specific knowledge held by farmers, advisors, and land managers. It is gathered through interaction with the CFD (1500 farmers) and CSA (1500 advisors) sister projects and the Stakeholder Groups (SG) and Farmer Groups (FG) attached to each PioneERS, as well as through open EU level brokerage events and national events.

Importance:

Practitioners act as the ultimate 'ground-truthing' mechanism. They provide insights into operational feasibility that cannot be found in peer-reviewed journals. For example, regarding Theme 1 (Measuring success), practitioners can reveal which metrics are actually meaningful to a farmer's daily decision-making. Regarding Theme 3 (Transition), this lens is the primary source for understanding the socio-economical barriers to adoption.

Lens 3: Experimental Research

Definition: This lens represents the empirical data generation through physical trials. It refers to the systemic research carried out on the 10 PioneERS (WP3) and the validation trials on the 19 InnovatERS. It involves the measurement of GHG fluxes, soil carbon sequestration, yields, and biodiversity metrics.

Importance:

This is the scientific core of the project. While models and literature provide estimates, only experimental research provides the hard evidence required to verify 'Climate Smartness' in real-world conditions. This lens provides the datasets necessary to validate Theme 2 (What works where) and provides the inputs for Lens 4 (Simulations). It turns the ERS into living labs where hypotheses are tested against the reality of the farm.

Lens 4: Simulations and Tools

Definition: This lens involves the use of carbon calculators, decision support systems (DSS), and predictive models (e.g., Cool Farm Tool, AgNav, CAP'2ER). It covers the activities in WP4 (Adoption of tools).

Importance:

Experimental research is expensive and site-specific. To understand the potential impact of CSR solutions at the EU level (Theme 2 and Theme 3), we must also rely on modelling. This lens allows us to:

1. Extrapolate: Take results from a PioneERS in France and predict impacts if applied to similar farms in similar zones.
2. Forecast: Estimate the long-term carbon sequestration potential beyond the 5-year scope of the project.
3. Benchmark: Compare different tools to ensure consistency in MRV (Monitoring, Reporting, and Verification).

Lens 5: Researchers' Expert Knowledge

Definition: This lens leverages the collective intellectual capital of the CSR consortium (33 partners). It involves expert elicitation, and the synthesis of interdisciplinary perspectives (agronomy, ecology, sociology, economics).
Importance:
This lens is crucial for synthesis and integration. It bridges the gap between raw experimental data and actionable recommendations. For Theme 4 (Capacity Building), the expert knowledge of the consortium partners, many of whom are leaders in their national AKIS, is the primary resource for defining best practices in research design. This lens facilitates the Collective learning and theory building task outlined in WP1.

Lens 6: Policy and Business

Definition: This lens focuses on the enabling environment. It examines regulations (CAP, Green Deal), market mechanisms (carbon farming credits), supply chain requirements, and business models. It connects mainly to WP5 (Maximising Impact).
Importance:
A practice may be scientifically proven (Lens 3) and practical for farmers (Lens 2), but if it is not economically viable or legally compliant, it will fail. This lens interrogates the financial sustainability of Climate Smart Agriculture practices. It asks: Is there a business case? Does current policy incentivise or hinder this practice? Regarding Theme 3 (Enabling transition), this lens is critical for identifying the external levers required to move from pilot scale to mass adoption.

The matrix in action

By forcing an intersection between these 6 Lenses and 4 Themes, the CSR project ensures a holistic analysis. For example, when addressing **Theme 2 (What works where?)**, we will not simply rely on **Experimental Research (Lens 3)** from the PioneERS. We will cross-reference this with **Literature (Lens 1)** to check for anomalies, validate it with **Practitioners (Lens 2)** to ensure operational feasibility, model it via **Simulations (Lens 4)** to estimate regional impact, and analyse it through **Policy (Lens 6)** to see if the practice aligns with future CAP eco-schemes.

This multi-lens framework provides the methodological rigor required to deliver on the project's ambitious goal: to develop practice-oriented climate smart solutions that are scientifically validated, socially accepted, and economically viable, thereby accelerating Europe's transition to climate-neutral agriculture.

By combining the six different 'lenses', the framework systematically brings together diverse types of knowledge and insights. The lenses we have used in the creation of the research framework are: literature, practitioners' local knowledge, experimental research, simulations and tools, researchers' expert knowledge, and policy and business. These six lenses are applied across four key themes: defining Climate Smart Agriculture practices and measuring successes, understanding which practices work where and why, enabling farmers' transition to climate neutral agriculture, and building capacity for Climate Smart Agriculture research.

Through the process of a workshop with WP and Task leaders, we collated research questions for each WP and Task (Appendix 1). We then used the Research Framework explained above to organise these into a matrix (Table 2). In doing so, we identified a number of 'gaps' (cells without question based on the workshop) which we then worked together to be clarified with respective WP or Task leaders to find if relevant research questions can be formulated to fill these gaps.

Table1. CSR project task matrix by lens and theme.

Lens	Defining Climate Smart Agriculture practices and measuring success	What Climate Smart Agriculture practices works where and why	Enabling the transition to Climate Smart Agriculture by farmers	Building capacity for Climate Smart Agriculture research
Literature	T1.1. How to operationalize the concepts of mitigation, adaptation and productivity such that ClimAPs have SMART targets?	T1.2 What is the evidence for synergies and trade-offs between mitigation, adaptation and productivity? T1.2 What is the evidence for multiple solutions being more than sum of its parts?	T1.3 What is the current/desired role of Agricultural Experimental Research Stations in their national AKIS and how can their role be strengthened? How should HEI interact with farmers, advisors or other knowledge brokers to integrate effectively with AKIS?	T2.1 How is the research-practice gap perceived by researchers? And how can we bridge this gap? T2.2 How can we effectively design Climate Smart Research, including exchanges and KE activities, to bridge the research practice gap?
Practitioners' local knowledge	T2.3 / T4.4 What do different actors understand by "emerging practices" or "climate smart agriculture"? what does a potential gap or disagreement tell us?	T1.4 How does involving farmer groups and stakeholder groups affect how CSR research addresses 'real conditions'?	T3.4 / T2.3 What are the barriers to upscaling the practices implemented in PioneERS?	T2.1 How is the research-practice gap perceived by practitioners across the EU in the context of climate smart agriculture? And how can we bridge this gap? T2.2 How can we effectively design Climate Smart Research, including exchanges and KE activities, to bridge the research practice gap?
Experimental research	T3.2 What are the best protocols that helped PioneERS monitor Climate Smart Agriculture progress?	T3.2 What has been the impact of implementing ClimAP in each PioneERS on mitigation, adaptation and productivity?	T5.5 What are the short-term and long-term financial returns expected from the business model? What is the cost–benefit ratio of adopting the CSR solutions compared to existing practices?	T3.5 How must the experimental infrastructures, governance and protocols of PioneERS evolve to transform from traditional trial sites into long-term 'Living Labs' that successfully co-design and validate Climate Smart Agricultural practices with stakeholders?
Simulations and tools	T3.3 Methodological question on how to systematically assess farm-scale impacts from the plot/sub-field trials in ERS, accounting for scaling issues and other uncertainties? T3.4 Methodological question on how to upscale to EU level	T3.1 Based on LCA analysis of ClimAPs, what is the potential for reaching 55% reduction from 1990? T3.3 Based on a cross-sectorial/across different pedoclimates, how much can you achieve from across the network (relative	T4.3 What do existing comparison studies of toolkits tell us about comparability, accuracy and usability of farm-level models to inform farmers, across different farming and pedo-climatic contexts? What limitations or gaps have been highlighted in previous comparisons?	T4.1 What common data structures and formats can harmonise heterogeneous datasets across the different farming systems/pedo-climatic zones? T4.1 What repository structure best supports user engagement, long-term usability and transparency for

	from PioneERS experience? Change to same wording as previous 3.4 question?	reduction to 1990) on 'model farms'?	How will we address this with the InnovatERS?	researchers across Europe? T4.1 What is the minimum set of metadata and documentation required to make the climate-related experiments fully replicable? T4.2 What is the best common methodology to allow the comparison of tools and services?
Researchers' expert knowledge	T2.3 / T4.4 What do different actors understand by "emerging practices" or "climate smart agriculture"? what does a potential gap or disagreement tell us?	T4.4 Do "emerging practices" live up to their potentials? Based on scientific evaluation of mitigation / adaptation / productivity and scaling of potentials based on pedo-climatic etc. considerations	T5.3 In what ways does the involvement of researchers in the co-design of dissemination products enhance the perceived credibility and usability of innovative Climate Smart Agriculture knowledge for farmers entering the transition phase?	T1.4 How to effectively conduct climate smart research? What is a European shared research agenda for Climate Smart Agriculture? T1.4 What is the best way to value knowledge generated in systemic-approach research (few repetition, no statistical significance)? T2.1 What is the state-of-play of Climate Smart Agriculture empirical research in Europe? T2.1 How is the research-practice gap perceived by researchers? And how can we bridge this gap? T2.2 How can we effectively design Climate Smart Research, including exchanges and KE activities, to bridge the research practice gap? T2.2: How do the networking and capacity building activities in CSR contribute to researchers' competences in effective design of Climate smart research?
Policy and business	T5.4 / T5.5 How are different types of farmers open to Climate Smart Agriculture adoption	T3.6 Under few policy/business incentive structures and using stakeholder input and public FADN data, upscale the	T5.1 / T5.3 Who are the most relevant / priority stakeholders to target with DEC activities to drive adoption/upscale? Who to connect with in	T5.2 What other EU, national, regional projects, networks and initiatives are relevant for building an extended stakeholder community

	via involvement of ERS into AKIS?	impact of implementing ClimAPs across all of EU on Ag sector mitigation, adaptation, productivity.	key networks (e.g. CAP network) to ensure the full and effective dissemination of project outputs? T5.4 What are the most relevant EU policies and policy mixes for the accelerated adoption of best/emergent practices for Climate Smart Agriculture? T5.5 What are the most relevant business models for the accelerated adoption of best/emergent practices for Climate Smart Agriculture?	and leveraging opportunities for collaboration and knowledge exchange?

Appendix 1

Table 2. Research questions for all WPs

WP	Research Questions
WP1	Task 1.1 Conceptual and research framework - How to operationalize the concepts of mitigation, adaptation and productivity such that ClimAPs have SMART targets?
	Task 1.2 Synthesis of synergies and trade-offs - What is the evidence for synergies and trade-offs between mitigation, adaptation and productivity? - What is the evidence for multiple solutions being more than sum of their parts?
	Task 1.3 Integrating research stations within national AKIS - What is the current/desired role of Agricultural Experimental Research Stations in their national AKIS and how can their role be strengthened? - How should HEI interact with farmers, advisors or other knowledge brokers to integrate effectively with AKIS?
	Task 1.4 Collective learning and theory building - How does involving farmer group and stakeholder group affect how CSR research addresses 'real conditions'? - How to effectively conduct climate smart research? What is a European shared research agenda for Climate Smart Agriculture? - What is the best way to value knowledge generated in systemic-approach research (few repetitions, no statistical significance)?
WP2	Task 2.1 Investigate the state-of-play of climate research and climate R&I design in the ERS network - In what form is the research-practice gap present? - What is the state-of-play of Climate Smart Agriculture empirical research in Europe? - How is the research-practice gap perceived by researchers? And how can we bridge this gap? - Which factors define the research-practice gap?
	Task 2.2 Capacity building of ERS - How can we effectively design Climate Smart Research, including exchanges and KE activities, to bridge the research practice gapT2.2 - How do the networking and capacity building activities in CSR contribute to researchers' competences in effective design of Climate smart research?
	Task 2.3 Bridging the research-practice gap - What do different actors understand by "emerging practices" or “climate smart agriculture”? what does a potential gap or disagreement tell us - What are the barriers for upscaling the practices implemented in PioneERS?
	Task 2.4 Lessons learnt: identifying pathways for effectively bridging the research-practice gap - What could be pathways for effectively bridging the research-practice gap.
WP3	Task 3.1 Development of individual research and innovations agendas and ClimAPs. - Based on LCA analysis of ClimAPs, what is the potential for reaching 55% reduction from 1990?
	Task 3.2 Implementation, monitoring and measurement of cutting-edge Climate Smart Agriculture approaches in real farming conditions - What are the best protocols that helped PioneERS monitor Climate Smart Agriculture progress? - What has been the impact of implementing ClimAP in each PioneERS on mitigation, adaptation and productivity?
	Task 3.3 Evaluate aggregated impacts towards climate neutrality and climate resilience - Based on a cross-sectorial/across different pedoclimates, how much can you achieve from across the network (relative reduction to 1990) on 'model farms'. Task 3.3 Methodological question on how to systematically assess farm-scale impacts from the plot/sub-field trials in ERS, accounting for scaling issues and other uncertainties?
	Task 3.4 Assess the adoption/upscale potential of Climate Smart Agriculture approaches researched on PioneERS by other farms - What are the barriers to upscaling the practices implemented in PioneERS?
	Task 3.5 Planning long-term implementation with stakeholders at PioneERS level - How must the experimental infrastructures, governance and protocols of PioneERS evolve to transform from traditional trial sites into long-term 'Living Labs' that successfully co-design and validate Climate Smart Agricultural practices with stakeholders?
	Task 3.6 Upscaling potential to EU level - Under few policy/business incentive structures and using stakeholder input and public FADN data, upscale the impact of implementing ClimAPs across all of EU on Agriculture sector mitigation, adaptation, productivity.
	Task 4.1 Selection of climate tools, services and DSSs

WP4	- What common data structures and formats can harmonise heterogeneous datasets across the different farming systems/pedo-climatic zones? - What repository structure best supports user engagement, long-term usability and transparency for researchers across Europe? - What is the minimum set of metadata and documentation required to make the climate-related experiments fully replicable?
	Task 4.2 Development of a methodology to compare tools and services and standardised MRV - What is the best common methodology to allow the comparison of tools and services?
	Task 4.3 Compare and test digital toolkits and services - What do existing comparison studies, of toolkits tell us about comparability, accuracy and usability of farm-level models across different pedo-climatic contexts?
	Task 4.4 Scientific validation of emerging practices - What do different actors understand by "emerging practices" and what does a potential gap or agreement tell us? - Do "emerging practices" live up to their potentials? Scientific evaluation of mitigation / adaptation / productivity... and scaling of potentials based on pedo-climatic etc. considerations.
WP5	Task 5.1 Dissemination, Exploitation and Communication Who are the most relevant / priority stakeholders to target with DEC activities to drive adoption/upscale? Who to connect with in key networks (e.g. CAP network) to ensure the full and effective dissemination of project outputs?
	Task 5.2 Communication, visibility and stakeholder engagement - What other EU, national, regional projects, networks and initiatives are relevant for building an extended stakeholder community and leveraging opportunities for collaboration and knowledge exchange?
	Task 5.3 Dissemination of effective innovative approaches and new knowledge generated for climate-smart agriculture - In what ways does the involvement of researchers in the co-design of dissemination products enhance the perceived credibility and usability of innovative Climate Smart Agriculture knowledge for farmers entering the transition phase? - Who are the most relevant / priority stakeholders to target with DEC activities to drive adoption/upscale? Who to connect with in key networks (e.g. CAP network) to ensure the full and effective dissemination of project outputs?
	Task 5.4 Exploitation and sustainability through policy actions - How are different types of farmers open to Climate Smart Agriculture adoption via involvement of ERS into AKIS? - What are the most relevant EU policies and policy mixes for the accelerated adoption of best/emergent practices for Climate Smart Agriculture?
	Task 5.5 Business models for practice-oriented solutions and IPR management - What are the most relevant business models for the accelerated adoption of best/emergent practices for Climate Smart Agriculture? - What are the short-term and long-term financial returns expected from the business model? - What is the cost–benefit ratio of adopting the CSR solutions compared to existing practices?

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