



MS3.2 First ClimAP PioneERS

ClimAP summary and analysis

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List of Abbreviations

CSR	Climate Smart Research
ClimAP	Climate Action Plan
ERS	Experimental Research Station
InnovatERS	Innovating Experimental Research Stations
PioneERS	Systemic Pioneering Experimental Research Stations
WP	Work Package
CSA	Climate Smart Advisors
CFD	Climate Fram Demo
GHG	Greenhouse Gas
SG	Stakeholders Group
FG	Farmers Group
CSF	Climate Smart Farming
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1. Introduction

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).

Work Package 3 implements research into cutting-edge Climate Smart Farming (CSF) approaches on ten Pioneering Experimental Research Stations (PioneERS) located across contrasting pedo-climatic zones. Its objective is to develop farm-system approaches capable of delivering major GHG mitigation, from -55% to climate neutrality relative to relevant references, while strengthening climate adaptation and resilience. PioneERS represent diverse farming systems, including crop-based, crop-livestock, livestock, and monogastric systems, and are designed to test and implement climate-smart solutions under real farming conditions. Task 3.1 develops one Climate Action Plan (ClimAP) for each PioneERS. Each ClimAP defines a research and innovation agenda, identifies the technical, agroecological and socio-technical approaches to be tested, estimates expected impacts and risks, and structures implementation during and beyond the project. Co-developed with Stakeholder Groups and Farmers Groups, the ClimAPs support subsequent monitoring, annual evaluation, adoption analysis, long-term planning and EU-level upscaling assessment within WP3. The PioneERS will analyse synergies and trade-offs between productivity, climate mitigation and adaptation under real farming condition.

1.1 Objectives and key elements of PioneERS

WP3 focuses on developing Climate Action Plans (ClimAPs) for each of the ten Pioneering Experimental Research Stations (PioneERS) located across contrasting pedo-climatic zones in Europe and New Zealand. The main objectives of WP3 are:

- To develop a Climate Action Plan (ClimAP) for each PioneERS, defining a research and innovation agenda, identifying technical, agroecological, and socio-technical approaches to be tested, and estimating expected impacts and risks.
- To co-develop these ClimAPs with Stakeholder Groups and Farmers Groups, ensuring that solutions are context-specific, innovative, and transferable.
- To structure implementation of these plans during and beyond the project, supporting monitoring, annual evaluation, adoption analysis, and EU-level upscaling assessment.
- To have a mitigation of at least -55% of farms GHG emissions in comparison to the baseline year of a farm from a comparable system.

The key elements of the PioneERS, as described in the project document and framed in the deliverable 1.1 conceptual and analytical framework, include:

- **A diversity of systems:** PioneERS cover a wide range of farming systems, from crop-based to livestock and mixed systems, allowing for the evaluation of climate mitigation and adaptation pathways across different contexts.
- **Real farming conditions:** Research is conducted under real-world conditions, ensuring that findings are relevant and applicable to commercial farms. This will be also submitted to groups of farmers and agricultural stakeholders.

- **Systemic approach:** WP3 emphasizes a systemic approach to climate-smart agriculture, considering synergies and trade-offs between productivity, climate mitigation, and adaptation.
- **Co-construction:** Stakeholder and farmer engagement within working groups is central to the development and implementation of ClimAPs, ensuring that solutions are co-created and aligned with local needs and constraints.
- **Long-term vision:** ClimAPs are designed to support long-term planning and implementation, with a focus on achieving significant reductions in greenhouse gas emissions (e.g., -55% relative to 1990 levels) and enhancing resilience and adaptation.

1.2 Methods and process

The conceptual and analytical framework for conducting climate-smart agricultural research in the CSR project is structured around a multi-lens approach, integrating multiple sources of knowledge and perspectives. This framework is designed to ensure that research is both scientifically robust and practically applicable, bridging the gap between research and real-world farming conditions. The PioneERS ClimAP are built on the following foundational concepts and frameworks:

- **Climate Smart Agriculture in Real Conditions in the PioneERS:** Research is conducted under real-world farming conditions, considering the pedo-climatic context, interactions, synergies, and trade-offs at the farm scale. The project uses a 'model farm' approach to ensure that results are scalable and transferable.
- **Climate Adaptation:** Actions taken to prepare for and adjust to the current and projected impacts of climate change. Adaptation solutions are tailored to local climate risks and farming systems.
- **Climate Mitigation:** Actions taken to reduce greenhouse gas emissions and enhance carbon sequestration. This includes improving slurry management, optimizing fertilizer use, and integrating renewable energy systems.
- **Productivity:** Measured as economic or business performance, considering inputs and outputs, and ensuring that climate-smart solutions do not compromise productivity or profitability neither competitiveness.
- **Role of Ecosystems:** Ecosystems are central to climate-smart agriculture, providing services such as carbon sequestration, water regulation, and biodiversity support. Research considers both the impact of agriculture on ecosystems and the potential of ecosystems to support climate-smart practices.
- **Capacity Building:** Strengthening the skills, knowledge, and attitudes of researchers and stakeholders within PioneERS to conduct and apply climate-smart agricultural research.
- **Reflexivity:** Critical examination of assumptions, values, and methods to ensure that research is adaptive, inclusive, and impactful.
- **Systems Thinking:** Understanding the complexity and interdependencies of agricultural systems, considering multiple scales (plot, farm, landscape) and levels (agronomic, socio-economic, governance).
- **Transdisciplinary Research:** Integrating academic and non-academic knowledge through co-creation and collaboration with farmers, advisors, and policymakers.

Within WP3 and PioneERS, CSR employs a lens-based research framework, which organizes research questions around four grand challenges (themes) and six research lenses (D1.1). In the WP3 and for the redaction, implementation, monitoring and final evaluation of ClimAP, the following methods and processes are implemented:

- **First development of ClimAPs:** Each PioneERS develops a Climate Action Plan (ClimAP) that defines the research agenda, identifies technical and socio-technical approaches, and estimates expected impacts and risks. ClimAPs are co-created with Stakeholder and Farmer Groups.
- **Monitoring and Evaluation of the ClimAP:** PioneERS monitor and evaluate the implementation of ClimAPs annually, using a set of indicators that cover mitigation, adaptation, productivity, and ecosystem services. Monitoring includes both quantitative data (e.g., greenhouse gas emissions, soil carbon sequestration) and qualitative assessments (e.g., stakeholder feedback).
- **Co-construction of the ClimAP** and eventual adjustment: Stakeholder and farmer groups are actively involved in the development and refinement of ClimAPs, ensuring that solutions are context-specific and feasible. This includes regular meetings, workshops, and feedback sessions.
- **Systemic Approach of ClimAP:** Research on PioneERS considers the whole farm system, including interactions between crops, livestock, and ecosystems, and the synergies and trade-offs between different climate-smart practices.
- **Capacity Building** for PioneERS manager, researcher, FG and SG: During ClimAP development, implementation and final analysis, WP3 includes activities to build the capacity for doing climate research of researchers and stakeholders, including exchange visits, masterclasses, and training on climate-smart research methods and tools.
- Finally **upscaling and dissemination:** Results from ClimAP implementation and analysis are used to inform upscaling strategies and are disseminated through practice abstracts, factsheets, and tailored communication plans in collaboration with other WPs. This ensures that successful practices are adopted beyond the PioneERS network.

1.3 Farming context and description of the PioneERS

The consolidated analysis of the general characteristics of the PioneERS (table 1) highlights the structural diversity across PioneERS, the wide range of agro-climatic zones, production systems and management strategies. This diversity constitutes an interest for the project, as it enables the evaluation of climate mitigation and adaptation pathways across contrasting environmental and socio-technical contexts but also a challenge considering the harmonization of the research approach especially on the systemic approach.

A first key observation is the clear differentiation between system types, with three dominant categories: (i) crop-based systems (Czechia, Netherlands, Denmark), (ii) crop-livestock-dominated systems (France, Belgium, Finland, Poland, New Zealand), and monogastric (pigs) systems (Italy, UK). These system types are associated with distinct emission profiles and mitigation opportunities. For example, livestock systems are primarily driven by enteric methane emissions, whereas arable systems are dominated by nitrogen-related emissions and energy use. Mixed systems provide opportunities for circularity but also introduce complexity in management and trade-off analysis. The Polish PioneERS include a mixed dairy–crop system,

where crop and livestock interactions can be assessed at commercial scale. The Italian PioneERS further broadens the portfolio by adding a heavy-pig and arable-crop system in Emilia-Romagna, relevant for testing climate-smart strategies in monogastric production chains.

Secondly, the analysis reveals that agricultural GHG emission sources are consistent across countries, despite system differences. Enteric methane (CH₄), soil nitrous oxide (N₂O), and carbon dioxide (CO₂) from inputs and energy use are identified as the dominant emission sources. This convergence confirms that mitigation strategies must focus on a limited number of key processes, even though implementation pathways differ depending on local conditions.

Thirdly, the influence of pedoclimatic conditions is particularly strong, especially in extreme environments such as boreal peatlands (Finland), oceanic high-rainfall systems (Belgium, France), and reclaimed clay soils (Netherlands polders - Lelystad). These conditions directly affect both emission dynamics and the feasibility of mitigation measures. For instance, wet winter conditions limit greatly winter grazing possibilities in France, peat soils in Finland represent both a major emission source and a highly sensitive system, while clay soils in the Netherlands constrain field operations due to compaction risks for example. The Polish site combines moderate rainfall with recurring drought and summer heatwave episodes, making it relevant for testing resilient mixed-farming strategies. Italy also illustrates another pedoclimatic context, where temperate subcontinental lowland conditions are increasingly affected by very heavy rainfall events and very high summer temperatures.

Another important finding concerns the increasing exposure to climate variability across all sites. All PioneERS identify climate risks such as drought, excessive rainfall, temperature extremes or hydrological instability (Annex 1 ClimAP description excel format). These risks affect not only productivity but also the effectiveness of mitigation measures. For example, reduced fertilizer use may lead to yield penalties under drought conditions, while high rainfall can increase nutrient losses and emissions.

Furthermore, the analysis highlights the importance of system scale and experimental design. Some stations operate at plot scale (Netherlands, Denmark, Czechia...), while others represent full commercial-scale systems (New Zealand, France...). This diversity allows the project to combine controlled experimentation with real-world applicability, which is essential for assessing scalability and adoption potential. Representative farm size calculations will be used to address upscaling possibilities and climate effects at a farm scale. This is one of the challenges faced when trying to harmonize approaches within WP3 discussions.

Finally, the results underline that the transition toward climate-smart agriculture requires context-specific solutions within a shared analytical framework (summarised in the introduction and described in detail in D1.1). While the PioneERS operate under different conditions, they converge toward common objectives: reducing GHG emissions, increasing soil organic carbon sequestration, improving resource-use efficiency, and enhancing resilience to climate change.

Table 1 : PioneERS overview

Country	Type of farming system	Farm size / production scale	Main production	Climate and environmental conditions	Description of the experimental research station	Largest GHG emission sources	Biggest climate change impact / risk on the PioneERS
Belgium	Mixed crop–livestock (organic system)	19.45 ha (experimental system scale)	Meat (grass-fed crossbred calves) and food crops (cereals, legumes, vegetables)	Cool humid oceanic climate (Cfb), elevation ~500 m; avg. temperature ~10°C; cold winters with frost; mild summers; high rainfall (~1,154 mm/year); low solar radiation; Ardenne conditions	System experiment initiated in 2022 and implemented since 2023; aims to test mixed crop–livestock systems under organic management combining food production, climate mitigation, circularity and resilience; livestock based on grass-fed dairy crossbred calves; crops oriented toward human consumption instead of feed; strong diversification and low-input strategy	Enteric CH ₄ from cattle; N ₂ O from soils; emissions from manure storage and spreading; soil-related emissions	Increased climatic variability; higher frequency of droughts; more intense rainfall events leading to erosion; reduced forage availability in summer; heat stress in livestock; shift in grass growth seasonality; increased pest/disease pressure; soil saturation and reduced workability
Czechia	Crop farming	114.6 ha	Cereals, oilseed rape, potatoes, sugar beet	Continental climate; relatively low precipitation (~472 mm/year); strong seasonal variability; temperature-driven constraints	Experimental station located in Prague–Ruzyně; long-term experimental platform focused on soil tillage systems and crop production under changing climatic conditions; includes long-term trials established since 1995	Soil tillage emissions (CO ₂); mineral fertilizers (N ₂ O); soil carbon losses	Increasing temperatures; drought frequency; soil degradation risks; reduced yield stability
Denmark	Mixed crop–livestock (arable + pig production)	300 ha; 800 sows; 9000 finisher pigs/year; ~90 ha arable research platform	Pork production (finishers and sows), piglets, feed crops for livestock	Temperate oceanic climate (Cfb); moderate rainfall; relatively stable temperatures; sandy loam soils	Integrated crop–livestock research system combining arable production and pig systems; focuses on soil processes, manure management and feed systems; experimental platform includes CENTS and Accel trials	N ₂ O and CO ₂ from fields; CH ₄ from manure storage; major emissions from feed production and manure management (hotspots)	Extreme climatic events including flooding and summer droughts; soil structure degradation; nutrient losses; yield variability

Country	Type of farming system	Farm size / production scale	Main production	Climate and environmental conditions	Description of the experimental research station	Largest GHG emission sources	Biggest climate change impact / risk on the PioneERS
France	Livestock (dairy system)	~130 ha	Dairy milk production based on forage systems (grass, maize silage, grass silage)	Oceanic climate; ~1,200 mm rainfall/year; average temperature ~12°C; strong grass growth potential with seasonal variability	Long-term experimental farm focused on reducing GHG emissions in dairy systems since 2018; historically focused on reducing external inputs (fertilizers, concentrates); system based on forage autonomy	Enteric methane (CH ₄) from dairy cows	Climatic hazards including summer drought and winter excess rainfall; reduced forage quality and yield; altered grazing periods; seasonal imbalance in grass growth
Finland	Dairy production based on grassland systems (mixed soil types: mineral + peat)	~52 ha (average farm equivalent); ~60 dairy cows per system	Dairy milk production; silage production for feeding	Boreal climate (Df); cold winters; short growing season; strong seasonal variability; peat and mineral soils	Research platform combining grassland agronomy, peatland management and animal production; includes eddy covariance measurements and barn-scale experiments; integrates soil and livestock components	CO ₂ , N ₂ O and CH ₄ emissions from peat and mineral soils; CH ₄ from enteric fermentation; manure application emissions	Spring thaw emissions; high water table leading to peatland emissions; drought reducing biomass production; frost damage affecting vegetation growth; hydrological sensitivity
Italy	Pig farm and arable crops	75 ha in rotation and a piggery for reproduction (35–40 sows), a fattening phase (144 head units) and a growing-fattening piggery (about 400 head units)	Finished pigs, piglets and arable crops	Emilia-Romagna includes plains, hills and mountains with both continental and Mediterranean influences; in the plain where the station is located the climate is temperate subcontinental.	CREA's experimental station "Azienda Beccastecca" in San Cesario sul Panaro (Modena) covers about 75 ha of autumn-winter cereals and alfalfa used for feed production and includes pig facilities for reproduction and growing-fattening. The farm tests the influence of rearing methods and nutrition strategies on pig production efficiency, animal welfare and carcass, meat and fat quality, while also evaluating manure management, environmental	GHG emissions deriving mainly from feed (feed chain) and manure storage, NH ₃ emissions and P emissions deriving from manure	Very heavy rainfall and very high temperatures during the summer favor drought and water stress.

Country	Type of farming system	Farm size / production scale	Main production	Climate and environmental conditions	Description of the experimental research station	Largest GHG emission sources	Biggest climate change impact / risk on the PioneERS
					<i>impact and efficient use of manure.</i>		
New Zealand	Dairy production (pasture-based system)	55 ha effective; 148 cows + ~50 young stock; ~14.6 t FPCM/ha	Dairy milk production	Temperate oceanic climate; high pasture productivity; rainfall variability; mild temperatures	Commercial-scale dairy system used for experimental comparisons (current vs future farmlets); focuses on pasture-based production systems and system optimization	CH ₄ (68% – enteric); N ₂ O (~13%); CO ₂ (~20%) mainly from feed and fertilizers	Extreme weather events including storms, flooding and drought; reduced pasture growth; feed shortages; production variability
Netherlands	Crop farming (arable system)	1100 ha research station (3.1 ha experimental plot)	Potatoes, winter wheat and diversified crop rotations	Temperate maritime climate; mild winters; cool summers; avg. ~11°C; ~800 mm precipitation/year; clay soils prone to compaction	Large-scale research station in Flevoland; experimental field integrated in “Farm of the Future” system; includes controlled traffic farming and advanced soil management practices	Fertilizer production and application (CO ₂ and N ₂ O); fossil energy emissions; soil N ₂ O emissions	Excessive rainfall causing soil compaction; limited workability; drought stress; salinization risk; limited freshwater availability
Poland	Mixed	940 ha arable + pasture; 200 milking cows	Mixed systems – Dairy / Crops / Sheep	Temperate transitional climate in Wielkopolska, influenced by oceanic and continental air masses; average annual precipitation about 593 mm; warm summers, relatively mild winters, occasional frost and heatwaves; drought periods are frequent and increasingly relevant for agriculture.	Brody, PULS Research Station is located about 50 km west of Poznań and combines a 920 ha Experimental Farm with a 20 ha Research Station. The system integrates crop and animal production, including dairy cattle, beef cattle and sheep, with grazing management, feed production and dedicated research infrastructure such as long-term trials, plot experiments and animal experiments including respiration chambers.	Animal production	Drought is becoming more frequent, with increasingly long periods without rainfall that negatively affect crop yields. Weather extremes, including prolonged rainless periods and summer heatwaves, are an increasing challenge for agriculture in the region.

Country	Type of farming system	Farm size / production scale	Main production	Climate and environmental conditions	Description of the experimental research station	Largest GHG emission sources	Biggest climate change impact / risk on the PioneERS
UK	Mixed system: arable crops, pigs (indoor/outdoor), sheep pasture, woodland	205 ha arable land; 660 sows; integrated farm system	Pig production (finishers and piglets), arable crops	Temperate maritime climate; moderate rainfall; gently undulating land; no steep slopes	University research farm integrating teaching and research; hosts national Pig Centre; multidisciplinary research platform integrating biology, engineering and environmental sciences	Manure management emissions; fertilizer use; major Scope 3 emissions from pig feed production	Variable rainfall patterns; both excess rainfall and drought; soil and system sensitivity to climate variability

2. Results and comments

2.1 General description of the research design

Table 2 : Description of the research conducted in PioneERS

Country	Source of GHG, carbon sequestration or climate risk researched	Description
Belgium	Livestock farming methane emissions	Fattening of crossbred calves from dairy herds mainly based on grass (10–15% concentrates), reducing the carbon footprint of beef production by valorizing dairy-origin animals and limiting external inputs.
	Mineral fertilizers emissions	Organic farming system excludes mineral fertilizers, thereby eliminating emissions linked to their production and application and reducing dependency on external inputs.
	Whole farm system performance	Shift from feed production to food production increases system efficiency and food output per hectare while maintaining or reducing emissions per unit area.
	Soil coverage and erosion control	Implementation of diversified cover crops improves soil structure, reduces erosion, enhances biological activity and contributes to carbon sequestration and nitrogen fixation.
	Organic matter management	Increased use of organic fertilization improves soil carbon storage, enhances nutrient cycling and reduces dependency on external inputs.
	Climate resilience through diversification	Mixed crop–livestock system enhances resilience to climatic variability (drought and excess water) through diversification of production and resource flows.
Czechia	Soil tillage	Long-term field experiments (since 1995) comparing tillage systems; reduced tillage and residue retention aim to decrease CO ₂ emissions and improve soil carbon sequestration.
	Carbon sequestration	Reduced depth of tillage and retention of crop residues increase soil organic carbon stocks by several hundred kg C/ha/year.
	CO ₂ emissions from soil	Identification of critical periods of increased CO ₂ emissions under different tillage practices; monitoring under varying climatic conditions.
	CH ₄ and N ₂ O emissions	Monitoring planned using analyzers; future research to quantify methane and nitrous oxide emissions under different soil and crop management practices.
	Crop yield and quality	Assessment of sustainability of crop yields and grain quality under modified tillage and fertilization regimes to ensure economic viability.
Denmark	CO ₂ – soil organic carbon (SOC)	SOC storage potential assessed through long-term experiments (CENTS, Accel); evaluation of crop and soil management strategies including biochar through LCA approaches.

Country	Source of GHG, carbon sequestration or climate risk researched	Description
	N ₂ O emissions	Quantification of N ₂ O emissions under different cover crop strategies using field measurements; integration with LCA data from national reports and literature.
	CH ₄ emissions	Assessment of methane mitigation measures in barns and manure storage systems through LCA modelling based on external datasets and previous research.
	Soil erosion and flooding risks	Evaluation of tillage and crop rotation effects on soil structure, hydraulic properties and resistance to erosion and flooding using experimental platforms.
Finland	GHG emissions from soil (CO ₂ , N ₂ O, CH ₄)	Continuous year-round measurements on mineral and peat soils using eddy covariance techniques combined with chamber measurements; evaluation of management practices (ploughing timing, fertilization type, grass species).
	Enteric methane emissions (CH ₄)	Measurement using GreenFeed systems in experimental barns; analysis of feed composition, intake and feeding strategies; integration of results into LCA models.
	Agronomy and nutrient leaching	Plot trials and lysimeter systems used to assess nutrient leaching and interactions between productivity and emissions; integration with national inventory data.
France	Enteric methane emissions	Multiple strategies tested: substitution of soybean meal, use of feed additives, optimization of forage quality, reduction of non-productive animals and improved herd management.
	Carbon sequestration	Improvement of crop rotations, implementation of hedgerow management plans and agroforestry systems to enhance carbon storage.
	Reduction of inputs	Long-term reduction of mineral nitrogen and concentrate use; promotion of legume-rich systems to enhance nitrogen autonomy and reduce emissions.
Italy	Climate risk: soil compaction	Controlled traffic farming, improved soil management and optimized crop rotations to reduce compaction and maintain soil structure and productivity.
	Climate risk: drought stress	Implementation of underground water storage systems capturing drainage water in winter for reuse during dry periods; evaluation of irrigation resilience.
	GHG emissions: fuel use	Reduced tillage and improved soil conditions reduce fuel consumption and associated CO ₂ emissions.
	Feed production and transportation	Pig feed represents a major emission source, contributing 26% to 68% of the pork industry's carbon footprint, mainly through fertilizer use, fossil fuels in cultivation and land use change. The Italian PioneERS therefore proposes the use of local varieties of cereals with a high protein level, especially barley and sorghum, to replace maize and soybean in pig diets.
	Pig feed	If the pig's diet is not properly balanced, it can lead to excessive use of crude protein (CP) and phosphorus (P). Precision feeding is proposed as a mitigation strategy in order to reduce nitrogen and phosphorus excretion.

Country	Source of GHG, carbon sequestration or climate risk researched	Description
	GHG emissions: fertilizer production and use	Reduction of fertilizer inputs and improvement of nitrogen use efficiency through optimized fertilization strategies and precision tools.
	Pig feed	Heavy pig rations contain a significant amount of off-farm purchased raw materials, creating strong dependence on market price fluctuations. The use of local feed resources is proposed as a mitigation strategy to increase on-farm feed production and reduce dependency on purchased feed.
Netherlands	Climate risk: soil compaction	Soil compaction results in several issues in arable farming, such as a limited root development, limited nutrient uptake, increased drought and oxygen stress, and a reduction in working days. The field trial aims to have very good soil quality with limited soil compaction, by applying controlled traffic farming, working under the right circumstances and having a crop rotation which supports soil quality.
	Climate risk: drought stress	With a reduction of precipitation because of a changing climate, the need for water to irrigate fields increases. At the same time, water availability for irrigation is reduced, and salinization is a growing issue. By implementing an underground water storage facility that harvests water out of drainage tubes during winter and stores this until summer, the water availability for irrigation is increased.
	GHG emission: fertilizer production and application	The production and application of fertilizers are amongst the highest sources of GHG emissions in arable farming. By reducing the input of fertilizer and increasing the efficiency of the applied fertilizers, GHG emissions can be reduced.
	GHG emission: fuel combustion	Fuel combustion is an important source of CO ₂ emissions in arable farming. By having a good soil quality and applying reduced tillage, fuel usage is potentially reduced as soil cultivation requires less energy.
New Zealand	CH ₄	Enteric methane is the largest source of GHG emissions in pasture-based dairy systems. Research focuses on the feed, cow, and farm system. As pasture makes up around 80% of the diet, feed-related research aims to improve pasture production and quality through management and species selection, and to assess the targeted use of supplementary feeds at certain times of the year that may reduce methane and GHG intensity. Cow-related research focuses on breeding programmes to improve genetic merit and feed conversion efficiency, as well as calving and

Country	Source of GHG, carbon sequestration or climate risk researched	Description
		<p>breeding strategies to optimise days in milk and seasonal production.</p> <p>System levers include stocking rate and fertiliser, which must be balanced to maintain or improve pasture growth and utilisation, while minimising cow maintenance requirements and improving overall farm efficiency.</p> <p>Where possible, the GreenFeed system will be used to directly measure methane emissions, and modelling, including life cycle assessment (LCA), will be used to estimate methane output at the farm level. At present, there are no methane mitigation technologies, such as feed additives or vaccines, that are readily adoptable on-farm in NZ, so the effect of any promising technologies will need to be modelled to provide insight into their potential future impact on farm GHG.</p>
	N2O	<p>Nitrous oxide contributes ~ 15% of total GHG emissions in pasture-based dairy systems. Research is primarily focused on nitrogen fertiliser type, rate, and application strategy, and use of low-N supplementary feed to meet cow requirements. Any reductions in nitrogen input will be incorporated into the LCA to evaluate effects on whole-farm emissions.</p>
	CO2	<p>Soil organic carbon storage is already very high in NZ soils, so opportunity to increase stores is limited.</p> <p>CO2 contributes ~20% of total GHG emissions in pasture-based dairy systems, and this is primarily due to supplementary feed and fertilizer use. Thus, research will focus on supplementary feed, and fertilizer use, balancing the trade off from loss of production with reductions in CO2 emissions. CO2 reductions will be modelled using the LCA to estimate whole-farm emissions.</p>
	Risk of drought and flooding	<p>Evaluation of alternative pasture species (e.g., plantain/clover) may fill a feed deficit due to summer/autumn droughts.</p> <p>Alternatively, if pasture growth/quality is reduced, supplementary feed with low-embedded emission may enable more to be fed with less effect on GHG emissions.</p>
Poland	Enteric methane (CH ₄)	<p>Research on feed composition, pasture management, cow genetics and system design; measurement using GreenFeed and modelling via LCA; focus on pasture-based systems.</p>

Country	Source of GHG, carbon sequestration or climate risk researched	Description
	Nitrous oxide (N ₂ O)	Optimization of fertilizer type, rate and application; evaluation of low-N supplementary feeds; integration into whole-farm LCA modelling.
	Climate risks: drought and flooding	Evaluation of alternative pasture species (e.g. plantain/clover) and supplementary feeding strategies to maintain productivity under climate stress.
	Dairy Production	Livestock are a significant source of greenhouse gas emissions, but modifying dairy cow diets may reduce this impact. The Polish PioneERS investigates the partial replacement of soybean with locally available rapeseed products (oil cake or meal). Emissions will be assessed in dairy cows using respiration chambers, allowing precise quantification of greenhouse gas emissions and evaluation of the effectiveness of the feeding strategy.
	Crop production – soil tillage	Soil tillage contributes to greenhouse gas emissions in crop production. The Polish PioneERS will compare conventional full-field tillage with strip-till systems, monitoring plant growth, yield, yield components and greenhouse gas emissions to determine whether strip-till can reduce emissions without compromising productivity.
	Carbon dioxide (CO ₂)	Reduction through optimization of feed systems and fertilizer use; assessment of trade-offs between production and emissions.
	Fertilizer	The Polish PioneERS will assess how integrating a biogas plant into the crop–livestock system may reduce emissions by converting manure into energy and using digestate as fertilizer. Digestate-based fertilization will be compared with manure and conventional fertilization in order to quantify greenhouse gas emissions and carbon footprint effects at field and farm-system scale.
UK	Pig feed (Scope 3 emissions)	Research on low-emission feeds, alternative feed sources and local feed production; evaluation of full supply chain emissions.
	Manure management	Experimental trials on rapid slurry removal, pit washing and potential anaerobic digestion; assessment of emissions and nutrient circularity.
	Renewable energy	Integration of solar panels, wind turbines and future anaerobic digestion to reduce fossil energy use and emissions.
	Fertilizer use	Optimization of fertilizer types and timing; integration of organic fertilizers; assessment of emissions and nutrient efficiency.
	Regenerative agriculture	Evaluation of combined practices (minimum tillage, grazing integration, cover crops) to enhance soil carbon sequestration and resilience.

The overview of research designs across the PioneERS ClimAP shows system-based approaches, moving beyond single-factor experimentation toward holistic evaluation of agricultural systems. For example, Poland illustrates this systems approach through the integration of dairy production, crop production and a biogas unit within the same experimental platform. Italian ClimAP links feed sourcing, diet formulation, manure-related emissions and crop production.

A first key finding is the central role of soil processes across all sites. Carbon sequestration, soil organic matter dynamics, and nitrogen cycling are addressed through diverse management strategies such as reduced tillage (Czechia), cover crops (Denmark, Belgium), agroforestry (France), regenerative practices (UK)... This convergence demonstrates that soil management is not only a mitigation lever but also a critical component of system resilience (and ecosystem services).

Secondly, the analysis highlights the importance of livestock-related emissions, particularly enteric methane, in dairy and mixed systems (France, Finland, New Zealand, Belgium, Poland). Research efforts converge on feed optimization, genetic improvement, and system-level adjustments but also production shift (suckler beef to dairy beef in Belgium PioneERS). The widespread use of measurement technologies (e.g. GreenFeed) and modelling approaches (LCA) indicates a shift toward quantitative, data-driven mitigation strategies. This will be covered in detail in the measurement plans due by may 2026 for each PioneERS.

Thirdly, input reduction and efficiency improvement emerge as cross-cutting priorities. Nitrogen use efficiency is a central research objective in all countries ClimAP. These strategies target both direct emissions (N₂O) and indirect emissions associated with input production (CO₂).

Another major trend concerns the integration of adaptation strategies within mitigation-oriented research designs. Climate risks such as drought, flooding and soil degradation are addressed through innovative solutions including water storage infrastructure (Netherlands), diversified crop rotations (Denmark, Belgium, Czechia), and alternative pasture systems (New Zealand, France). This demonstrates a clear shift toward climate-resilient system design rather than isolated mitigation measures.

The analysis also reveals the increasing importance of international and comparable Life Cycle Assessment (LCA) as a common evaluation framework. LCA are already widely used on PioneERS and enables the comparison of different practices and systems by accounting for both direct and indirect emissions, as well as trade-offs between environmental, technical and economic performance. However, differences remain in the availability of data, availability of tools, precision of models and emission factors for local inputs and the maturity of experimental systems. It will be addressed during the first annual evaluation of the impact due by the end of 2026 summer.

Overall, Table 2 demonstrates that the PioneERS are collectively implementing integrated climate-smart agricultural solutions, where mitigation and adaptation are addressed simultaneously through systemic innovation.

2.2 ClimAP research questions

Table 3 : ClimAP research questions

<i>Country</i>	<i>ClimAP research questions</i>	<i>Short Description of implementation</i>	<i>Objective</i>	<i>Expected Climate Impact</i>
<i>Belgium</i>	<i>Does mixed crop–livestock system allow moving toward climate neutrality?</i>	<i>System-level experiment combining crops and livestock under organic management</i>	<i>Evaluate system-level performance</i>	<i>Up to -60% GHG emissions vs conventional</i>

Country	ClimAP research questions	Short Description of implementation	Objective	Expected Climate Impact
	<i>Is grass-based fattening of dairy crossbred calves feasible?</i>	<i>Pasture-based fattening with limited concentrates</i>	<i>Maintain productivity with low inputs</i>	<i>Reduced emissions compared to conventional beef</i>
	<i>How to optimize manure management within the system?</i>	<i>Internal recycling of manure nutrients</i>	<i>Improve nutrient cycling</i>	<i>Reduced external inputs and emissions</i>
	<i>How to maximize food production in low-input systems?</i>	<i>Diversified crop rotation and system design</i>	<i>Maintain productivity</i>	<i>Reduced emissions per unit product</i>
Czechia	<i>To what extent can CO₂ emissions from soils be reduced?</i>	<i>Field trials with different soil tillage practices</i>	<i>Quantify tillage effects</i>	<i>Reduced soil CO₂ emissions</i>
	<i>What is the effect of cover crops and mulch?</i>	<i>Field trials measuring CO₂, soil temperature and water</i>	<i>Improve soil conditions</i>	<i>Reduced emissions, improved water retention</i>
	<i>What is the effect of mineral fertilizers on yields?</i>	<i>Yield and quality monitoring</i>	<i>Maintain crop productivity</i>	<i>Sustainable yields</i>
	<i>What are benefits and risks of reduced tillage?</i>	<i>Comparative system analysis</i>	<i>Identify trade-offs</i>	<i>Increased carbon sequestration</i>
Denmark	<i>How much can cover crop biomass be increased?</i>	<i>Early establishment trials</i>	<i>Increase biomass input</i>	<i>Increased soil carbon</i>
	<i>Climate effect of harvesting cover crops for biogas?</i>	<i>Field trials + N₂O measurements</i>	<i>Evaluate trade-offs</i>	<i>Reduced N₂O, energy production</i>
	<i>Impact of grain legumes in rotations?</i>	<i>Inclusion of faba bean</i>	<i>Replace imported soy</i>	<i>Reduced GHG emissions</i>
	<i>Impact of high biomass crops?</i>	<i>Rotation experiments</i>	<i>Increase SOC</i>	<i>Improved resilience</i>
	<i>Impact of pig productivity improvements?</i>	<i>Farm data + LCA</i>	<i>Increase efficiency</i>	<i>Reduced emissions per kg product</i>
	<i>Impact of improved manure storage?</i>	<i>LCA modelling</i>	<i>Reduce CH₄ emissions</i>	<i>Significant mitigation</i>

Country	ClimAP research questions	Short Description of implementation	Objective	Expected Climate Impact
France	<i>How to increase the proportion of grasslands in the system ?</i>	<i>increase in grazing platform (grazeable area per cow)</i>	<i>Increase carbon storage and limit inputs</i>	<i>increase carbon storage</i>
	<i>How to increase production per cow?</i>	<i>comparing two types of rations over the course of a complete lactation allowing for high levels of production; assess balance between production/health/fertility and production.</i>	<i>Reduce the carbon footprint by increasing production per cow</i>	<i>Reduce the carbon footprint per liter</i>
	<i>How to implement Agroforestry to increase soil organic carbon?</i>	<i>monitoring the impact of agroforestry on a plot in rotation</i>	<i>Increase carbon storage</i> <i>Understand the impact on yields</i>	<i>increase carbon storage</i> <i>impact on welfare</i>
New Zealand	<i>What is the effect of cow, feed and system changes on methane emissions?</i>	<i>Farmlet comparison (current vs. future) with different feed, cow and system factors. Measured via GreenFeed systems (herd level) and modelled using LCA at the farm level.</i>	<i>Quantify effect of feed, cow and system levers on methane emissions.</i>	<i>Reduced enteric methane emissions and greater production will reduce total GHG emissions and emissions per kg FPCM</i>
	<i>What is the effect of altered fertilizer use (type, amount and regime) on N2O emissions?</i>	<i>Farmlet comparison (current vs. future) with different N inputs (fertilizer and feed) Modelled using LCA at the farm level.</i>	<i>Quantify effect of altered N fertiliser type, amount and application and tailored use of supplementary feed on N input and N2O emissions.</i>	<i>Reduced N inputs will reduce N2O, ultimately reducing total GHG emissions. Impact on production may reduce effect on emissions intensity.</i>
	<i>What is the effect of reduced supplementary feed with high embedded emissions (e.g., PKE) on associated CO2 emissions</i>	<i>Farmlet comparison (current vs. future) with different types of supplementary feed (PKE vs. non-PKE). Modelled using LCA at the farm level.</i>	<i>Compare the use of non-PKE feed source with PKE to evaluate the benefit from reduced embedded</i>	<i>Reduced GHG emissions due to less embedded CO2 typically associated with use of PKE</i>

Country	ClimAP research questions	Short Description of implementation	Objective	Expected Climate Impact
			CO2 emissions.	
	<i>What is the effect of altered pasture management, reduced N fertilizer and stocking rate on pasture grown and harvested?</i>	<i>Farmlet comparison (current vs. future) measuring pasture growth and utilization at paddock level.</i>	<i>Evaluate the effect of pasture management and system changes (e.g., SR and Fert use) on pasture grown and harvested.</i>	<i>Greater homegrown feed eaten, will result in greater production from less inputs (\$ and carbon)</i>
	<i>What is the effect of greater genetic merit on productivity and GHG emissions?</i>	<i>Farmlet comparison (current vs. future) measuring production (FPCM) and feed eaten by cows of divergent genetic merit</i>	<i>Evaluate the effect of cow genetic merit on production, FCE (at the herd level) and GHG emissions.</i>	<i>Greater GM cows will have greater FCE and lower maintenance requirements (more milk from less feed/emissions)</i>
	<i>What is the effect of cow selection for low-methane emissions?</i>	<i>Cow methane measured using PAC and herd divergence understood</i>	<i>Determine the divergence and potential gains if cows were selected for low-methane emissions</i>	<i>Cows that are naturally lower methane emitters will have similar production for less emissions</i>
	<i>What is the effect of potential technologies (e.g., ecopond) on GHG emissions?</i>	<i>Modelled using LCA to determine effect of potential technologies (e.g. ecopond and ruminant biotech bolus) on GHG emissions</i>	<i>Determine effect of technologies on farm GHG emissions (via modelling)</i>	<i>Reduced GHG emissions via uncoupling methane/DMI relationship to reduce methane emissions with no reduction in productivity.</i> <i>Capture manure methane from system</i>
<i>Finland</i>	<i>Role of legumes in grass mixtures?</i>	<i>Field trials comparing mixtures</i>	<i>Reduce fertilizer use</i>	<i>Reduced N₂O emissions</i>

Country	ClimAP research questions	Short Description of implementation	Objective	Expected Climate Impact
	<i>Effect of ploughing timing on peatland?</i>	<i>Field experiments</i>	<i>Optimize emissions balance</i>	<i>Reduced N₂O emissions</i>
	<i>Impact of water table on emissions?</i>	<i>Controlled field experiments</i>	<i>Quantify dynamics</i>	<i>Reduced CO₂/N₂O but ↑ CH₄</i>
	<i>Impact of unmanaged peatland?</i>	<i>Natural state comparison</i>	<i>Baseline assessment</i>	<i>Lower emissions</i>
	<i>Mineral vs organic fertilization?</i>	<i>Field comparison</i>	<i>Optimize inputs</i>	<i>Reduced emissions</i>
	<i>Effect of fertilization rate?</i>	<i>Plot trials</i>	<i>Optimize yield/emissions</i>	<i>Improved efficiency</i>
	<i>Increase legumes in diet?</i>	<i>Feeding trials</i>	<i>Reduce fertilizer use</i>	<i>Lower N₂O emissions</i>
	<i>Impact of irrigation?</i>	<i>Irrigation trials</i>	<i>Increase yield</i>	<i>Improved resilience</i>
	<i>Effect of delayed fertilization?</i>	<i>Timing experiments</i>	<i>Reduce N₂O</i>	<i>Lower emissions</i>
Italy	<i>Increase grassland proportion?</i>	<i>Expand grazing platform. Long term expectation, starting last years of CSR.</i>	<i>Increase carbon storage</i>	<i>Carbon C sequestration. Improve milk net carbon footprint.</i>
	<i>Agroforestry impact?</i>	<i>Monitoring plots. Long term expectation, starting last years of CSR.</i>	<i>Increase carbon storage</i>	<i>Increased C sequestration. Improve milk net carbon footprint.</i>
	<i>Can low emissions pig feeds reduce the emissions from pig production?</i>	<i>Trials of feed formulated to reduce emissions, investigating local feed production and alternative feeds (including the Soppeso regional project and other regional projects under evaluation).</i>	<i>To reduce emissions of heavy pig production</i>	<i>Reduction of GHG emissions per unit of product and reduction of NH₃ emissions per unit of product.</i>
	<i>Can low P content in the diet reduce eutrophication from pig production?</i>	<i>Trials of feed formulated to reduce phosphorus content (P_I_G – "Innovative Phosphorus</i>	<i>To reduce P excretion without losses in animal</i>	<i>Reduction of P emissions (eutrophication) per unit of product.</i>

Country	ClimAP research questions	Short Description of implementation	Objective	Expected Climate Impact
		<i>Management on the Pig Farm, from Feed to Field”, regional project).</i>	<i>performance or skeletal development in heavy pigs produced at 165–175 kg live weight at nine months and over.</i>	
Netherlands	<i>Reduce GHG through extended crop rotation & cover cropping strategies?</i>	<i>Combined system trial</i>	<i>Optimize nitrogen use</i>	<i>Reduced emissions</i>
	<i>Use of nitrogen sensors?</i>	<i>Sensor-based fertilization</i>	<i>Improve NUE</i>	<i>Reduced N inputs</i>
	<i>Potential of foliar fertilizers?</i>	<i>Legume-based fertilization</i>	<i>Reduce inputs</i>	<i>Lower emissions</i>
	<i>Underground water storage potential?</i>	<i>Infrastructure testing</i>	<i>Improve resilience</i>	<i>Increased adaptability</i>
	<i>Effect of controlled traffic farming?</i>	<i>Field trials</i>	<i>Reduce compaction</i>	<i>Reduced emissions</i>
Poland	<i>Effect of system changes on methane?</i>	<i>Farmlet comparisons + modelling</i>	<i>Quantify CH₄ drivers</i>	<i>Reduced methane emissions</i>
	<i>Effect of fertilizer use changes?</i>	<i>LCA modelling</i>	<i>Reduce N inputs</i>	<i>Lower N₂O emissions</i>
	<i>Effect of reducing high-emission feed?</i>	<i>Feed trials</i>	<i>Reduce CO₂</i>	<i>Lower emissions</i>
	<i>Effect of pasture management?</i>	<i>Farmlet monitoring</i>	<i>Improve efficiency</i>	<i>Lower emissions</i>
	<i>Effect of genetic merit?</i>	<i>Herd comparison</i>	<i>Improve productivity</i>	<i>Lower emissions intensity</i>
	<i>Impact of new technologies?</i>	<i>LCA modelling</i>	<i>Evaluate mitigation</i>	<i>Reduced emissions</i>
	<i>How will replacing soybean with rapeseed-based products affect</i>	<i>An experiment will be conducted using dairy cows fed a modified</i>	<i>Reduction of greenhouse gas emissions</i>	<i>Reduction of methane emissions from cows;</i>

Country	ClimAP research questions	Short Description of implementation	Objective	Expected Climate Impact
	greenhouse gas emissions and productivity?	rapeseed-based diet and compared with a control group receiving a standard diet. Emissions will be assessed using respiration chambers together with additional productivity parameters.	in milk production	reduction of the feed carbon footprint
	How will changing the tillage system (strip-till) affect greenhouse gas emissions and crop yields?	A field experiment will compare conventional full-field tillage with strip-till systems. Plant growth will be monitored during the growing season, with yield, yield components, modelling parameters and greenhouse gas emissions measured.	Assessment of how strip-till cultivation affects yield and greenhouse gas emissions	Strip-till cultivation reduces emissions without affecting yield.
	How will the introduction of digestate into fertilization affect the reduction of greenhouse gas emissions in crop production and across the entire farm system?	Manure will be processed in the biogas plant and the resulting digestate will be applied as fertilizer. Digestate fertilization will be compared with manure and conventional fertilization, and the carbon footprint and greenhouse gas emissions of each system will be calculated.	Assessment of how greenhouse gas emissions decrease after integrating a biogas plant into the field–livestock–field system.	Reduction of greenhouse gas emissions
	Selection of low-methane cows?	Measurement + modelling	Reduce CH ₄	Lower emissions
	How will changes in the entire field–livestock–biogas system affect the overall greenhouse gas emissions of the farm?	All Polish experiments will be integrated into a comprehensive system assessment in order to evaluate the contribution of the tested practices to reducing the farm's overall greenhouse gas emissions.	Reduction of total greenhouse gas emissions from the farm	Reduction of greenhouse gas emissions
UK	Can rapid slurry removal reduce emissions?	Barn trials	Reduce CH ₄	Lower emissions

Country	ClimAP research questions	Short Description of implementation	Objective	Expected Climate Impact
	<i>Can pit washing reduce emissions?</i>	<i>Experimental trials</i>	<i>Improve slurry quality</i>	<i>Reduced emissions</i>
	<i>Do regenerative practices improve resilience?</i>	<i>Field trials</i>	<i>Improve soil health</i>	<i>Reduced emissions</i>
	<i>Can low-emission pig feed reduce emissions?</i>	<i>Feed trials</i>	<i>Reduce Scope 3</i>	<i>Lower emissions</i>
	<i>Can alternative fertilizers reduce emissions?</i>	<i>DEFRA trials</i>	<i>Optimize fertilization</i>	<i>Reduced emissions</i>
	<i>Can better manure use reduce emissions?</i>	<i>Application trials</i>	<i>Improve nutrient use</i>	<i>Reduced emissions</i>
	<i>Can farm energy be self-generated?</i>	<i>Renewable energy trials</i>	<i>Reduce CO₂</i>	<i>Limited impact</i>
	<i>Impact of anaerobic digestion?</i>	<i>Feasibility studies</i>	<i>Reduce emissions</i>	<i>Significant reduction</i>
	<i>Will restoring hedges increase carbon?</i>	<i>Field restoration</i>	<i>Increase sequestration</i>	<i>Minor impact</i>

The compilation and summary of research questions across the PioneERS shows three core transformation pathways: (i) optimization of biogeochemical cycles, particularly nitrogen and carbon, (ii) reduction of enteric methane emissions in livestock systems, and (iii) systemic redesign of production systems to enhance resilience and reduce dependency on external inputs.

Nitrogen management is a cross-cutting research priority in the 10 ClimAP. Numerous research questions explicitly target nitrogen use efficiency (Netherlands, New Zealand), fertilizer optimization (Finland, Denmark), or substitution through legumes (Finland, Denmark, Belgium). This reflects the dual importance of nitrogen as both a productivity driver and a major source of nitrous oxide emissions. The convergence toward legume integration and precision fertilization highlights a transition toward biologically regulated and data-driven nutrient management systems.

Methane mitigation is a dominant research theme in livestock systems, dairy, beef and mixed systems (France, Finland, New Zealand, Belgium). Approaches combine feed strategies, genetic selection, and system-level adjustments, indicating that methane reduction cannot rely on a single technological solution but requires multi-level strategies integrated at animal, feed and system levels. Feed additives could be a priority or a major brake for various countries depending of the overall farmer and customer acceptance of those solutions.

The summary of research question addressed in the ClimAP highlights a strong predominance of system-level experimentation and redesign. Belgium's whole-system agroecological approach, Denmark's rotational innovations, and the UK's integration of manure, energy and feed systems illustrate a move away from isolated practices toward holistic system optimization. This systemic perspective within the research question is essential for identifying trade-offs, such as those between productivity and emissions, or between different emission sources.

The analysis also highlights the presence of significant trade-offs and uncertainties. Many research questions explicitly acknowledge risks related to productivity (Belgium, New Zealand), economic feasibility (Denmark, Netherlands), or operational constraints (Finland, UK). These trade-offs underline the importance of using tools such as Life Cycle Assessment (LCA) to evaluate net impacts across multiple indicators. Those indicators must include ecosystem services. It will be addressed in the following MS3.4 PioneERS first evaluation of the impacts due in month 15.

This table highlights that the ClimAPs are not collections of isolated measures but constitute coherent research agendas addressing systemic transformation, aligned with the objectives of achieving climate neutrality and climate resilient farming systems in Europe.

2.3 Innovative character of the implemented solutions

Table 4 : Innovative character of the implemented solutions

Country	Measure / Practice	Description of the innovative character
Belgium	Fattening of crossbred calves from dairy farms	Grass-based fattening of dairy crossbred calves is uncommon; valorizes a by-product of dairy systems and reduces reliance on specialized beef systems with higher emissions.
	Diversified cover crops	Rare in Ardenne region due to climatic constraints; improves soil fertility, reduces erosion and enhances resilience.
	Conversion to organic farming	Uncommon in the region, especially for food-oriented production systems; reduces dependency on synthetic inputs.
	Flexible use of temporary grassland	Grassland introduced only when agronomically required rather than systematically, improving system adaptability.
	Diversified crop rotation (cereals, legumes, vegetables, oilseed rape)	Strong diversification in a region dominated by permanent grassland; enhances resilience and food production capacity.
	Oat–pea and spelt–lentil mixtures	Rare crop associations in Belgium; improve nitrogen fixation and system diversity.
	Recycled fertilizers (bone meal, blood meal)	Innovative nutrient sources; debated due to cost and farmer acceptance but contribute to circularity.
Czechia	Optimized mineral fertilization	Integration of precision agriculture techniques to improve efficiency and reduce environmental impact.
	Cover crops	Increasing adoption of regenerative practices; dissemination through advisory systems and farmer networks.
	Reduced soil tillage	Combination of conventional and conservation practices adapted to climatic and agronomic conditions.
Denmark	Improved cover crop systems	Optimization of species mixtures and early establishment to maximize biomass production and carbon inputs.
	Introduction of perennial crops in rotations	Integration of multi-annual crops into cereal systems to enhance carbon storage and resilience.
	Increased use of legumes	Reduction of imported protein (soy) and enhancement of biological nitrogen fixation within systems.
	Improved winter cereal systems	Combination of no-till practices and cover crops to improve soil structure and reduce emissions.
Finland	Delayed second fertilization event	Novel fertilization timing to reduce N ₂ O emissions and improve nitrogen efficiency.
	Irrigation during drought periods	Adaptive measure to maintain biomass production under increasing drought conditions.
	Legume-based forage systems	Replacement of mineral fertilizers through biological nitrogen fixation.

Country	Measure / Practice	Description of the innovative character
	Reduced tillage depth	Proposed practice to maintain soil structure and reduce emissions.
	Reduced renewal frequency of grasslands	Optimization of grassland lifecycle to minimize emissions and disturbance.
	Precision farming and crop diversification	Integration of diverse crop mixtures and precision nutrient management tools.
	Legume-rich forage systems	Replacement of nitrogen fertilizers through clover-rich systems; improves forage quality and reduces emissions.
France	Maximise milk production with limited inputs	Must be performed while respecting environment (limiting negative impacts), economics, animal welfare (limiting negative impacts on fertility and health, and human welfare (improving working conditions or reducing working time)
	Implement legume rich short-term meadows in summer to improve summer grass quality	Grazing few hours per day in summer to replace part of nitrogen concentrate by legumes (paddocks rich in clovers that go on growing in summer even in case of drought)
Italy	Phase feeding of pigs (per fattening pig/year)	Precise feeding is used to adjust crude protein content and reduce nitrogen excretion through free amino acid supplementation. The innovation lies in molecular precision: delivering the exact amino acid profile at the right time to reduce both metabolic and environmental waste.
	Phase feeding of pigs (per fattening pig/year)	Reduction of phosphorus excretion through the use of phytase enzyme. The innovation lies in moving from passive phosphorus management based on added inorganic phosphorus to active and targeted management that releases the phosphorus already present in plant ingredients.
	Replace imported protein supplements with regional proteins (soybeans with peas or rapeseed)	Use in the diet of high-protein cereal varieties such as barley and sorghum in order to maintain excellent pig performance while replacing maize and soybean, the main ingredients traditionally used in pig feeding.
	Maximizing milk production with reduced inputs	Balancing productivity, environmental impact, animal welfare and economic viability.
	Reduction of the use of feed purchased from feed mills	This reduces farmers' dependence on feed purchased from outside the farm through the use of locally produced barley and sorghum, strengthening feed autonomy and regional circularity.
Netherlands	Underground water storage systems	Innovative infrastructure storing winter drainage water for reuse during drought periods; enhances resilience.
	Controlled traffic farming (CTF)	Reduction of soil compaction through regulated machinery traffic; still limited adoption in practice.
	Reduction of synthetic nitrogen inputs	Achieving high nitrogen use efficiency (>90%) through optimized fertilization strategies.
	Legume-based fertilization systems	Replacement of synthetic fertilizers with biological nitrogen sources; innovative but economically uncertain.
New Zealand	Grow more homegrown feed	Farmers and stakeholders provided feedback on proposed changes to cow, feed and system. There was agreement on

Country	Measure / Practice	Description of the innovative character
		<p>increasing homegrown feed, with general agreement on slightly higher stocking rate, and more focused/automated pasture management.</p> <p>There were mixed views on the use of alternative pasture species and crops, due to poor establishment previously.</p>
	Optimize use of supplementary feed	Mixed thoughts on use of alternatives to PKE due to cost increases, and uncertainty on response in GHG emissions.
	Optimise use of fertiliser	General agreement to use optimal fertilizer amount, type and application, but this requires more input from external experts.
	Greater cow genetic merit	Farmers and stakeholders agreed that genetic gain was important for a profitable system as well as reducing emissions.
	Select low-methane cows	Agreement to measure methane from both herds (Future and Current) to understand variation and potentially select/model low-emitting animals for the future herd.
	Implement new technologies	Agreement on modelling potential technologies
Poland	Increased reliance on homegrown feed	Optimization of pasture-based systems to reduce external inputs and emissions.
	Optimization of supplementary feed	Replacement of high-emission feeds (e.g. palm kernel expeller) with lower-emission alternatives.
	Improved fertilizer management	Reduction and optimization of nitrogen inputs.
	Improvement of cow genetic merit	Enhancement of productivity and feed conversion efficiency.
	Implementation of new technologies (e.g. EcoPond)	Testing and modelling of innovative technologies for emission reduction.
	Selection of low-methane cows	Emerging innovation based on genetic variability in methane emissions.
UK	Low-emission pig feed strategies	Development of alternative feed sources with reduced supply-chain emissions (Scope 3).
	Advanced slurry management techniques	Rapid slurry removal, pit cleaning, aeration, cooling and acidification to reduce methane emissions.
	Feed additives for pigs	Emerging mitigation strategy; less developed compared to ruminant systems.
	Optimized manure application	Application based on crop nutrient demand rather than storage constraints.
	Alternative fertilizers and inhibitors	Testing novel fertilizers and emission-reducing additives (e.g. CCM pellets).
	Renewable energy systems	Integration of solar, wind and potentially anaerobic digestion into farm energy systems.

Country	Measure / Practice	Description of the innovative character
	Regenerative agriculture practices	Combination of minimum tillage, cover crops and grazing to improve soil health.
	Anaerobic digestion (AD)	Potential full-farm integration to valorize slurry and reduce emissions.

The consolidated analysis of the ClimAP solutions highlights the increasing importance of precision agriculture and optimization strategies. These innovations represent a transition toward data-driven decision-making, where inputs are adjusted dynamically based on system needs.

Another innovation axis concerns livestock system transformation. These approaches demonstrate that reducing emissions in livestock systems requires integrated interventions across feed, animal and manure subsystems from livestock management optimization to enteric fermentation chemical inhibitors.

Another result to stress is the emergence of infrastructure-based innovations, particularly in the Netherlands (water storage) and the UK (renewable energy and anaerobic digestion). These solutions extend beyond field-level practices and require investment, coordination and integration at farm or territorial scale, highlighting the importance of systemic innovation.

However, the table also highlights important limitations and uncertainties of those innovative solutions. Some innovations remain economically uncertain (e.g. legume-based fertilization, alternative feeds), while others require significant investment (e.g. infrastructure solutions). Additionally, adoption barriers related to labour, knowledge and risk perception remain significant. It will be a major focal point for SG and FG of all PioneERS to discuss acceptability and major breaks to the implementation of the cutting-edge solutions tested.

Finally, the diversity of innovations across the PioneERS confirms that no single solution can address the complexity of agricultural emissions and climate risks. Instead, the transition toward climate-smart agriculture relies on a list/catalogue of complementary practices, adapted to local conditions but sharing common principles of efficiency, circularity and resilience.

Overall, Table 5 highlights that the ClimAPs are not only testing technical solutions but are actively contributing to the development of integrated, co-constructed and scalable innovation pathways, fully aligned with the objectives of other project such as ClieNFarms, Pathways, Climate Smart Advisers or Climate Farm Demo.

3. Conclusion on the first version of the PioneERS ClimAP

The collective work of CSR WP3 regarding ClimAP during the first months of the project highlights a need to update and discuss within PioneERS the research that are currently implemented/in current implementation/or future implementation. There are a lot of synergies to be found.

The measures implemented across the PioneERS demonstrate a strong innovative character through the combination of system redesign, technological optimisation, and agroecological principles, rather than relying on single, isolated interventions. A key innovation lies in the shift toward integrated, whole-farm approaches which reconnects crop and animal production to enhance circularity and reduce external inputs. This systemic redesign contrasts with conventional specialised systems and enables simultaneous gains in productivity, resilience and emission reduction. Another major innovative aspect described in the 10 ClimAP is the use of biological processes to replace synthetic inputs, particularly through the integration of legumes in crop rotations and forage systems. Technological innovation is also prominent, especially in the field of precision agriculture and data-driven management. Infrastructure-based solutions further extend the innovation landscape beyond field practices. The implementation of underground water storage systems represents a novel adaptation strategy, allowing farms to buffer climatic variability by storing winter water for summer use and securing yields level. The integration of anaerobic digestion and renewable energy systems illustrates how farms can transition toward circular energy systems while reducing emissions.

Importantly, the choice of innovations to be tested have been co-constructed with farmers and stakeholders, increasing their practical relevance and scalability and following a common framework (described in D1.1). This participatory approach, observed across all PioneERS, allows farmers to actively shape the design and testing of solutions on the experimental station.

Overall, those first versions of ClimAP of the 10 PioneERS illustrates their ability to combine agroecological, technological and systemic innovations into coherent, context-specific pathways, demonstrating that climate-smart agriculture requires integrated and adaptable solutions rather than single technical solutions.



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