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AgriDataValue

Smart Farm and Agri-environmental Big Data Value

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Agri-climate monitoring methods & resilience models V1

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Abstract	Climate change significantly impacts agriculture, causing unpredictable weather patterns like droughts, floods, and storms. These changes alter growing seasons and increase pest and disease distribution, necessitating urgent adaptation in agricultural practices. Evaluating agro-climatic indicators such as temperature, precipitation, and soil moisture is crucial for informed decision-making in land management, crop selection, and harvest planning. Soil health is threatened by climate change through increased erosion, nutrient depletion, and changes in soil moisture. Implementing soil conservation practices like cover cropping and reduced tillage can mitigate these impacts. The European Union's Common Agricultural Policy (CAP) supports farmers, improves productivity, and ensures a stable food supply while addressing climate change and managing natural resources sustainably. The new CAP framework includes objectives like enhancing biodiversity, reducing greenhouse gas emissions, and promoting renewable energy. Direct payments are linked to environmentally friendly practices, incentivizing sustainable farming methods. Developing and implementing adaptation strategies to enhance agricultural resilience is essential. Continuous monitoring and adjustment of these strategies are key to addressing the evolving impacts of climate change.

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Definitions, Acronyms and Abbreviations

CAP	Common Agricultural Policy
ADV	AgriDataValue
AES	Agro-Environmental Systems
BT	Brightness Temperature
CART	Classification and Regression Trees
CFSV2	Climate Forecast System Version 2
CH4	Methane
CMIP6	Coupled Model Intercomparison Project Phase 6
CO2	Carbon Dioxide
COPERNICUS	European Union's Earth Observation Programme
DD	Dynamical Downscaling
ESRI	Environmental Systems Research Institute
ESRI SENTINEL	Environmental Systems Research Institute Sentinel Satellite Imagery
ET	Evapotranspiration
ETinst	Instantaneous Evapotranspiration
FAO	Food and Agriculture Organization
FAO HWSD	Food and Agriculture Organization Harmonized World Soil Database
GCM	General Circulation Models
GEE	Google Earth Engine
GHG	Greenhouse Gas
GIS	Geographic Information System
H	Sensible Heat Flux
HSI	Heat Stress Index
HWSD	Harmonized World Soil Database
HydroSHEDS	Hydrological Data and Maps Based on Shuttle Elevation Derivatives at Multiple Scales
IPCC	Intergovernmental Panel on Climate Change
K1	Thermal Conversion Constant 1
K2	Thermal Conversion Constant 2
LE	Latent Heat Flux
LST	Land Surface Temperature
LSTmax	Maximum Land Surface Temperature
LSTmin	Minimum Land Surface Temperature

MFF	Multiannual Financial Framework
ML	Multiplicative Rescaling Factor
MOD16A2	Moderate Resolution Imaging Spectroradiometer (MODIS) Evapotranspiration Product
MOD16A2	MODIS Evapotranspiration Product
NASA SRTM	NASA Shuttle Radar Topography Mission
NBR	Normalized Burn Ratio
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NetCDF	Network Common Data Form
NOx	Nitrogen Oxides
NSI	Normalized Snow Index
PCA	Principal Component Analysis
Pv	Vegetation Proportion
PySEBAL	Python Surface Energy Balance Algorithm for Land
ra	Aerodynamic Resistance
RCP	Representative Concentration Pathways
Rlin	Incoming Longwave Radiation
Rlout	Outgoing Longwave Radiation
RMSE	Root Mean Square Error
Rn	Net Radiation
Rs	Incoming Shortwave Radiation
SD	Statistical Downscaling
SRTM	Shuttle Radar Topography Mission
SSP	Shared Socioeconomic Pathways
SSP2-4.5	Shared Socioeconomic Pathway 2-4.5
SSP5-8.5	Shared Socioeconomic Pathway 5-8.5
SVM	Support Vector Machines
Ta	Air Temperature
TCI	Temperature Condition Index
TIFF	Tagged Image File Format
TOA	Top of Atmospheric
Ts	Surface Temperature
TVDI	Temperature and Vegetation Drought Index
V	Wind Speed

VCI	Vegetation Condition Index
VHI	Vegetation Health Index
WWF HydroSHEDS	World Wildlife Fund Hydrological Data and Maps Based on Shuttle Elevation Derivatives at Multiple Scales
α	Albedo
λ	Latent Heat of Vaporization
ρ	Air Density

Executive Summary

Climate change poses significant challenges to agriculture, impacting crop growth and livestock production due to unpredictable weather patterns, including more frequent droughts, floods, and storms. In Europe, these changes are altering growing seasons and increasing the distribution of pests and diseases, necessitating urgent adaptation in agricultural practices. To address these challenges, it is essential to evaluate agro-climatic indicators such as temperature, precipitation, and soil moisture and many more. These indicators help in making informed decisions about land management, crop selection, and harvest planning. For instance, temperature and precipitation data can predict growing seasons and water stress periods, aiding in optimizing irrigation and selecting drought-resistant crops. Soil health is crucial for sustainable agriculture but is threatened by climate change through increased erosion, nutrient depletion, and changes in soil moisture. In Europe, soil erosion and degradation are major concerns. Implementing soil conservation practices like cover cropping and reduced tillage can mitigate these impacts, maintaining soil structure and fertility.

The EU's CAP aims to support farmers, improve productivity, and ensure a stable food supply while tackling climate change and managing natural resources sustainably. The new CAP framework includes ten macro-objectives, such as enhancing biodiversity, reducing greenhouse gas emissions, and promoting renewable energy. Direct payments are linked to the adoption of environmentally friendly practices, incentivizing sustainable farming methods. Understanding vulnerability to climate change involves analyzing exposure and sensitivity to climatic variations. Indicators provide a simplified measure of these factors, helping to assess the impacts on agriculture and develop adaptation strategies. For example, the Temperature Condition Index (TCI) and Heat Stress Index (HSI) are used to assess the impact of temperature on crops and livestock, guiding irrigation and crop management practices. Pilot data collection and analysis are crucial for evaluating the effectiveness of climate control systems and soil management practices. Standardizing data formats and sampling times ensures consistency and comparability across different pilots. Advanced variable selection methodologies help identify the most influential parameters for agricultural productivity and climate resilience.

This emphasizes the importance of developing and implementing adaptation strategies to enhance agricultural resilience. This includes optimizing farming practices, conserving biodiversity, and managing water and carbon footprints. Continuous monitoring and adjustment of these strategies are essential to address the evolving impacts of climate change. The CAP's performance in mitigating climate change and protecting natural resources is measured through specific indicators. These include greenhouse gas emissions, soil organic carbon, and renewable energy production. The CAP also aims to halt biodiversity loss and improve the sustainability of agricultural practices.

Highlighting the critical need for adaptive strategies in agriculture to cope with climate change. By leveraging agro-climatic indicators, implementing soil conservation practices, and adhering to the CAP's framework, Europe can enhance the resilience and sustainability of its agricultural systems. Continuous evaluation and adaptation are key to addressing the challenges posed by a changing climate.

1. Introduction

1.1 Climate change effect on agriculture and outlook for Europe

Climate change is one of the most pressing challenges humanity faces in the 21st century, with potentially devastating consequences for the environment, economy, and society. The agricultural sector is particularly vulnerable due to its dependence on specific climatic conditions for crop growth and livestock production. Farmers are increasingly facing unpredictable weather patterns, including more frequent and severe droughts, floods, and storms, which threaten food security and the sustainability of agricultural systems. In Europe, the effects of climate change on agriculture are becoming more pronounced. Shifts in temperature and precipitation patterns are altering growing seasons and the distribution of pests and diseases, posing significant risks to crop yields and livestock productivity. This necessitates urgent action to adapt agricultural practices to the evolving climate.

To effectively address these challenges, it is essential to evaluate relevant agro-climatic indicators, such as temperature, precipitation, soil moisture, and other environmental parameters. These indicators provide valuable information on specific weather and climatic conditions, helping farmers, researchers, and policymakers understand climate trends and anticipate potential risks to crops and livestock. Agro-climatic indicators are crucial for making informed decisions regarding land management, crop selection, and harvest planning. For instance, temperature and precipitation data can help predict the onset of growing seasons and identify periods of water stress, enabling farmers to optimize irrigation schedules and select drought-resistant crop varieties. Soil moisture indicators can inform soil management practices, such as the application of organic matter to improve water retention and reduce erosion.

Soil health is a fundamental component of sustainable agriculture and is significantly impacted by climate change. Healthy soils support plant growth, water retention, and nutrient cycling, but climate change can exacerbate soil degradation through increased erosion, nutrient depletion, and changes in soil moisture dynamics. In Europe, soil erosion and degradation are major concerns, particularly in regions prone to extreme weather events. Heavy rainfall can lead to soil erosion, while prolonged droughts can reduce soil moisture and organic matter content, diminishing soil fertility and structure. To mitigate these impacts, it is crucial to implement soil conservation practices such as cover cropping, reduced tillage, and organic amendments. These practices help maintain soil structure, enhance water retention, and promote biodiversity within the soil ecosystem. Monitoring soil health through indicators such as soil organic carbon, moisture levels, and nutrient content is essential for developing effective soil management strategies.

The European Union’s Common Agricultural Policy (CAP) plays a pivotal role in supporting farmers and promoting sustainable agricultural practices. The new CAP for 2023-2027 has considerably raised climate-friendly standards for the sector. It aims to support farmers in improving agricultural productivity while ensuring a stable supply of affordable food. Additionally, the CAP seeks to safeguard farmers’ livelihoods, help tackle climate change, manage natural resources sustainably, and maintain rural areas and landscapes across the EU. The CAP’s new framework includes ten macro-objectives, each detailed in several sub-objectives measured by specific indicators identified by the European Commission. These objectives encompass a broad range of goals, from enhancing biodiversity and soil health to reducing greenhouse gas emissions and promoting renewable energy production. By linking direct payments to the adoption of environmentally friendly practices, the CAP incentivizes farmers to implement sustainable farming methods that contribute to climate change mitigation and adaptation.

1.2 Cap general overview

The EU’s Common Agricultural Policy (CAP) aims to:

- support farmers and improve agricultural productivity, ensuring a stable supply of affordable food;
- safeguard European Union farmers to make a reasonable living;
- help tackle climate change and the sustainable management of natural resources;
- maintain rural areas and landscapes across the EU;
- keep the rural economy alive by promoting jobs in farming, agri-food industries and associated sectors.

The new CAP 2023-2027 entails ten (10) macro-objectives. Each of them is detailed in several sub-objectives measured by specific indicators identified by the European Commission (EC).

The new Common Agricultural Policy (CAP) 2023-2027 has considerably raised the climate-friendly standards for the sector, whose practices are both affected by and affecting climate change. Within their ordinary activities, farmers have to fulfil several commitments in order to receive European Union's financial support. These commitments fall within a broader project focused on the achievement of social, environmental and economic goals in the agricultural sector through the CAP.

Figure 1 CAP 2023-2027 macro-objectives

The Common Agricultural Policy (CAP) will help the sustainability transition and strengthen the efforts of European farmers to tackle climate change and protect the environment. 40% of the CAP budget will be climate-relevant. The new CAP entails the following instruments to help farmers reaching the ambitious goals set in the EU Green Deal.

Figure 2 CAP instruments for the EU Green Deal

Direct payments to farmers are closely linked to the adoption of environmentally friendly practices.

1.3 Climate indicators

1.3.1 Vulnerability, Exposure, and Sensitivity

The complexity of vulnerability to climate change can make its analysis particularly challenging for a community. Engaging in such analysis may require significant investment in terms of human and financial resources, especially for conducting in-depth studies and collecting relevant data. Faced with this reality, it is sometimes preferable to adopt an approach based on indicators to understand vulnerability. This approach provides an overview of part of the issue without requiring overly complex and costly work. In general, vulnerability refers to the propensity of exposed elements to be damaged by a hazard. In the context of climate change, it represents the extent to which components of a system are affected by climatic variations, resulting from physical, social, economic, or environmental factors. This vulnerability depends on the system's exposure to climate change and its sensitivity to these variations.

Exposure to climate change is defined as the extent to which a system is confronted with significant climatic variations over a given period, including extreme events and changes in climatic averages. This assessment aims to determine the significance and likelihood of these climatic variations. The exposed elements, whether tangible or intangible, include populations, infrastructure, and ecosystems, which could be impacted by these natural or anthropogenic phenomena.

Sensitivity is an inherent characteristic of an element, whether it be a community or an organization, making it particularly receptive to hazards. This results in a propensity to be affected, positively or negatively, by unexpected events. The impacts of climate change can be direct, such as fluctuations in agricultural yields due to temperature variations, or indirect, such as damage caused by coastal flooding due to sea-level rise. The sensitivity of a territory to climatic hazards depends on various parameters, such as economic activities, population density, and demographic composition.

1.3.2 What is an indicator?

An indicator is "a selected piece of data from a larger statistical set because it possesses particular significance and representativeness". As the name suggests, an indicator provides an indication or measurement of a certain situation or phenomenon. Its role is to simplify information to highlight sometimes complex aspects. It allows quantification of this information, often in the form of a simple or aggregated measure that can be tracked over time or compared to reference values such as policy objectives or predefined thresholds. An indicator is defined in relation to a specific objective.

It can be used for comparison, trend detection, priority setting, policy coordination, planning, or evaluation purposes. Sometimes, it is used as a substitute when direct information is not available. Indicators can be quantitative, semi-quantitative, or qualitative, depending on the values they represent. In summary, an indicator simplifies and quantifies information to facilitate its analysis and interpretation. It is a flexible tool that simplifies and quantifies information to meet the needs of a given situation.

Indicators of climatic and meteorological conditions constitute a vital category of tools used to assess and understand climate characteristics and changes, as well as their impacts on our environment and societies. These indicators capture a variety of parameters related to climate and weather conditions. Their utility lies in their ability to provide valuable information on long-term climate trends, seasonal variations, as well as extreme weather events. These data enable the assessment of climate impacts on ecosystems, natural resources, human activities, and infrastructure. Additionally, they serve as a basis for developing adaptation and mitigation strategies against climate change, as well as policies for sustainable environmental management.

2. Climate Indicators

2.1 Historical Indicators

2.1.1 Land cover classification

We will produce land cover classification (figure3) [1] for each Pilot Site on a 5-year temporal basis including 1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020, and 2025. These land cover maps will show the evolution of each area through time.

The results will be a level 4 classification using the 20 classes below:

- Shrubs: Woody perennial plants with persistent and woody stems and without any defined main stem being less than 5 m tall. The shrub foliage can be either evergreen or deciduous.
- Herbaceous vegetation: Plants without persistent stem or shoots above ground and lacking definite firm structure. Tree and shrub cover is less than 10 %.
- Cultivated and managed vegetation/agriculture: Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.
- Urban / built up: Land covered by buildings and other man-made structures.
- Bare / sparse vegetation: Lands with exposed soil, sand, or rocks and never has more than 10 % vegetated cover during any time of the year.
- Snow and ice: Lands under snow or ice cover throughout the year.
- Permanent water bodies: Lakes, reservoirs, and rivers. Can be either fresh or salt-water bodies.
- Herbaceous wetland: Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water.
- Moss and lichen.
- Closed forest, evergreen needle leaf: Tree canopy >70 %, almost all needle leaf trees remain green all year. Canopy is never without green foliage.
- Closed forest, evergreen broad leaf: Tree canopy >70 %, almost all broadleaf trees remain green year round. Canopy is never without green foliage.
- Closed forest, deciduous needle leaf: Tree canopy >70 %, consists of seasonal needle leaf tree communities with an annual cycle of leaf-on and leaf-off periods.
- Closed forest, deciduous broad leaf: Tree canopy >70 %, consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
- Closed forest, mixed.
- Open forest, evergreen needle leaf: Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, almost all needle leaf trees remain green all year. Canopy is never without green foliage.
- Open forest, evergreen broad leaf: Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, almost all broadleaf trees remain green year round. Canopy is never without green foliage.
- Open forest, deciduous needle leaf: Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, consists of seasonal needle leaf tree communities with an annual cycle of leaf-on and leaf-off periods.
- Open forest, deciduous broad leaf: Top layer- trees 15-70 % and second layer- mixed of shrubs and grassland, consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
- Open forest, mixed.
- Oceans, seas. Can be either fresh or salt-water bodies.

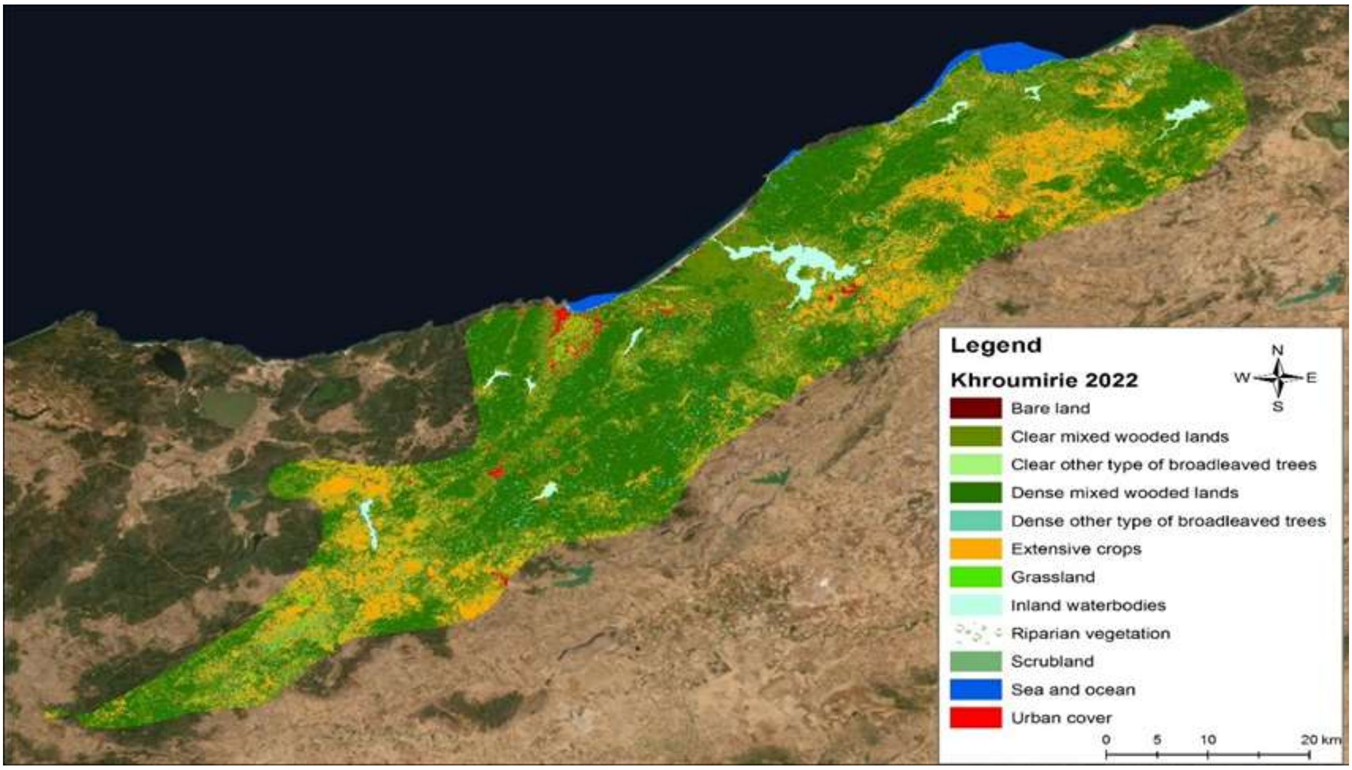


Figure 3 Land cover map for the Khroumirie area 2022

2.1.2 Land Surface Temperature

Land Surface Temperature (LST) [2] is the temperature of the Earth's surface measured from space using Landsat satellites. Landsat sensors capture the thermal infrared radiation emitted by the surface, particularly in the range of 10.60 to 12.51 micrometers. For this study we will be using only band 10 as it is more accurate with a lower root mean square error (RMSE) than band 11. Atmospheric effects are corrected, and the temperature is calculated using algorithms that account for the surface emissivity (emissivity is the total amount of thermal energy emitted per unit area and per unit time). The spatial resolutions of Landsat enable detailed mapping of temperature. LST data helps understand environmental changes and their impacts.

For the calculation of LST (Land Surface Temperature), Landsat data will be used. The bands used in the intermediate calculations of LST will therefore be those of Landsat images.

1. Calculation of Top of Atmospheric (TOA) Spectral Radiance

$$TOA = M_L \times Band10 + A_L$$

With ML = Multiplicative rescaling factor specific to the band (here 10) can be found in the metadata, and AL = Additive rescaling factor specific to the band (here 10) can be found in the metadata.

2. Conversion from Top of Atmosphere (TOA) to Brightness Temperature (BT)

$$BT = \frac{K_2}{ln(\frac{K_1}{TOA}+1} - 273.15$$

With K2 et K1 Specific thermal conversion constants for the band (here band 10) can be found in the metadata. To obtain results in Celsius, the radiance temperature is adjusted by adding the absolute zero (approximately -273.15°C).

3. Calculation of NDVI

The NDVI is a widely used index in remote sensing to assess the health, density, and vigor of vegetation in a given area. This index is calculated by subtracting the reflectance of light in the red spectral band from the reflectance in the near-infrared spectral band, then dividing the result by the sum of these two reflectances

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The NDVI typically ranges from -1 to +1, where values close to +1 indicate dense and healthy vegetation, while values close to -1 indicate a lack of vegetation, such as water or bare soil. Intermediate NDVI values are associated with varying levels of vegetation, with higher values indicating denser and healthier vegetation. NDVI helps in monitoring crop growth, detecting areas affected by plant diseases or water stress, assessing changes in vegetation cover, and monitoring natural ecosystems.

4. Calculation of Vegetation Proportion Pv

$$P_v = \sqrt{\frac{NDVI - NDVI_{min}}{NDVI_{Max} - NDVIMin}}$$

The minimum and maximum values of the NDVI will be calculated for the area and used.

5. Calculation of Emissivity

$$\epsilon = 0.004 \times P_v + 0.986$$

The value of 0.004 corresponds to a coefficient specific to the environment, and 0.986 corresponds to a correction value for the equation.

6. Calculation of Land Surface Temperature (LST)

$$LST = \frac{BT}{1 + \frac{0.00115 \times BT}{1.4388} \times Ln(\epsilon)}$$

2.1.3 Temperature condition index

In agriculture, the Temperature Condition Index (TCI) [3] assesses the impact of temperature on crops and provides valuable insights into potential risks or benefits. A below normal index value may indicate unfavourable conditions, such as heat stress or cold damage, which can lead to reduced yields. Conversely, above-normal index values may suggest favourable temperature conditions, promoting vigorous crop growth. Monitoring TCI over time allows farmers to anticipate and adapt to climate changes, optimizing agricultural practices for enhanced resilience and productivity. The results of TCI assessments guide farmers in making informed decisions regarding irrigation, pest control, and crop management strategies, contributing to more sustainable and efficient agricultural systems.

$$TCI = \frac{LST_{Max} - LST}{LST_{Max} - LST_{Min}} \times 100$$

Where:

- TCI: Temperature Condition Index
- LST: Land Surface Temperature

- LST max: Maximum Land Surface Temperature for the area
- LST min: Minimum Land Surface Temperature for the area

2.1.4 Heat stress index

The Heat Stress Index [4] in agriculture is a measure used to assess the impact of high temperatures on crops and livestock. It takes into account factors such as air temperature, and wind speed to quantify the level of thermal stress experienced by plants or animals.

$$HSI = (0.5 * (LST + 61)) + (0.31 * LST * e^{0.14 * LST} - 14.3) + (0.2 * V * (0.5 * LST - 10))$$

Where:

- HIS: Heat Stress Index
- V: Wind speed

High values of the thermal stress index indicate conditions that may harm agricultural productivity, potentially causing heat-related damage or reduced yields. Farmers use this index to make informed decisions regarding irrigation, shading, and other management practices to mitigate thermal stress and enhance the resilience of crops and livestock to extreme temperatures. Monitoring the thermal stress index is crucial for adapting agricultural strategies to climate change and ensuring sustainable and effective agricultural management practices.

2.1.5 Vegetation health index

The Vegetation health index [5] is an indicator used in remote sensing to assess the condition or health of vegetation. This index allows for monitoring the status of crops, grasslands, forests, and other types of vegetation over large geographical areas using data obtained from sensors onboard satellites or aircraft. The VCI is typically calculated by analyzing variations in the reflectance of light across different spectral bands, particularly in the near-infrared and red wavelengths. These data are collected at regular intervals during the plant growing season.

$$VCI = \frac{NDVI - NDVI_{Min}}{NDVI_{Max} - NDVI_{Min}} \times 100$$

By comparing the reflectance across these different spectral bands, the VCI can provide information about vegetation density, health, and vigor. A high VCI generally indicates healthy and vigorous vegetation, while a low VCI may indicate stress conditions such as drought, plant diseases, or damage from pests. The VCI is widely used in natural resource monitoring, crop management, disaster prevention, and land management decision-making. It enables natural resource managers and policymakers to track vegetation changes over large geographic areas and take appropriate actions to address crop water, nutrition, and protection needs.

The Vegetation Health Index (VHI) is a measure used in agriculture and remote sensing to assess the condition and vitality of vegetation. It combines data from multiple spectral bands, often centered on the visible and near-infrared zones of the electromagnetic spectrum, to quantify the health status of plants. The VHI takes into account factors such as leaf chlorophyll content, water content, and overall plant vigor.

$$VHI = a \times VCI + (1 - a) \times TCI$$

Higher VHI values generally indicate healthier vegetation, while lower values may suggest stress or reduced vitality. This index is valuable for monitoring crop health, assessing the impact of environmental factors such as drought or diseases, and assisting farmers in making informed decisions regarding irrigation, fertilization, and pest control. By providing a quantitative measure of vegetation health, the VHI contributes to precision farming practices and enables the optimization of agricultural productivity.

2.1.6 Evapotranspiration

Evapotranspiration (ET) [6] refers to the combined processes of water evaporation from the soil and transpiration from plants. Landsat satellites contribute to estimating evapotranspiration by capturing multispectral images. The thermal infrared bands of Landsat sensors are particularly useful for measuring land surface temperature, a crucial parameter in ET calculation. Through the PySEBAL model and algorithms, we can analyze Landsat data to estimate the amount of water vapor leaving the Earth's surface due to these processes. Monitoring evapotranspiration is essential for assessing water use, agricultural water management, and understanding the overall water balance of ecosystems (the PySEBAL model will be discussed in detail in the modelling section of the document).

2.1.7 Normalized difference water index

The Normalized Difference Water Index (NDWI) [7] is a vegetation index in remote sensing designed to highlight the presence of water in various landscapes. Calculated by comparing the reflectance of near-infrared and green or short-wave infrared bands, NDWI is particularly effective in distinguishing bodies of water from other land features.

$$NDWI = \frac{PIR - MIR}{PIR + MIR}$$

Positive values of NDWI generally indicate the presence of water, as water absorbs in the near-infrared and reflects in the green or short-wave infrared. This index is widely used to monitor changes in surface water bodies, assess drought conditions, and aid in water resource management. In agriculture, NDWI helps identify areas with sufficient soil moisture and promotes precision irrigation practices.

2.1.8 Temperature vegetation dryness index

The Temperature and Vegetation Drought Index (TVDI) [8] is designed to assess vegetation health and drought based on thermal infrared data. It calculates the temperature difference between the soil surface and the vegetation cover, with higher values indicating drier and potentially stressed vegetation. TVDI is particularly useful for monitoring drought conditions and understanding the impact of water stress on ecosystems. Positive TVDI values suggest normal or healthy vegetation, while negative values indicate potential moisture deficits and drought. This index is valuable for agricultural and environmental applications, helping to identify regions experiencing water stress, guide irrigation strategies, and provide insights into overall vegetation health in response to climate change.

$$TVDI = \frac{LST_s - LST_{min}}{LST_{max} - LST_{min}}$$

Where:

- LSTs representing the LST of the pixel under consideration
- LSTmin representing the minimum LST
- LSTmax representing the maximum LST

2.1.9 Normalized burn ratio

The Normalized Burn Ratio (NBR) [9] is used to detect and quantify the severity of burned areas after a fire. Calculated from the near-infrared and shortwave infrared bands of satellite imagery, NBR highlights changes in vegetation cover and vegetation condition caused by the fire. Healthy vegetation strongly reflects in the near-infrared, while the shortwave infrared is sensitive to changes in both live and dead vegetation.

$$NBR = (NIR - SWIR)/(NIR + SWIR)$$

Therefore, burned areas exhibit lower NBR values due to the reduction in live vegetation. This index aids researchers and land managers in assessing the impact of wildfires, monitoring vegetation regeneration, and prioritizing post-fire restoration efforts. Higher negative NBR values often indicate more severe burning effects, aiding in the characterization of fire-affected landscapes and contributing to effective post-fire management strategies.

2.1.10 Historical flood mapping

Historical flood [10] mapping from Landsat involves the analysis of satellite imagery captured by Landsat satellites over time to identify and map areas affected by flooding events. By comparing imagery from different time points, we can observe variations in surface water and identify areas that have experienced inundation. Historical flood mapping from Landsat aids in understanding the recurrence and patterns of flooding, assessing the impact on landscapes and communities, and informing disaster management and mitigation strategies. The data allows for the creation of long-term flood histories, supporting efforts to improve resilience and response mechanisms to future flood events.

2.1.11 Soil composition

Soil composition [11] refers to the combination and relative proportions of mineral particles, organic matter, water, and air present in a specific soil type. Mineral particles, classified into sand, silt, and clay, collectively determine the soil texture. Organic matter, composed of decomposed plant and animal residues, contributes to soil fertility and structure. The arrangement and interaction of these elements influence the physical, chemical, and biological properties of the soil, including its water retention capacity, nutrient availability, and microbial activity. Soil composition varies considerably across regions, impacting agricultural suitability, water drainage, and ecosystem health. Understanding soil composition is essential for effective land management, sustainable agriculture, and environmental conservation practices.

2.1.12 Normalized snow index (snow area, extent)

The Normalized Snow Index (NSI) [12] derived from Landsat satellite images, is a tool used to identify and map the extent of snow-covered areas. By analyzing reflectance values in specific spectral bands sensitive to snow properties, such as visible and near-infrared, the NSI highlights snow-covered areas and distinguishes them from other landscape elements.

$$NDSI = (Green - SWIR)/(Green + SWIR)$$

Positive NSI values generally indicate the presence of snow, with higher values corresponding to a larger extent of snow cover. This index is particularly useful for monitoring the seasonal dynamics of snow, assessing snowmelt patterns, and understanding the impact of snow cover on hydrological processes. Information derived from the NSI helps us better understand the variability of the snowpack, aiding in water resource management, climate studies, and ecological assessments in snow-covered regions.

2.2 Climate Future Projections

Using the CMIP6 models [13] to derive the projections of all the important climate indicators. These indicators will be produced on 2 time scales. First we will be producing long term projections for the years: 2030-2050-2070 under the SSP2-4.5, and SSP5-8.5 scenarios. Secondly, we will be producing short term projections that will tackle the next 5 years starting from 2025 to 2030. However the short term projections will be limited to:

Near-surface specific humidity, Precipitation, Surface downwelling longwave radiation, Surface downwelling shortwave radiation, Daily mean near-surface wind speed, Daily near-surface air temperature, Daily minimum near-surface air temperature, Daily maximum near-surface air temperature. While the long term projections will have 23 indicators that we will discuss below. All data will be downscaled depending on the study area.

The Coupled Model Intercomparison Project Phase 6 (CMIP6) is a collaborative international effort involving climate modelling groups worldwide. CMIP6 aims to improve our understanding of climate processes, project future climate scenarios, and provide a basis for assessing the potential impacts of climate change. It involves a suite of global climate models contributed by different research institutions and organizations. These models simulate various components of the Earth's climate system, including the atmosphere, oceans, land surface, and sea ice. The CMIP6 models are used to generate future climate projections under different greenhouse gas emission scenarios, providing crucial information for climate research, policymaking, and adaptation planning.

The Shared Socioeconomic Pathways (SSPs) are scenarios developed as part of the CMIP6 framework to represent different possible future trajectories of society, demographics, and economics. They are used in conjunction with Representative Concentration Pathways (RCPs) to explore a range of climate futures. Two specific SSPs mentioned are SSP2-4.5 and SSP5-8.5:

- SSP2-4.5 (Medium Challenges and Mitigation): This scenario represents a future where global society faces moderate challenges in terms of sustainability and environmental issues. It assumes that, through a combination of technological advances, policy efforts, and societal changes, there is a successful mitigation of greenhouse gas emissions. The radiative forcing associated with this scenario is approximately 4.5 Watts per square meter by the year 2100.
- SSP5-8.5 (High Challenges and Limited Mitigation): This scenario portrays a future where global society faces high challenges and experiences limited mitigation efforts. It envisions a trajectory where economic and population growth continues without substantial efforts to curb greenhouse gas emissions. As a result, radiative forcing is projected to reach approximately 8.5 Watts per square meter by the end of the century, indicating a high level of warming and associated climate impacts.

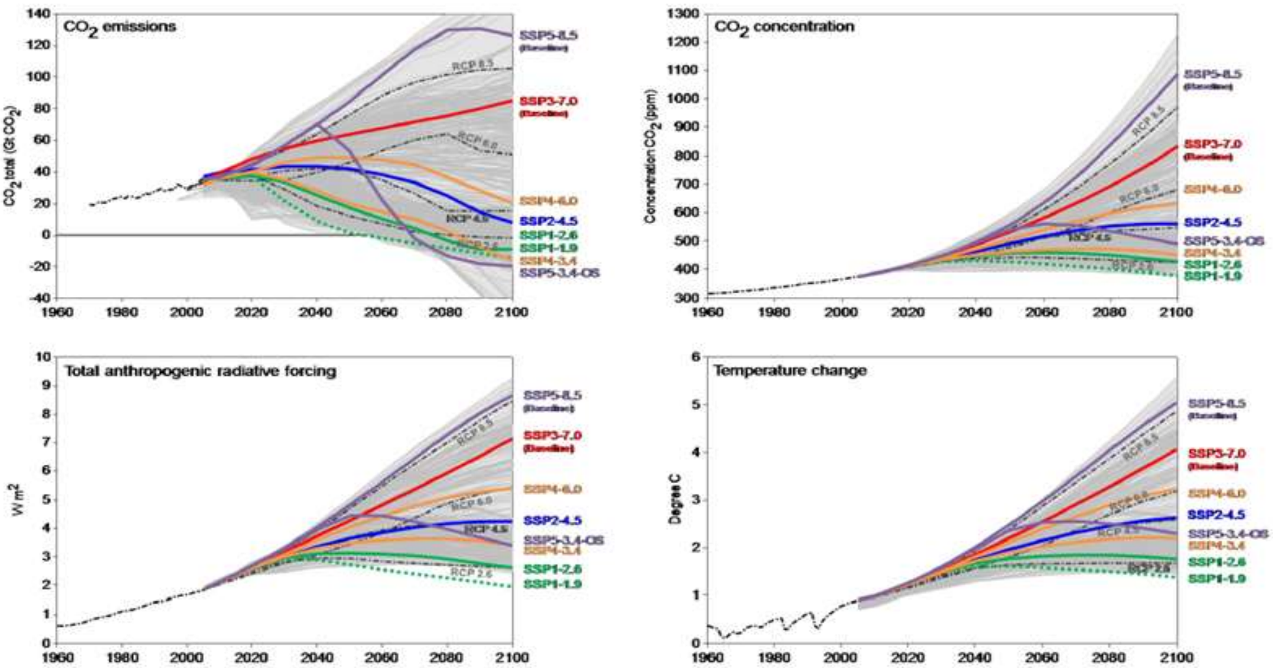


Figure 4 CMIP6 Scenarios showing the CO2 emissions, CO2 concentrations, total anthropogenic radiative forcing, and temperature change projection to the year 2100

2.2.1 Air temperature

Air temperature is one of the most important indicators of our climate. It significantly influences the Earth's climate system, affecting everything from weather patterns to ecosystems. When we talk about air temperature in the context of CMIP6 (the Coupled Model Intercomparison Project Phase 6), we're referring to the temperature of the atmosphere at different heights. CMIP6 uses advanced global climate models to predict what our future climate might look like. These models take into account various emission scenarios, known as Shared Socioeconomic Pathways (SSPs), to simulate how air temperature might change over time and across different regions.

By analyzing the data from CMIP6, we can gain valuable insights into how temperature patterns might shift. This includes understanding regional differences and overall global trends. Such information is crucial for assessing the potential impacts of climate change on natural systems, agriculture, and water resources. Understanding these changes helps us develop strategies to adapt to and mitigate the effects of climate change. For instance, in agriculture, knowing how temperatures might change can guide decisions on crop selection and water management, ensuring food security in a warming world.

2.2.2 Capacity of soil to store water.

The ability of soil to retain water, known as soil water storage, is a vital climate indicator that affects water availability for plants, agriculture, and ecosystems. Within the framework of CMIP6 (Coupled Model Intercomparison Project Phase 6), climate models simulate how various factors like precipitation, temperature, and land-use changes influence soil water storage under different emission scenarios. These models help us predict how soil's water-holding capacity might evolve in the future, impacting both regional and global water cycles. By examining these projections, we can better understand potential shifts in water availability, which is essential for managing water resources effectively. This knowledge is crucial for developing sustainable land use and agricultural practices. For instance, understanding future changes in soil water storage can guide irrigation strategies and crop selection, ensuring that agriculture remains resilient in the face of climate change.

2.2.3 Daily maximum near-surface air temperature

Projections of daily maximum near-surface air temperatures are key climate indicators generated by climate models. These projections help us understand how the highest temperatures at the Earth's surface might change over time. Climate models take into account various elements, such as greenhouse gas levels, solar radiation, and feedback mechanisms, to simulate future temperature scenarios.By examining these daily maximum temperatures, we gain crucial insights into the potential impacts of climate change. This includes understanding how extreme temperatures might evolve, the resulting heat stress on ecosystems, and the broader implications for agriculture, animal health, and energy demand.

For instance, knowing how peak temperatures might shift can inform strategies to protect crops and livestock from heat stress, ensure the reliability of energy supplies during heatwaves, and safeguard natural habitats. This information is vital for developing effective adaptation and mitigation strategies in response to a warming world.

2.2.4 Daily minimum near-surface air temperature

Projections of daily minimum near-surface air temperatures are vital in climate modeling, offering a glimpse into how the coldest temperatures at the Earth's surface might evolve over time. These projections are generated by climate models that consider a range of factors, including greenhouse gas levels, solar radiation, and atmospheric dynamics. By studying these daily minimum temperatures, we can gain a deeper understanding of the impacts of climate change on cold extremes, frost events, and overall temperature variability. This knowledge is crucial for predicting how ecosystems, agriculture, and human health might be affected.

For instance, insights into shifting minimum temperatures can help farmers protect frost-sensitive crops, guide wildlife conservation efforts to manage cold stress, and inform public health strategies to address temperature-related illnesses. These projections are indispensable for crafting effective adaptation and mitigation plans in response to our changing climate.

2.2.5 Evapotranspiration including sublimation and transpiration

Projections of evapotranspiration, which include both sublimation and transpiration, are vital for understanding water cycle dynamics and are key components of climate modelling. Evapotranspiration refers to the process where water transitions from liquid to vapor, encompassing sublimation (where ice or snow changes directly to vapor) and transpiration (the release of water vapor from plants). Climate models simulate these processes by considering various factors such as air temperature, humidity, wind speed, and vegetation cover. By analyzing projections of evapotranspiration, we can gain insights into potential changes in water availability, the energy balance of land surfaces, and overall hydrological cycles.

These projections are crucial for assessing the impacts of climate change on water resources and agriculture. For example, understanding how evapotranspiration might change can help in managing irrigation practices, predicting drought conditions, and ensuring sustainable water use in agriculture. This information is essential for developing strategies to adapt to and mitigate the effects of a changing climate.

2.2.6 Moisture in upper portion of soil column

Projections of moisture in the upper layers of the soil are crucial climate indicators that shed light on water availability for vegetation, agriculture, and ecosystems. Climate models simulate future soil moisture scenarios by considering factors such as precipitation, temperature, and land-use changes. By analyzing these projections, researchers can understand how climate change might affect water availability for plants, which in turn impacts agricultural productivity, ecosystem health, and overall water resource management. These insights are essential for predicting shifts in hydrological patterns and informing sustainable land use practices.

For instance, knowing how soil moisture levels might change can help farmers plan irrigation schedules, guide conservation efforts to protect ecosystems, and develop strategies to manage water resources more effectively. These projections are vital for crafting strategies to mitigate the impacts of changing soil moisture on various sectors.

2.2.7 Near-surface air temperature

Projections of near-surface air temperature are a cornerstone of climate modeling, offering essential insights into how temperatures close to the Earth’s surface might change over time. These projections are generated by climate models that take into account a variety of factors, including greenhouse gas concentrations, solar radiation, and atmospheric dynamics. By analyzing these temperature projections, scientists can better understand the potential impacts of climate change on extreme temperatures, regional temperature variations, and overall temperature trends. This information is crucial for assessing how different sectors might be affected. For instance, understanding changes in near-surface air temperature is vital for predicting heat stress in both ecosystems and agriculture. It helps farmers plan for crop resilience and manage livestock health. Additionally, these projections are important for anticipating shifts in energy demand, as higher temperatures can lead to increased use of air conditioning and other cooling systems.

Moreover, regional temperature variations can have significant implications for local climates, influencing weather patterns and potentially leading to more frequent and severe heatwaves. This can affect human health, particularly for vulnerable populations, and necessitate the development of effective public health strategies.

2.2.8 Near-surface relative humidity

Projections of near-surface relative humidity are a key component of climate modeling, offering vital insights into the moisture content of the air close to the Earth's surface over time. These projections are essential for understanding how atmospheric humidity might change, which can significantly influence weather conditions, precipitation patterns, and overall climate dynamics. Climate models simulate future scenarios of near-surface relative humidity by considering a range of factors, including temperature, atmospheric pressure, and the amount of moisture in the atmosphere. By analyzing these projections, scientists can assess potential changes in humidity levels and their impacts on various sectors.

For instance, changes in relative humidity can affect agriculture by influencing plant growth and water needs. High humidity levels can increase the risk of plant diseases, while low humidity can lead to drought stress. Similarly, animal health can be impacted by humidity changes, as extreme humidity levels can cause heat stress in livestock and affect their productivity. Moreover, understanding shifts in humidity is crucial for predicting weather patterns and preparing for extreme weather events. For example, higher humidity levels can lead to more intense and frequent rainfall, while lower humidity can contribute to prolonged dry spells. These projections also help in formulating adaptation strategies and policies to address the challenges posed by changing humidity patterns. This includes developing water management practices, improving agricultural resilience, and enhancing public health measures to cope with the effects of altered humidity levels.

2.2.9 Precipitation

Precipitation projections are crucial for understanding how the amount and distribution of rainfall might change over time. Climate models generate these projections by taking into account factors like temperature, atmospheric humidity, and regional climate dynamics. By analyzing these projections, we can gain valuable insights into potential shifts in precipitation patterns. This is essential for several reasons. Changes in rainfall can significantly impact water availability, which is vital for drinking water supplies, agriculture, and maintaining healthy ecosystems. For instance, regions that rely heavily on consistent rainfall for crop production may need to adapt to new precipitation patterns to ensure food security.

Moreover, understanding precipitation projections helps us prepare for extreme weather events such as floods and droughts. Increased rainfall can lead to more frequent and severe flooding, while decreased rainfall can result in prolonged droughts. Both scenarios require robust disaster preparedness and response strategies to protect communities and infrastructure. These projections also inform water resource management practices. By anticipating changes in rainfall, we can develop more effective strategies for storing and distributing water, ensuring that there is enough to meet the needs of both people and the environment.

In addition, precipitation projections are vital for climate adaptation efforts across various sectors. For example, in agriculture, knowing how rainfall patterns might change can guide decisions on crop selection and irrigation practices. In urban planning, it can influence the design of drainage systems and flood defenses.

2.2.10 Snowfall flux

Snow flux is a critical component of Earth's water cycle, impacting seasonal snow cover, water availability, and various ecological processes. Climate models simulate future scenarios of snow flux considering factors such as temperature, atmospheric moisture content, and regional climate conditions. Analyzing these projections is essential for understanding potential changes in snow regimes, which can affect snow accumulation, timing of snowmelt, and overall water resource dynamics. Snow flux projections provide valuable insights into studies of regional hydrology, water resource management, and the impacts of climate change on snow-dependent areas.

2.2.11 Cold spells duration

The duration of cold waves refers to the period during which a specific region experiences abnormally cold temperatures compared to typical climatic conditions. In climate modelling, such as in CMIP6, projections of the duration of cold waves provide insight into potential changes in the frequency and duration of extreme cold events. Climate models simulate future scenarios taking into account various factors, including atmospheric dynamics, temperature patterns, and regional climate variations. Analyzing projections of the duration of cold waves is crucial for understanding the impacts of climate change on extreme cold temperatures, as these events can have significant consequences for agriculture, energy demand, and animal health.

2.2.12 Number of frost days (Tmin < 0°C)

The number of frost days, defined as days when the minimum temperature drops below 0°C, is an important climate indicator with implications for agriculture, ecosystems, and various sectors. In climate modelling, projections of the number of frost days provide valuable insights into potential changes in the frequency of cold events. Climate models simulate future scenarios, taking into account factors such as temperature patterns, atmospheric dynamics, and regional climate variations. Analyzing projections of frost days helps assess the impact of climate change on frost-sensitive crops, plant and animal ecosystems, and infrastructure vulnerable to freezing temperatures. These projections contribute to our understanding of regional climate variability and facilitate the development of adaptation strategies to evolving frost regimes, particularly in regions where frost events play a crucial role in agricultural planning and ecosystem dynamics.

2.2.13 Number of ice days (Tmax < 0°C)

The number of ice days, defined as days when the maximum temperature remains below 0°C, is an important climate indicator that influences various aspects of ecosystems and human activities. In climate modelling, such as in CMIP6, projections of the number of ice days provide insight into potential changes in the frequency of extreme cold events. Climate models simulate future scenarios taking into account factors such as temperature regimes, atmospheric dynamics, and regional climate variations. Analyzing projections of ice days is crucial for understanding the impacts of climate change on agriculture, water resources, and infrastructure vulnerable to freezing temperatures. The number of ice days can influence frost-sensitive crops, water supply systems, and transportation networks.

2.2.14 Number of hot days (T > 35°C)

The number of hot days, defined as days when the maximum temperature exceeds 35°C, is a crucial climate indicator with implications for various sectors, including agriculture. Projections of the number of hot days provide insights into potential changes in the frequency and intensity of extreme heat events. Climate models simulate future scenarios considering factors such as greenhouse gas emissions, atmospheric dynamics, and regional climate variations. Analyzing projections of hot days is crucial for understanding the impacts of climate change on heat-sensitive crops, heat-related animal diseases, and human health risks. These projections contribute to our understanding of regional climate variability and facilitate the development of adaptation strategies to evolving heat patterns, especially in regions where extreme heat events can profoundly affect agriculture.

2.2.15 Number of very hot days (T > 45°C)

The number of extremely hot days, defined as days when the maximum temperature exceeds 45°C, is a critical climate indicator providing insights into extreme heat events. In climate modelling, projections of the number of extremely hot days offer valuable information on potential changes in the frequency and intensity of extreme heat. Climate models simulate future scenarios considering factors such as greenhouse gas emissions, atmospheric dynamics, and regional climate variations. Analyzing projections of extremely hot days is crucial for understanding the severe impacts of climate change on agriculture, water resources, animal health, and human health. These projections contribute to our understanding of regional climate variability and help develop adaptation strategies to mitigate the potentially devastating effects of extreme heat events, especially in regions where such temperatures can pose significant challenges.

2.2.16 Number of consecutive dry days

The number of consecutive dry days is a crucial climate indicator that sheds light on the length of periods without significant rainfall. Projections of these dry spells are essential for understanding how the frequency and duration of droughts might change in the future. Climate models simulate these scenarios by considering various factors, including temperature patterns, atmospheric dynamics, and regional climate variations. By analyzing projections of consecutive dry days, we can gain valuable insights into the potential impacts of climate change on water resources, agriculture, and overall hydrological conditions. Prolonged periods without rain can lead to decreased soil moisture, reduced water availability, and the onset of drought conditions, which can have far-reaching consequences. For instance, in agriculture, extended dry spells can stress crops, reduce yields, and necessitate more intensive irrigation practices. This can strain water resources and increase the cost of food production. In natural ecosystems, prolonged droughts can affect plant and animal species, disrupt habitats, and lead to increased wildfire risks.

Understanding these projections is also vital for water resource management. By anticipating longer dry periods, we can develop strategies to conserve water, improve storage systems, and ensure a reliable supply for both human and ecological needs. Additionally, these insights can inform disaster preparedness plans, helping communities to better cope with the challenges posed by extended droughts.

2.2.17 Number of days with precipitation above 20 mm

The number of days with precipitation exceeding 20 mm is a climate indicator that provides information on the frequency of heavy precipitation events. Climate models simulate future scenarios considering factors such as temperature regimes, atmospheric dynamics, and regional climate variations. An increase in the frequency of heavy precipitation events can contribute to flash floods, soil erosion, and other challenges. These projections contribute to our understanding of regional climate variability and facilitate the development of strategies for water resource management, improving resilience to floods, and mitigating the impacts of extreme precipitation events in various sectors.

2.2.18 Drought frequency and severity

The frequency and intensity of droughts are vital climate indicators that reveal the occurrence and severity of prolonged water scarcity. Projections of drought frequency and intensity provide crucial insights into how often and how severe these drought events might become in the future. Climate models simulate these scenarios by considering factors such as temperature patterns, precipitation trends, and atmospheric dynamics. Understanding these projections is essential because changes in drought patterns can have widespread and significant consequences. For instance, more frequent and intense droughts can drastically impact agricultural yields, leading to food shortages and increased prices. Farmers may face challenges in maintaining crop health and productivity, necessitating more efficient water use and drought-resistant crop varieties. Water availability is another critical area affected by droughts. Prolonged periods of water scarcity can strain water resources, affecting everything from drinking water supplies to industrial usage. This can lead to conflicts over water rights and necessitate the development of more sustainable water management practices. Ecosystem health is also at risk. Droughts can stress plant and animal species, disrupt habitats, and increase the likelihood of wildfires. These changes can lead to a loss of biodiversity and alter the functioning of ecosystems, which in turn affects services that humans rely on, such as pollination and water purification.

By analyzing projections of drought frequency and intensity, we can better prepare for these challenges. This includes developing strategies for water conservation, improving agricultural practices, and enhancing ecosystem resilience. These efforts are crucial for mitigating the impacts of climate change and ensuring that communities and natural systems can adapt to a future with potentially more severe and frequent droughts.

2.2.19 Number of days with precipitation above 50 mm

The number of days with precipitation exceeding 50 mm is a climate indicator that provides insight into the frequency of extremely heavy precipitation events. Projections of the number of days with precipitation exceeding 50 mm help understand potential changes in the occurrence of intense and prolonged rainfall. Climate models simulate future scenarios considering factors such as temperature regimes, atmospheric dynamics, and regional climate variations. An increase in the frequency of such events can lead to severe flooding, landslides, and other challenges.

2.2.20 Growing season length

The duration of the growing season is a key climate indicator that represents the period during which temperatures are conducive to plant growth. Projections of the duration of the growing season provide insights into potential changes in the length of favorable conditions for vegetation. Climate models simulate future scenarios considering factors such as temperature regimes, precipitation, and atmospheric dynamics. Changes in the duration of the growing season can affect agricultural yields, alter vegetation patterns, and influence ecological processes. These projections contribute to our understanding of regional climate variability and facilitate the development of strategies for adaptive agriculture, land management, and conservation efforts in response to changes in the timing and length of growing seasons.

2.2.21 Average largest 1-day and 5-day precipitation

The average of the highest daily and 5-day precipitation is a climatic indicator that provides information on the intensity and duration of extreme precipitation events. Projections of the average of the highest daily and 5-day precipitation help understand potential changes in the magnitude and duration of heavy rainfall periods. Climate models simulate future scenarios taking into account factors such as temperature regimes, atmospheric dynamics, and regional climate variations. Changes in the averages of the highest daily and 5-day precipitation can have significant consequences for infrastructure, water resources, and flood resilience. These projections contribute to our understanding of regional climate variability and facilitate the development of strategies for water resource management, improving flood preparedness, and mitigating the impacts of extreme precipitation events in various sectors.

2.2.22 Flood Risk and Flood Depth

Historical analysis: A historical analysis has been done on the area for flood water occurrence at 30 meters spatial resolution. We produced a map of the location and temporal distribution of surface water from 1984 to 2023 and provides statistics on the extent and change of those water surfaces through time. This data was generated using 7,785 scenes from Landsat 4, 5, 7, and 8. Each pixel was individually classified into water / non-water using an expert system and we produced 4 distinct images.

- Water occurrence: The frequency with which water was present. Range between 0 and 100%.
- Water max extent: Binary image containing 1 anywhere water has ever been detected. 0 for no water and 1 for water.
- Water seasonality: Number of months water is present. Range between 0 and 12.
- Water recurrence: The frequency with which water returns from year to year. Range between 0 and 100%.

Flood map indicators: Along with the land classification and the historical analysis already established, we developed an algorithm to derive the severity pixel by pixel of flooding in the study area. This algorithm uses elevation, slope, precipitation projection, distance from river, flow accumulation points, evapotranspiration, and land cover classification.

Elevation and slope were derived from NASA SRTM Digital Elevation 30m, precipitation and consecutive dry days projections for the 2030, 2050, 2070 years at SSP 4.5 and 8.5 were derived from CMIP6, distance from rivers was derived from WWF HydroSHEDS Free Flowing Rivers Network v1, flow accumulation was derived from WWF HydroSHEDS Flow Accumulation, 15 Arc-Seconds, evapotranspiration was derived from MOD16A2.006: Terra Net Evapotranspiration 8-Day Global 500m.

- These inputs were compounded, and they were assigned severity indicator ranging between 1 and 5 where 1 is considered to have a very low chance of flooding and 5 is considered to have a very high chance of flooding. These results were used in an equation where each indicator was given a weight out of 100, and a final severity number was calculated. This severity number indicates which areas will be flooded first in the case of certain flooding scenario.
- Along with the flood severity indicator we produced riverine, and coastal flooding projections for 2030, 2050, 2070 at SSP 4.5 and 8.5 with a 10, 50, 100 return periods.
- Flood Risk formula: (Slope*0.2) + (Precipitation*0.15) + (Precipitation>20mm*0.05) + (Precipitation>50mm*0.1) + (LandCover*0.05) + (FlowDirection&Accumulation*0.15) + (EvapoTranspiration*0.15) + (ConsecutiveDryDays*0.15)
- Slope: slope of each pixel in degrees
- Precipitation: maximum precipitation per pixel in mm/year at different scenarios
- Precipitation>20mm: maximum number of days where precipitation per pixel in higher than 20mm/day at different scenarios
- Precipitation>50mm: maximum number of days where precipitation per pixel in higher than 50mm/day at different scenarios
- Landcover: Level4 landcover map
- FlowDirection&Accumulation: Water accumulation points for each pixel
- EvapoTranspiration: Maximum evapotranspiration per pixel in mm/year at different scenarios
- ConsecutiveDryDays: Maximum number of consecutive dry days per year at different scenarios

2.2.23 Landslide

Landslides refer to the movement of rock, soil, and debris down a slope, often triggered by factors such as heavy rainfall, earthquakes, or human activities. In the context of climate modelling, understanding and predicting landslide susceptibility involves considering climate-related variables such as precipitation patterns and changes in soil moisture.

Landslide = 0.3 * extreme precipitations + 0.1 * soil characteristics + 0.1 * land cover + 0.3 * slope + 0.2 * soil moisture

The extreme precipitation layer was obtained from the World Bank Climate Change Knowledge Portal CMIP6 model output, soil characteristics were obtained from the FAO HWSD v2, land cover data was obtained from the ESRI SENTINEL 10 m database while soil moisture was obtained from the COPERNICUS CMIP6 database. Layers were obtained under NetCDF and tiff format. Subsequent downscaling was performed at 1 km. The weights assigned to the factors stem from the contribution of each to the total risk. Based on this formula, the final landslide layer is presented with a score ranging from 0-1 with values closer to 1 indicating higher risks.

Extreme Precipitation: Extreme precipitation events, such as intense rainfall over a short period or prolonged moderate rainfall, are primary triggers for landslides. This is due to several geophysical processes:

- Increased Pore Water Pressure: When rainfall infiltrates the soil, it increases the water content within the soil pores, leading to higher pore water pressure. Elevated pore water pressure reduces the effective stress that holds soil particles together, weakening the soil structure and making it more susceptible to failure.
- Water-Induced Erosion: High-intensity rainfall can cause surface erosion, removing the protective layer of soil and vegetation, which further destabilizes slopes and initiates shallow landslides.
- Hydrological Loading: In areas with steep slopes, rapid accumulation of water from heavy rain can add additional weight to the slope. This increased load can exceed the shear strength of the soil, leading to a sudden downslope movement.
- Runoff Generation: In cases where the soil becomes saturated and can no longer absorb water, excess rainfall results in surface runoff. This runoff can erode channels and trigger debris flows, a type of landslide characterized by a fast-moving slurry of water, soil, and rock.

Soil Characteristics: Soil properties, such as texture, structure, cohesion, and permeability, play a crucial role in determining slope stability:

- Shear Strength: The shear strength of soil depends on its cohesion (the ability of particles to stick together) and internal friction (resistance to sliding). Soils with high clay content have high cohesion but can become extremely slippery when wet, while sandy soils have low cohesion and are prone to erosion.
- Permeability and Drainage: Soils with high permeability, like sandy soils, allow water to drain through quickly, reducing the risk of pore pressure buildup. Conversely, clayey or silty soils have low permeability, leading to slower drainage and higher susceptibility to landslides due to increased water retention and pore pressure.
- Soil Depth and Composition: Shallow soils over bedrock are more prone to landslides when wet because they lack the depth to absorb and distribute water. Additionally, the presence of weathered material or weak rock layers can serve as slip surfaces, predisposing slopes to failure.

Land Cover: Land cover, particularly vegetation, influences slope stability in several ways:

- Root Reinforcement: Vegetation roots bind soil particles, increasing soil cohesion and shear strength. This "root reinforcement" effect is significant in preventing shallow landslides and stabilizing soil on steep slopes.
- Interception and Evapotranspiration: Vegetation intercepts rainfall, reducing the amount of water that reaches the soil surface. Trees and plants also transpire water, lowering soil moisture content and reducing the risk of saturation and slope failure.
- Surface Protection: Plant cover protects the soil surface from direct rainfall impact, which helps prevent erosion. In contrast, deforested or barren slopes are more susceptible to erosion and subsequent slope instability.
- Land Use Changes: Urbanization, deforestation, and agricultural activities can alter the natural drainage patterns and soil structure, increasing the likelihood of landslides. For example, roads and buildings increase surface runoff and concentrate water flow, destabilizing slopes.

Slope: The slope angle is one of the most fundamental factors influencing landslide susceptibility:

- Gravitational Forces: The steeper the slope, the greater the downslope component of gravitational force acting on the soil mass. This force drives the potential for landslides, particularly when other stabilizing factors (e.g., vegetation, soil cohesion) are compromised.

- Critical Slope Angle: Each material type has a critical slope angle, beyond which the material cannot remain stable. For example, loose, granular materials like sand have a lower critical slope angle compared to cohesive materials like clay.
- Slope Geometry: Convex slopes are more prone to failure due to tension forces, while concave slopes can accumulate water and materials, making them susceptible to debris flows. The presence of irregularities, such as undercut slopes or terraces, can also destabilize slopes.

Soil Moisture: Soil moisture, a measure of the water content in the soil, is a dynamic factor influencing landslide occurrence:

- Saturation and Instability: High soil moisture levels indicate saturated conditions, reducing the effective stress within the soil and increasing the risk of slope failure. Saturated soils lose their shear strength, especially in fine-grained soils like clay.
- Antecedent Moisture Conditions: The amount of moisture present in the soil prior to a rainfall event can significantly influence landslide risk. If the soil is already near saturation, even moderate rainfall can trigger a landslide.
- Hydraulic Conductivity: The rate at which water moves through the soil profile, known as hydraulic conductivity, affects how quickly soils become saturated. Soils with low hydraulic conductivity, such as clayey soils, remain saturated for longer periods, increasing landslide risk.

This methodology integrates multiple environmental layers to create a composite landslide risk map, where each layer represents a critical factor contributing to landslide susceptibility. Here's a detailed breakdown of the steps involved:

1. Data Acquisition and Sources

- Extreme Precipitation (World Bank Climate Change Knowledge Portal, CMIP6 Model Output):

The CMIP6 (Coupled Model Intercomparison Project Phase 6) dataset provides climate projections, including future scenarios for precipitation patterns. Extreme precipitation data is critical for understanding the frequency and intensity of rainfall events that can trigger landslides.

The data was obtained as NetCDF files, a common format for climate data, storing variables like precipitation intensity and duration over spatial grids.

- Soil Characteristics (FAO HWSD v2):

The FAO Harmonized World Soil Database (HWSD) v2 provides global soil properties such as texture, organic matter content, and drainage capacity, which influence soil stability.

- Land Cover (ESRI SENTINEL 10 m Database):

This database provides high-resolution land cover data from Sentinel-2 satellite imagery, offering insights into vegetation cover, urban areas, and other land uses that impact slope stability.

- Soil Moisture (COPERNICUS CMIP6 Database):

Soil moisture data from the CMIP6 database indicates the amount of water present in the soil, affecting the soil's weight and cohesion.

Soil moisture data, usually available as time series in NetCDF format, helps in understanding the antecedent conditions that predispose an area to landslides.

2. Data Preprocessing and Format Conversion

The datasets were obtained in NetCDF (Network Common Data Form) and TIFF (Tagged Image File Format).

NetCDF is used for multidimensional climate and environmental data, allowing the storage of variables such as precipitation, temperature, and soil moisture in a spatial-temporal context.

TIFF is a raster format commonly used for storing spatial data like land cover and soil maps at high resolutions.

3. Reprojection and Resampling:

Each dataset was reprojected to a common spatial reference system to ensure spatial alignment, which is crucial for overlaying different layers.

Resampling was performed to ensure that all datasets have the same spatial resolution, necessary for accurate risk assessment. In this case, downscaling to a resolution of 1 km was done, with larger resolution data (e.g., CMIP6) interpolated to match the target resolution.

4. Data Cleaning and Filtering:

Precipitation and soil moisture datasets were filtered to remove outliers or spurious values, which could skew the risk assessment.

Soil and land cover data underwent a classification process to categorize soil types and land use into relevant classes for the analysis.

5. Downscaling to 1 km Resolution

Purpose of Downscaling:

The original datasets have varied in their spatial resolution. For instance, global climate models often operate at coarse resolutions (e.g., 100 km), which are not suitable for local-scale analysis. Downscaling was performed to refine this data to 1 km resolution, providing more granular and actionable information using empirical bayesian kriging semi-variograms

6. Weight Assignment to Factors
- Rationale for Weights:

Weights were assigned to each factor based on their relative contribution to landslide risk. This was derived from empirical studies and expert judgment that quantify the influence of each factor.

Normalization:

The weights were adjusted to ensure that the combined index reflects the relative contribution of each factor correctly. This step involves adjusting the weights accordingly to sum to 1.

7. Calculating the Composite Landslide Risk Index
- Standardization of Layers:

Each layer (e.g., precipitation, slope) was standardized to a common scale (0-1), where 0 represents low susceptibility and 1 represents high susceptibility. Standardization involved transforming the raw data into percentile ranks or using a min-max scaling approach.

- Weighted Sum Calculation:

The standardized layers were multiplied by their respective weights and summed up to generate the final risk score for each pixel. This risk score ranges from 0 to 1, indicating increasing levels of landslide risk.

8. Final Output: Landslide Risk Map

Risk Classification: The final landslide risk index was categorized into classes (e.g., low, moderate, high, and very high risk) to facilitate interpretation and application.

2.3 Climate Methodologies

2.3.1 What is Downscaling

Downscaling is a method that derives local-to-regional-scale (1 km) information from larger-scale models or data analyses. High-resolution climate or climate change information will be obtained from relatively coarse-resolution GCMs. There are two broad categories of downscaling procedures: dynamical downscaling (DD) techniques and statistical (or empirical) downscaling (SD) procedures. SD methods will be used in this project (Kriging) as they offer several practical advantages over DD procedures, especially in terms of flexible adaptation to specific study purposes, and inexpensive computing resource requirements.

However, there is no “best” downscaling method or dataset, and the best method/dataset for a given problem depends on that problem’s specific needs. Several data products based on downscaling higher-level spatial data are available. The appropriate method and dataset to use depends on the intended application. The method selected will be able to credibly resolve spatial and temporal scales relevant for the application.

In general, when a problem depends on using a large number of climate models and emission scenarios to perform preliminary assessments and to understand the uncertainty range of projections, then using a statistical downscaled dataset is recommended. When the assessment needs a more extensive parameter list or is analysing a region with few long-term observational data, dynamically downscaled climate change projections are recommended.

2.3.1.1 Kriging

Kriging is a geostatistical interpolation technique that can be used to predict unknown values at specific locations based on the values at surrounding locations. In the context of climate data analysis, Kriging can be applied to downscale climate projections from General Circulation Models (GCMs) to a finer spatial scale, which is more meaningful for analysing local and regional climate conditions.

The process begins with obtaining data in NetCDF format from the CMIP6 outputs. This data is then rasterized to be downscaled to the corresponding scale. By transposing NetCDFs to raster and then points, the gridded network will be assimilated to a weather station network. The different points holding different climatic values can be considered as “spatial weather stations”. Through a specific Kriging technique based on the use of semi variograms, spatiotemporal variations will be revealed.

Semi variograms are statistical tools used in geostatistics to assess the spatial autocorrelation of measured sample points. The semi variogram depicts how the similarity between two random variables decreases as the distance between them increases. It is commonly represented as a graph that shows the difference in measure and the distance between all pairs of sampled locations. There are certain characteristics that are commonly used to describe these models:

- Range: The distance where the model first flattens out is known as the range. Sample locations separated by distances closer than the range are spatially autocorrelated, whereas locations farther apart than the range are not.
- Sill: The value that the semi variogram model attains at the range (the value on the y-axis) is called the sill.
- Nugget: At zero separation distance (lag = 0), the semi variogram value is theoretically 0. However, at an infinitesimally small separation distance, the semi variogram often exhibits a nugget effect, which is some value greater than 0.

Spatiotemporal variations refer to changes in measured properties of interest across different locations (spatial variability) and different time intervals (temporal variability) in a field or region. For example, in the context of climate data, spatiotemporal variations might refer to how temperature or precipitation varies across different geographical locations and at different times of the year. These variations can be analysed using various techniques to understand the distribution and association of spatial phenomena over time. The full complexity of spatiotemporal patterns can only be recognized over time.

A relationship between alphanumeric and spatial variations will be established based on historical data. by comparing the historical satellite data with the algorithm applied on historical climatic projections. This relationship will then be applied to the projection data. To ensure that the simulated data aligns well with the observed data, a spatial correlation analysis and validation test will be conducted using this historical data. This approach, which couples simulated projections with observed historical data, aims to minimise discrepancies from actual conditions and reduce the likelihood of errors related to data. By leveraging historical data in this way, we can enhance the accuracy and reliability of our projections.

As most data will be transposed into GIS format, a detailed spatiotemporal evolution will be ensured. Accordingly, areas of particular vulnerability will be highlighted, hence allowing subsequent prioritised proactive and/or reactive measures. This ensures evidence and priority-based budget allocation for orienting interventions.

The implicit assumptions made are: (1) The predictors are variables of relevance and are realistically modelled by the GCM, (2) The transfer function is valid also under altered climatic conditions. This is an assumption that in principle cannot be proven in advance. The observational record should cover a wide range of variations in the past; ideally, all expected future realisations of the predictors should be contained in the observational record. (3) The predictors employed fully represent the climate change signal. The climate change projections will add value to the existing stock of highly detailed information that will be suitable to the project's capacity to replicate the process and acceptable to users too. The downscaled projections developed through this project will be at a scale that can be used for climate impact assessments at multiple different levels (figure5).

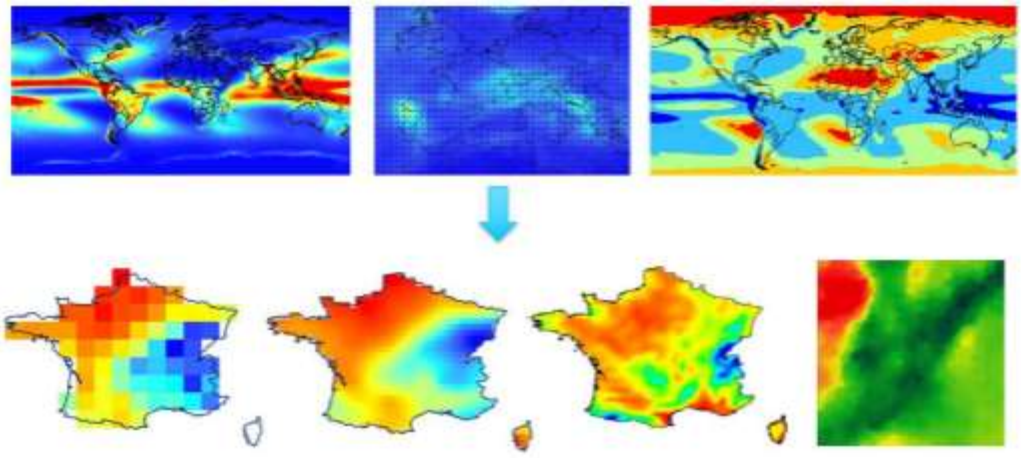


Figure 5 An example of our downscaling efficiency from 100 km to 1 km

2.3.2 Supervised Classification

Supervised classification is a method in machine learning where the model is trained on a labelled dataset to predict or classify new, unseen data. The model learns from the training dataset to understand how to best map examples of input data to specific class labels. This process is akin to a student-teacher interaction, where the 'teacher' provides specific feedback on the algorithm's performance.

There are four main types of classification tasks in machine learning: binary, multi-class, multi-label, and imbalanced classifications.

- Binary classification involves predicting one of two classes. It's used in scenarios where there are only two possible outcomes, such as determining whether an email is spam or not.
- Multi-class classification involves predicting one of more than two classes. An example would be classifying a set of images into multiple categories.
- Multi-label classification involves predicting one or more classes for each example. This is used when each example can belong to multiple classes.
- Imbalanced classification refers to classification tasks where the distribution of examples across the classes is not equal.

Each type of classification has its own advantages and disadvantages.

- Binary classification is straightforward and computationally efficient, but it's limited to problems with only two classes.
- Multi-class classification can handle problems with more than two classes, but it can be more complex and computationally intensive.
- Multi-label classification can handle problems where each example can belong to multiple classes, but it can be challenging to model the correlations between different classes.
- Imbalanced classification can handle problems with unequal class distributions, but it can be difficult to achieve good performance for the minority class.

Supervised and unsupervised classification represent two distinct methodologies in machine learning. Despite these challenges, supervised classification is often preferred over unsupervised classification because it tends to be more accurate and reliable, especially for complex land cover types that are difficult to distinguish spectrally. However, it requires more effort and expertise to select the training samples and assign them to the correct classes. Supervised classification involves training a model on a labelled dataset, where the input data used for training is paired with corresponding output labels. The model learns to map the input variables to the desired output, enabling it to produce precise predictions or classifications when faced with new, unobserved data. The user has more control over the classification process as they manually select the training data and assign them to the correct classes. On the other hand, unsupervised classification uses machine learning algorithms to analyse and cluster unlabeled dataset. These algorithms discover hidden patterns in data without the need for human intervention1. Unsupervised classification is automated and does not require any user input. It involves grouping unlabeled data based on their similarities or differences. While supervised learning relies on labelled data to predict outputs, unsupervised learning uncovers hidden patterns within unlabeled data

There are several ways to apply supervised classification, including logistic regression, support vector machines (SVM), decision trees, artificial neural networks, and instance-based learners. Each of these methods has its own strengths and weaknesses, and the choice of method depends on the specific problem at hand.

Google Earth Engine (GEE) is particularly well-suited for supervised classification due to its ability to handle large-scale geospatial datasets. GEE provides a variety of machine learning algorithms for supervised classification, including CART, RandomForest, NaiveBayes, and SVM. These classifiers can be used to perform a variety of tasks, such as land cover mapping, urban planning, and environmental monitoring.

The general workflow for performing supervised classification is as follows:

- Collect training data: This involves identifying a set of training points for different classes (e.g., water, forest, urban) on the satellite imagery.

- Assemble features: The features should have a property that stores the known class label and properties storing numeric values for the predictors.
- Instantiate a classifier: Set its parameters if necessary.
- Train the classifier: This is done using the training data.
- Classify an image or feature collection: The trained classifier is then used to classify the rest of the satellite image into the predefined classes.
- Estimate classification error: This is done with independent validation data.

2.3.3 PySEBAL Model

The core principle behind PySEBAL is the surface energy balance, which is based on the conservation of energy at the Earth's surface. The energy balance equation is:

$$Rn - G = H + LE$$

- **Net Radiation (Rn):** This is the sum of all incoming and outgoing radiation at the surface. It includes:
    - Shortwave Radiation: Incoming solar radiation minus the reflected portion (albedo).
    - Longwave Radiation: Incoming and outgoing thermal radiation. The surface emits longwave radiation based on its temperature, which is influenced by the Stefan-Boltzmann law.
- **Soil Heat Flux (G):** This represents the energy that is conducted into the soil. It is typically a small fraction of the net radiation, often estimated using empirical relationships based on surface temperature and vegetation cover.
- **Sensible Heat Flux (H):** This is the heat transferred between the surface and the air due to temperature differences. It is calculated using the aerodynamic resistance, which depends on wind speed and surface roughness.
- **Latent Heat Flux (LE):** This is the energy used for evapotranspiration, the process of water vaporizing from soil and plant surfaces. It is the residual term in the energy balance equation.

Remote Sensing Principles:

PySEBAL leverages remote sensing data and climatic models to estimate the components of the energy balance. Key remote sensing principles include:

- **Spectral Reflectance:** Different surfaces (e.g., water, vegetation, soil) reflect and absorb solar radiation differently across various wavelengths. By analyzing these spectral signatures, we can infer surface properties.
- **Thermal Infrared (TIR) Data:** TIR bands provide surface temperature data, which is crucial for calculating sensible heat flux and net radiation.
- **Vegetation Indices:** Indices like NDVI (Normalized Difference Vegetation Index) are derived from visible and NIR bands to estimate vegetation cover and health, which influence evapotranspiration rates

Actual Implementation of PySEBAL:

1. **Data Acquisition and Preprocessing**

Satellite Data: Landsat 4,5,7,8 and 9 images are acquired, ensuring they cover the study area and time period of interest. These images are pre-processed to correct for radiometric and atmospheric effects, and to mask out clouds and any erroneous pixels.

Meteorological Data: Weather data is collected from CFSV2: NCEP Climate Forecast System Version 2, including air temperature, wind speed, and solar radiation. This data is essential for calibrating the model and scaling instantaneous ET to daily values.

2. **Energy Balance Calculation**

- **Net Radiation (Rn):** Calculate using surface albedo, surface temperature, and incoming solar radiation. The formula is:

$$Rn=(1-\alpha)*Rs+Rl_{in}-Rl_{out}$$

where α is the albedo, Rs is the incoming shortwave radiation, Rl_{in} is the incoming longwave radiation, and Rl_{out} is the outgoing longwave radiation.

- **Soil Heat Flux (G):** Estimate as a fraction of Rn, typically using empirical relationships:

$$G=c*Rn$$

where c is a coefficient that varies with surface conditions.

- **Sensible Heat Flux (H):** Calculate using the temperature gradient between the surface and the air, and the aerodynamic resistance:

$$H=\rho*c_p*(T_s-T_a)/r_a$$

where ρ is the air density, c_p is the specific heat of air, T_s is the surface temperature, T_a is the air temperature, and r_a is the aerodynamic resistance.

3. **Evapotranspiration Estimation**

- **Instantaneous ET:** Calculate using the latent heat flux at the time of the satellite overpass. Convert LE to ET using the latent heat of vaporization:

$$ET_{inst}= LE/\lambda$$

where λ is the latent heat of vaporization.

- **Daily ET:** Scale the instantaneous ET to daily values using meteorological data and diurnal temperature variations. This involves integrating the instantaneous ET over the course of a day.

3. Pilot data

Data plays a crucial role in pilot execution, providing the objective foundation for decision-making and performance evaluation, which ultimately contributes to model development. Accurate data collection and analysis enable real-time monitoring and adjustments, ensuring that implemented strategies are effective and align with established objectives. The quality and accuracy of data not only facilitate the identification of areas for improvement and the adaptation of practices but also optimise resource use and enhance the overall sustainability of the systems.

3.1 Impact on Pilots

3.1.1 Data homogeneity

3.1.1.1 Naming of relevant variable

It is crucial to establish a standard criterion for identifying the relevant climatic and agricultural conditions in all pilots. This should include the precise definition of the following types of parameters:

1. **Climate parameters**: temperature, humidity, solar radiation, among others.
2. **Soil parameters**: conductivity, soil moisture, concentration of soluble solids, etc.
3. **Geographical location**: characteristics of the terrain, such as mountainous areas, plateaus, desert areas, among others.

The correct identification and uniformity in the naming of these parameters will allow a more effective comparability of the data between the different pilots, facilitating a more robust analysis.

3.1.1.2 Sampling time

To ensure the comparability and consistency of the data obtained in the different pilots, it is essential to define a sampling frequency that allows to adequately capture climate variations both in the short and long term. This process involves selecting time intervals that not only reflect pre-established changes, but also align with seasonal cycles and critical phases of process development. It is therefore recommended to adjust the sampling frequency to the specific action cycles of each process, considering both climatic and agricultural factors. A well-planned sampling period should ensure that all key parameters are monitored in a timely and accurate manner, which will facilitate a more robust interpretation and thorough analysis of the data over time.

3.1.1.3 Format of the data file

The data collected must be homogeneous in a format to facilitate efficient and accurate analysis. It is recommended to use standard and widely accepted file formats, with clearly defined labels for each parameter, ensuring interoperability with Big Data platforms. In addition, it is essential to define a format that allows robust traceability of the data, complying with the previously established requirements. This ensures that the information obtained faithfully reflects the conditions of the environment, employing methods that ensure the accuracy and correct execution of the processes. Thus, it is ensured that the data collected accurately represents the reality of the monitored environment.

3.1.2 Importance of input data and its relationship with target

3.1.2.1 Method of relevant parameters selection

It is essential to apply advanced variable selection methodologies to identify the most influential parameters in agricultural production and climate resilience. These methodologies can include linear regression models, logistic regression, multivariate analysis, or more complex techniques such as principal component analysis (PCA) and machine learning algorithms, such as random forest or neural networks.

Proper parameter selection not only optimises the accuracy of predictive models, but also reduces computational complexity and data acquisition cost. By identifying key variables, within climatic conditions, soil conditions, water resources, and nutritional levels, monitoring and control efforts can be focused on the factors that have the greatest impact on productivity and sustainability.

In addition, it is critical that the parameter selection process takes into account the interactions between variables. Factors such as temperature, humidity and cultivation practices not only influence individually, but also interact with each other, jointly affecting agricultural results. A robust approach must identify these interrelationships and select the parameters that provide a complete view of the agricultural system. Finally, it is important that the selection process is aligned with the specific objectives of the agricultural production system, based on the respective use cases of the pilot.

3.1.2.2 Importance of maintain the favorable range

It is important that the selected parameters are kept within a predefined optimal range to ensure both the accuracy of the data and the health of the agricultural production system. Keeping these values within the appropriate limits allows you to quickly identify potential sensor errors or failures in monitoring systems, ensuring the integrity of the data collected.

In addition, maintaining parameters within the favourable range is essential to maximise the yield of the agricultural process and minimise the stress caused by adverse conditions. The selected factors have critical thresholds that, if exceeded or kept outside the optimal range for prolonged periods, can negatively affect the development of the farming system and resource efficiency.

Constant monitoring of these parameters is equally important for the implementation of adaptation strategies. Detecting early deviations allows corrective decisions to be made, the dose to be modified or protection systems to be activated against extreme elements. In a context of climate change, where environmental conditions can vary unpredictably, keeping these parameters within the favourable range not only improves the resilience of the system, but also contributes to sustainability.

3.1.2.3 Implications of surpassing high threshold

Exceeding the thresholds set out in the parameters can have serious consequences, causing significant stress and compromising both immediate performance and sustainability. Excess temperature, for example, can accelerate dehydration, disrupt natural processes, and reduce nutrient absorption, resulting in lower productivity and quality of development.

In the case of soil salinity, if levels exceed the tolerable limits of the cultivated species, it can inhibit the ability of the roots to absorb water, causing osmotic stress and ultimately reduced crop growth and yield. This not only affects production in the short term, but can also cause irreversible damage to the structure and fertility of the soil, compromising its productive capacity in future cycles, affecting the entire related biological cycle. In addition, exceeding critical thresholds can have an impact on the efficiency of input usage. For example, when the temperature is too high, irrigation water evaporates more quickly, requiring an increase in water supply to maintain optimal conditions, increasing operating costs. Similarly, in soils with high salinity, it may be necessary to employ soil washing techniques or improve drainage systems, which implies a greater use of resources and energy.

On an ecological level, exceeding these thresholds can also destabilise surrounding ecosystems, affecting biodiversity and altering the natural balance. Ultimately, exceeding high thresholds not only affects the productivity and sustainability of the agricultural system, but also has implications for resilience to climate change and other external factors.

3.1.2.4 Implications of surpassing low threshold

When critical parameters fall below minimum thresholds, both in cropping systems and in animal husbandry, adverse effects can be generated that compromise growth, productivity and general health. In crops, insufficient soil moisture levels can limit water availability, reducing nutrient uptake and affecting plant development. Likewise, temperatures that are too low can slow down photosynthesis and cause damage that compromises the quality and quantity of production.

In animal production systems, exceeding low temperature or humidity thresholds can induce stress in animals, reducing their welfare, growth and productivity. For example, temperatures below optimal ranges can cause an increase in metabolic demand to maintain body temperature, leading to lower performance in milk, meat, or egg production. Similarly, insufficient humidity can increase the risk of respiratory diseases and skin conditions, affecting the health and welfare of animals.

Furthermore, a lack of critical nutrients, both in soil for crops and in animal feed, can result in a reduction in growth efficiency. In crops, a deficiency of key nutrients decreases the ability of plants to carry out vital functions such as protein formation and photosynthesis. In animals, the shortage of essential nutrients in their diet affects growth, production, and resistance to disease.

Falling parameters below critical thresholds not only affects immediate yield, but also has long-term impacts on the sustainability of crop and livestock systems. Weakened crops or animals under suboptimal conditions require higher inputs, such as additional irrigation, fertilisers, or feed supplements, which increases operating costs. Therefore, continuous monitoring and prompt correction of critical parameters are critical to avoid negative effects on productivity, animal health, and overall system sustainability.

3.2 Evaluation of the developed the agroclimatic monitoring method

3.2.1 Evaluation in terms of the climate impact in short horizon

3.2.1.1 Climate control

It is essential to evaluate the climate control system implemented in the pilots to determine its effectiveness in managing extreme conditions and its impact on the agricultural and livestock environment in the short term. This assessment should look at how the system handles extreme temperatures, humidity levels, and other key parameters that affect both crops and animals.

For crops, it is crucial to check how the climate control system keeps temperatures within optimal ranges and regulates relative humidity to avoid heat or water stress conditions that can negatively affect plant growth and development. The assessment should include the system's ability to respond quickly to sudden changes in climate and adjust environmental conditions to minimise adverse impacts. In the case of animal production, it must be evaluated how the system controls temperatures and humidity to ensure the welfare of the animals. It is important to analyse how variations in these parameters influence animal health, performance and comfort. An effective system should be able to maintain optimal conditions that prevent health problems related to heat stress or excessive humidity, thus ensuring sustainable and efficient production.

Additionally, the assessment should consider the system's ability to integrate real-time data and make automatic adjustments or recommendations for proactive climate management. The effectiveness of the climate control system should also be measured based on its impact on reducing operating costs associated with mitigating adverse conditions and improving productivity and sustainability of both crops and animals.

3.2.1.2 Soil control

Evaluating the soil control system implemented in pilots is important to determine its effectiveness in managing and maintaining soil conditions in the short term. This assessment should look at how the system monitors and regulates critical soil parameters, such as moisture, salinity, temperature, and nutrient levels, to ensure an optimal environment for both crops and animals.

In crops, it is necessary to evaluate how the system controls and adjusts soil moisture to avoid drought or saturation conditions, which can negatively impact plant growth. It is also important to check how the system detects and manages elevated salinity levels or nutritional deficiencies that can affect soil health and crop productivity. The system's ability to make precise adjustments based on real-time measurements is essential to maintaining soil quality and fertility. However, in animal production, soil control can also influence the management of housing and grazing spaces. The assessment should consider how the system maintains optimal conditions in grazing areas and in the animal housing environment, ensuring that the soil does not degrade or become a risk to animal health. This includes managing soil compaction, erosion, and waste accumulation, which can affect habitat quality and animal welfare.

The assessment should look at how the system integrates soil data with other environmental variables to provide a holistic view of conditions in fields and grazing areas. The system's ability to make recommendations based on accurate, real-time data, and to facilitate proactive soil management, is critical to optimising soil health, crop sustainability, and animal welfare.

3.2.2 Evaluation in terms of the climate impact in long horizon

3.2.2.1 Farming practices

Assessing how the agricultural practices implemented in the pilots contribute to resilience to climate change in the long term is a relevant factor. This assessment should consider several key aspects related to the sustainability and environmental impact of the practices employed, such as soil conservation, reduction of greenhouse gas emissions, and resource efficiency.

Soil conservation: Evaluate the effectiveness of agricultural practices in preserving soil health and structure over time. This includes looking at management techniques such as crop rotation, the use of cover crops, no-tillage, and the implementation of erosion barriers. The assessment should measure how these practices contribute to moisture retention, improved soil fertility and reduced erosion, factors that are crucial to maintaining the productivity and resilience of the agricultural system in the face of prolonged climate change.

Emissions reduction: Examine the impact of agricultural practices on reducing emissions of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NO_x). The assessment should include the effectiveness of strategies such as optimising fertiliser use, manure management, and adopting carbon capture technologies. Reducing emissions not only contributes to mitigating climate change, but can also improve the long-term sustainability of agricultural practices.

Resource use efficiency: Evaluate how agricultural practices optimise the use of critical resources such as water, nutrients, and energy. This includes looking at the implementation of efficient irrigation systems, integrated pest and disease management, and the adoption of advanced technologies for resource monitoring and control. The evaluation should measure how these practices affect resource utilisation efficiency and their ability to adapt to variations in resource availability due to climate change.

3.2.2.2 Biodiversity

It is essential to analyse the impact of pilot practices on local biodiversity, assessing both the positive and negative effects on agricultural ecosystems over time. This assessment should consider several key aspects related to the preservation and promotion of biodiversity in the context of the agricultural practices implemented.

Positive effects: Examine how agricultural practices promoted in the pilots can contribute to the enhancement of biodiversity. This includes evaluating the implementation of techniques such as planting diverse crops, creating conservation habitats (e.g., hedges, areas of natural vegetation, and ponds), and using practices that favour the presence of pollinators and other beneficial organisms. The assessment should measure how these practices influence species richness and abundance, ecosystem health, and the stability of biological communities.

Negative effects: Identify and analyse the potential negative impacts that agricultural practices may have on local biodiversity. This includes assessing the effects of simplifying agricultural landscapes, intensive use of pesticides and fertilisers, and monoculture practices that can reduce species diversity and deteriorate natural habitats. The assessment should consider how these impacts affect the structure and function of ecosystems, as well as their ability to provide crucial ecosystem services.

Monitoring and adaptation: Assess the monitoring methods employed to track changes in biodiversity over time and the ability of agricultural practices to adapt to these changes. This includes analysing the frequency and accuracy of biodiversity observations and how the results obtained influence decision-making and adjustments in agricultural practices. The assessment should consider the capacity of the systems to implement corrective measures and promote biodiversity recovery in the event of identified negative impacts.

3.2.2.3 Water and carbon footprint

In the pilots' practices, it is necessary to evaluate the water and carbon footprint, considering how they affect the use and management of water and greenhouse gas emissions over time. This assessment should analyse how agricultural practices influence the sustainability of water resources and the contribution of agricultural activities to climate change.

Water footprint

Water consumption: Evaluate how implemented agricultural practices affect water consumption in crop and livestock systems. This includes analysing the efficiency of irrigation systems, water management at different stages of the crop, and reducing water losses. The assessment should measure how these practices affect the demand for water resources and their impact on local and regional water sources.

Water Quality: Examine how agricultural practices influence water quality, considering the reduction of runoff and the leaching of contaminants such as nutrients and pesticides. The assessment should include the effectiveness of practices to prevent contamination of water sources and maintain the health of aquatic ecosystems.

Carbon footprint

Greenhouse Gas Emissions: Assess how agricultural practices affect greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NO_x). This includes analysing the contribution of activities such as fertiliser application, manure management and tillage practices to total emissions. The assessment should determine how these practices impact the carbon footprint and their contribution to climate change.

Carbon Sequestration: Examine the capacity of agricultural practices to capture and store carbon in soil and plant biomass. This includes looking at techniques such as crop rotation, the use of cover crops, and agroforestry. The assessment should measure how these practices contribute to increasing carbon storage and reducing the overall carbon footprint.

3.2.3 Recommendation of adaptation strategies

Based on the detailed analysis of the factors presented in the previous sections, the appropriate adaptation strategies will be defined and implemented to achieve the objectives established in the pilots to be developed. The formulation of these strategies is essential to build a clear and effective roadmap that guides decision-making in the management of animal farming and production systems.

Definition of Strategies

Specific Objectives: To establish specific goals based on the results of the climate, soil and geographical impact analysis, as well as on the evaluation of the water and carbon footprint. These goals should be quantifiable and aligned with long-term sustainability and resilience goals.

Adaptive Approaches: Identify and prioritise adaptive approaches that allow agricultural and livestock practices to be adjusted in response to changing environmental conditions. This can include adopting advanced technologies, changing management practices, and implementing innovative solutions to optimise resource use.

Implementation Plan: Develop a detailed plan that defines the implementation stages, the resources needed, and those responsible for each action. This plan should include specific timelines and metrics to evaluate the progress and effectiveness of the strategies.

Development of a Roadmap

Strategy Structuring: Create a roadmap that provides a structured and sequential view of the actions to be taken. This roadmap should include the steps needed for the implementation of the strategies, the timelines for each phase, and the checkpoints for continuous evaluation.

Integration of Technological Solutions: Incorporate the technological solutions proposed in the roadmap in a way that complements and reinforces adaptation strategies. This includes the integration of monitoring systems, data analysis tools, and soil and climate control technologies.

Management Model Optimization

Added Value: Ensure that adaptation strategies and technological solutions bring added value to animal farming and production systems. This means maximising operational efficiency, improving sustainability, and increasing resilience in the face of climate challenges.

Evaluation and Adjustment: Implement a continuous evaluation system to monitor the performance of the strategies and adjust the management model based on the results obtained. This includes regularly reviewing success metrics and adapting strategies in response to new information or changing conditions.

The formulation and implementation of adaptation strategies based on these principles will provide a robust and flexible framework that will support informed decision-making and improve the effectiveness of pilots. By structuring the model effectively, the integration of technological solutions will be facilitated and the fulfilment of long-term sustainability and resilience objectives will be ensured.

4. Cap Performance Indicators:

4.1 CAP contribution to climate change mitigation and adaptation

Food systems around the world are facing unprecedented challenges: the increasingly evident effects of climate change are being combined with biodiversity loss, soil degradation, volatile agricultural markets and other environmental and socio-economic crises.

There is growing evidence about the effects of climate change on agriculture, that are mainly driven by:

- changes in precipitation
- changes in temperature
- periodicity and severity of extreme events
- rise in sea level
- increase in CO2 concentration

These drivers have direct and indirect effects on the level and the variability of crop yields. Climate disruptions end up affecting crop yields and cause damage to structures and infrastructure in the countryside. Extreme events therefore have consequences on ecological functions, farms and the food market at European level.

These aspects are thoroughly measured within D 4.2 by means of a wide set of historical indicators, short term and long term future projections (see Chapter 3, Climate indicators). This analysis allows us to anticipate future scenarios and take action in order to mitigate climate change effects on agricultural production.

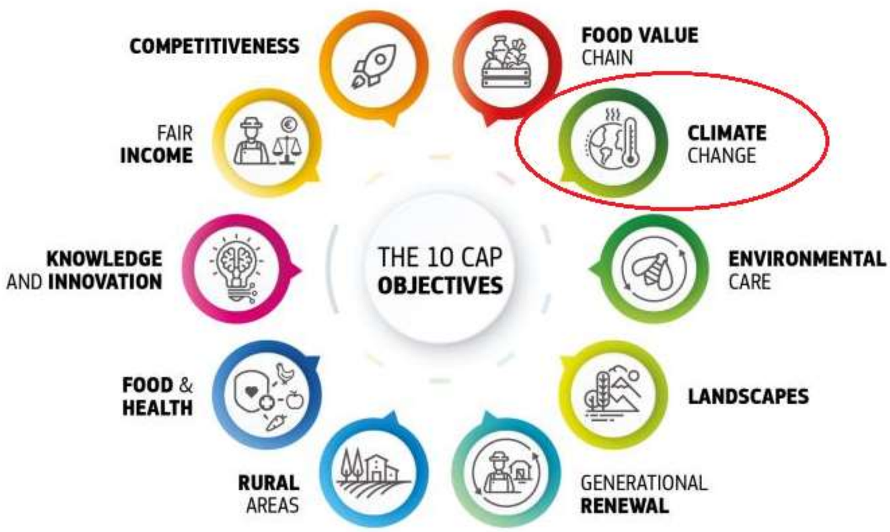


Figure 6 CAP 2023-2027 macro-objectives

Contributing to climate change mitigation is one of the key policy objectives of the new CAP (Specific objective n.4). EU agriculture has a key role to play in helping to reach the commitments of the Paris' agreement and EU strategies on sustainability, including the EU Green Deal.

This sector suffers from the consequences of climate change but it is also the cause of some negative impacts on the environment which are addressed and mitigated by the measures entailed in the new CAP.

The European Commission has identified the following indicators in order to measure CAP's performance in the field of climate change mitigation and adaptation:

SPECIFIC OBJECTIVE 4

CONTRIBUTING TO CLIMATE CHANGE MITIGATION AND ADAPTATION

To contribute to climate change mitigation and adaptation, including by reducing greenhouse gas emissions and enhancing carbon sequestration, as well as to promote sustainable energy.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
GHG emissions from agriculture	C.45	GHG emissions from agriculture
Mean organic carbon content	C.41	Mean organic carbon content
Production of renewable energy	C.43	Production of renewable energy
	C.44	Agricultural trade balance
Physical area under AECM	OIR_06_1.1	Physical area under AECM

Figure 7 CAP Indicators - Specific Objective 4

The indicator "**GHG emissions from agriculture**" (C.45) is composed of two sub-indicators, one assessing greenhouse gas (GHG) emissions[1] and one ammonia emissions[2].

Soil organic carbon, the major component of soil organic matter, is extremely important in all soil processes. The indicator estimates the total organic carbon content in arable soils. It is important to maintain and increase the carbon content in agricultural soils, since it has positive benefits on the soil health and on improving the farm's resilience to climate change (such as drought).

Finally, the indicator "**production of renewable energy**" aims at measuring the production of renewable energy from agriculture and forestry (C.43) and the direct use of energy in agriculture, forestry and food processing (C.44).

The new CAP has set higher environmental standards for Member States to be implemented through national CAP plans. Farmers are encouraged to adopt environmentally friendly practices by means of several incentives, such as:

- enhanced conditionality: beneficiaries of the CAP have their payments linked to a stronger set of mandatory requirements. For example, on every farm at least 3% of arable land is dedicated to biodiversity and non-productive elements, with a possibility to receive support via eco-schemes to achieve 7%. Wetlands and peatlands are also protected.

[1] The indicator measures net GHG emissions (methane (CH_4) and nitrous oxide (N_2O)) from agriculture including agricultural soils. That sector includes the following sources of GHG from agriculture: enteric fermentation of ruminants (CH_4; manure management (CH_4, N_2O); rice cultivation (CH_4); agricultural soil management (mainly CH_4, N_2O); emissions of methane (CH_4) and nitrous oxide (N_2O) from agricultural land uses (grassland and cropland)

[2] This indicator measures total annual ammonia emissions (NH_3) from agriculture, also broken down by subcategory as follows: Synthetic N-fertilizers; Cattle dairy; Cattle non-dairy; Swine; Laying hens; Broilers; All other agricultural subsectors (as a difference)

- eco-schemes: at least 25% of the budget for direct payments is allocated to eco-schemes, providing stronger incentives for climate-and environment-friendly farming practices and approaches (such as organic farming, agro-ecology, carbon farming, etc.) as well as animal welfare improvements;
- rural development: at least 35% of funds are allocated to measures to support climate, biodiversity, environment and animal welfare;
- operational programmes: in the fruit and vegetables sector, operational programmes allocate at least 15% of their expenditure towards the environment;
- climate and biodiversity: 40% of the CAP budget has to be climate-relevant and strongly support the general commitment to dedicate 10% of the EU budget to biodiversity objectives by the end of the EU's multiannual financial framework (MFF) period

4.2 Climate change impact on CAP environmental performance indicators

The European Commission has identified the following specific objectives and related indicators in order to track CAP's environmental performance:

SPECIFIC OBJECTIVE 5

PROTECTING NATURAL RESOURCES

To foster sustainable development and efficient management of natural resources such as water, soil and air, including by reducing chemical dependency.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
Soil erosion by water	C.42	Soil erosion by water (*)
Ammonia emissions	C.45	Emmissions from agriculture
Surplus of N and P	C.40	Water quality
Water quality	C.40	Water quality
Water abstraction in agriculture	C.39	Water abstraction in agriculture
Sustainable use of pesticides	C.48	Sales of plant protection products
Farming intensity	C.33	Farming intensity

Figure 8 CAP Indicators - Specific Objective 5

Soil, water and air are essential to the functioning of agriculture and forestry.

Soil in the EU is facing a number of challenges which are directly linked to climate change, including erosion, degradation, and desertification, as well as a decline in organic matter and loss of biodiversity.

Water is vulnerable to a number of challenges, often associated with unsustainable management practices. Such challenges include:

- pollution from pesticide residues, fertilisers, and chemicals;
- heavy sedimentation caused by soil erosion;
- overuse, unsustainable abstraction.

Water is also a key factor due to climate change, which implies flooding and rising sea levels contaminating land and water resources, glaciers, ice caps and snow fields rapidly disappearing, but also draughts.

Air quality is mainly linked with vehicular emissions but also agricultural emissions.

In order to protect the natural resources essential to agriculture, the CAP:

- safeguards both the quantity and quality of **water** used in agriculture by establishing buffer strips along watercourses, supporting beneficial farming practices, more efficient irrigation systems, and enhancing the enforcement of rules in nitrate vulnerable zones;
- sets mandatory standards for minimum **soil** cover and encourages further practices that limit soil erosion and maintain organic matter;
- protects **air quality** by encouraging reductions in ammonia emissions, placing restrictions on the burning of residues and preventing the spraying of pesticides in windy conditions.

The above mentioned indicators aim at measuring the CAP performance in protecting natural resources, thereby considering the complex ecosystems of soil, water and air. These indicators also encourage good practices, such as extensive grazing, efficient water management, sustainable use of pesticides and keeping land cover against erosion. Soil, water and air are going to suffer the impact of climate change over time. The new CAP aims at reducing these effects by adopting several measures to defend these complex ecosystems.

Another important specific objective of the CAP in the environmental field is **"Halting and reversing biodiversity loss"**.

SPECIFIC OBJECTIVE 6

HALTING AND REVERSING BIODIVERSITY LOSS

To contribute to halting and reversing biodiversity loss, enhance ecosystem services and preserve habitats and landscapes.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
Farmland Bird Index	C.35	Farmland Bird Index (FBI) (*)
Conservation status of agricultural habitats	C.36	Conservation status of agricultural habitats (grassland)
Area under NATURA 2000	C.34	Natura 2000 areas
Area under organic farming	C.19	Agricultural areas under organic farming

Figure 9 CAP Indicators - Specific Objective 6

Climate change will lead to major environmental shocks, thereby putting at risk several species and reducing genetic diversity. This will lead to an increased vulnerability to pests, diseases and other pressures which will ultimately damage our food system. Through Specific Objective 6, the European Commission aims at halting biodiversity loss and increasing the area under organic farming, which has a significantly lower carbon footprint because fossil fuel-based fertilisers and most synthetic pesticides are prohibited.

4.3 Climate change impact on agricultural practices and CAP socio-economic performance indicators

The European Commission has identified a wide range of indicators measuring the potential socio-economic impact of the CAP.

SPECIFIC OBJECTIVE 1

SUPPORTING VIABLE FARM INCOME

To support viable farm income and resilience of the agricultural sector across the Union in order to enhance long-term food security and agricultural diversity as well as to ensure the economic sustainability of agricultural production in the Union.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
Agricultural entrepreneurial income	C.26	Agricultural entrepreneurial income (*)
Agricultural entrepreneurial income and wages	Non CMEF indicator	Agricultural entrepreneurial income and wages
Agricultural factor income	C.25	Agricultural factor income (*)

SPECIFIC OBJECTIVE 2

INCREASING COMPETITIVENESS

To enhance market orientation and increase farm competitiveness both in the short and long term, including greater focus on research, technology and digitalisation.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
Total factor productivity	C.27	Total factor productivity in agriculture (*)
	C.14	Labour productivity in agriculture
Gross fixed capital formation in agriculture	C.28	Gross fixed capital formation in agriculture
Cost and revenue structure of income	Non CMEF indicator	Cost and revenue structure of agricultural income
Agri-food trade imports and exports	I.06	Agricultural trade balance
Ratio EU prices versus world market	I.04	EU commodity price variability
Number of farms, hectares and Livestock units	C.17	Agricultural holdings (farms)
	C.18	Agricultural area
	C.21	Livestock units
	C.33	Farming intensity

Figure 10 CAP Indicators - Specific Objective 1 and 2

SPECIFIC OBJECTIVE 3

STRENGTHENING THE POSITION OF FARMERS IN VALUE CHAINS

To improve the farmers' position in the value chain.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
Value added for primary producers in food chain	RPI_03	Value for primary producers in the food chain
Agricultural output per sector	Non CMEF indicator	Agricultural output per sector

Figure 11 CAP Indicators - Specific Objective 3

SPECIFIC OBJECTIVE 7

ATTRACTING YOUNG AND NEW FARMERS

To attract and sustain young farmers and new farmers and facilitate sustainable business development in rural areas.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
Attracting young farmers	C.23	Age structure of farm managers
Agricultural training of young farmers	C.24	Agricultural training of farm managers
Economic farm size by age class	C.17	Agricultural holdings (farms)

SPECIFIC OBJECTIVE 8

PROMOTING GROWTH AND EQUALITY IN RURAL AREAS

To promote employment, growth, gender equality, including the participation of women in farming, social inclusion and local development in rural areas, including the circular bio-economy and sustainable forestry.

SECTION	INDICATOR CODE	INDICATOR NAME AND DOCUMENTATION
Employment rates for age group 20-64	C.05	Rural employment rate
GDP per capita	C.08	GDP per capita
Distribution of CAP support	OID_00_1	Direct Payments (DP)
Poverty rate in rural areas	C.09	Degree of rural poverty
Number of tourist beds	C.30	Tourism infrastructure

Figure 12 CAP Indicators - Specific Objective 7 and 8

Climate change will have a significant impact on several socio-economic indicators as identified by the European Commission. Food insecurity will cause economic instability for the sector, minimise revenues, increase poverty and keep the young generations away from this sector.

The CAP 2023-2027 has paid particular attention to the socio-economic implications of the agricultural sector by adopting several indicators in this field.

The CAP provides income support with priority for small and medium-sized farms and young farmers. It encourages Member States to implement more flexible tax and inheritance rules and improve young farmers' access to land. It also links financial support with more sustainable agricultural practices (i.e. reduction of pesticides or antibiotics).

4.4 ADV contribution to the CAP 2023-2027 and future perspectives

The Common Agricultural Policy (CAP), representing over a third of the EU budget, relies heavily on data for its design, monitoring, and evaluation. The European Commission has recognized the importance of an evidence-based approach in policy decisions, which necessitates the integration of various data sources and subsequent analysis. This approach ensures that policy decisions are informed by the best available evidence, including quantitative data like statistics and measurements, and qualitative data such as stakeholder input and expert advice.

Despite the Commission's efforts to utilize existing data, several barriers hinder the optimal use of collected data. These include a lack of standardization and limitations due to data aggregation, which reduce data availability and usability. The Commission has initiated several legislative and other measures to improve data usage, but challenges remain.

The role of data in CAP is multifaceted. It is crucial for assessing the performance of the CAP in relation to its objectives, which include improving living standards in the agricultural community, addressing environmental and climate-related aspects, and fostering rural development. The Commission uses large volumes of data, primarily administrative, collected from Member States. However, the current tools and data do not always provide significant elements needed for well-informed policy-making, such as details on environmental practices and off-farm income.

While the Commission has made strides in leveraging data for CAP policy-making, ongoing efforts are needed to overcome existing barriers and fully harness the potential of data-driven decisions. This includes improving data standardization, enhancing data-sharing mechanisms, and adopting advanced analytical tools to ensure that policy decisions are based on comprehensive and reliable data.

In alignment with these efforts, projects like the ADV initiative provide a significant contribution toward optimizing data usage in agricultural policy-making. By identifying specific indicators (historical, long-term future projections and short term future indicators), which are closely related to CAP macro-objectives, the ADV project will be able to foresee the future impacts of climate change on agriculture and foster mitigation measures, while at the same time allowing an efficient use of resources.The ADV contribution could raise awareness in the agricultural sector about the need to take action and implement mitigation measures which could include several solutions, i.e. the use of mitigation technologies, better soil management and reduction in agricultural production losses and waste.

Furthermore, the ADV project is also consistent with CAP macro-objective 10 - Fostering knowledge and innovation, because it supports modernisation in agriculture and rural areas through promoting and sharing knowledge, innovation and digitalisation, and by encouraging their uptake by farmers through improved access to research, innovation, knowledge exchange and training.

As a local CAP Paying Agency, APPAG has access to some useful data related to the Trentino region, in which it operates.

This data includes the following:

- Agricultural land use (macro-level): it is a document whose purpose is to verify both the agricultural use of the undeveloped areas and the type of crops in place at the time of the survey. The map, thus allowing each part of the territory to be associated with its actual use, represents an important tool for the socio-economic analysis of the agricultural crops carried out and a fundamental support for identifying and monitoring the anthropic pressures that can negatively affect the territorial conditions that define an optimal balance between urban settlement and the maintenance of agricultural ecosystems already present in the territory.
- Trentino farms graphic crop plans (micro-level): tool which allows to detail the polygons corresponding to the planned crops on the farm based on the Land Parcel Identification System (LPIS). LPIS is a register, unique for the entire national territory, of all agricultural areas, created and updated in compliance with European Union and national regulations. It is based on the archive of digital orthophotos from aerial or satellite images of the territory, which allows for the acquisition of qualitative and quantitative data, broken down into agricultural parcels and represented on a Geographical Information System (GIS).

The LPIS makes it possible to geolocalise, visualize and spatially integrate the constituent data of the Integrated Administration and Control System (IACS) at agricultural parcel level and to determine land use and maximum eligible areas under the various Union aid schemes.

Graphical data is integrated with farmers' declarations of land use and validated by APPAG's cross-checks and on-site inspections when provided for by national and provincial legislation.

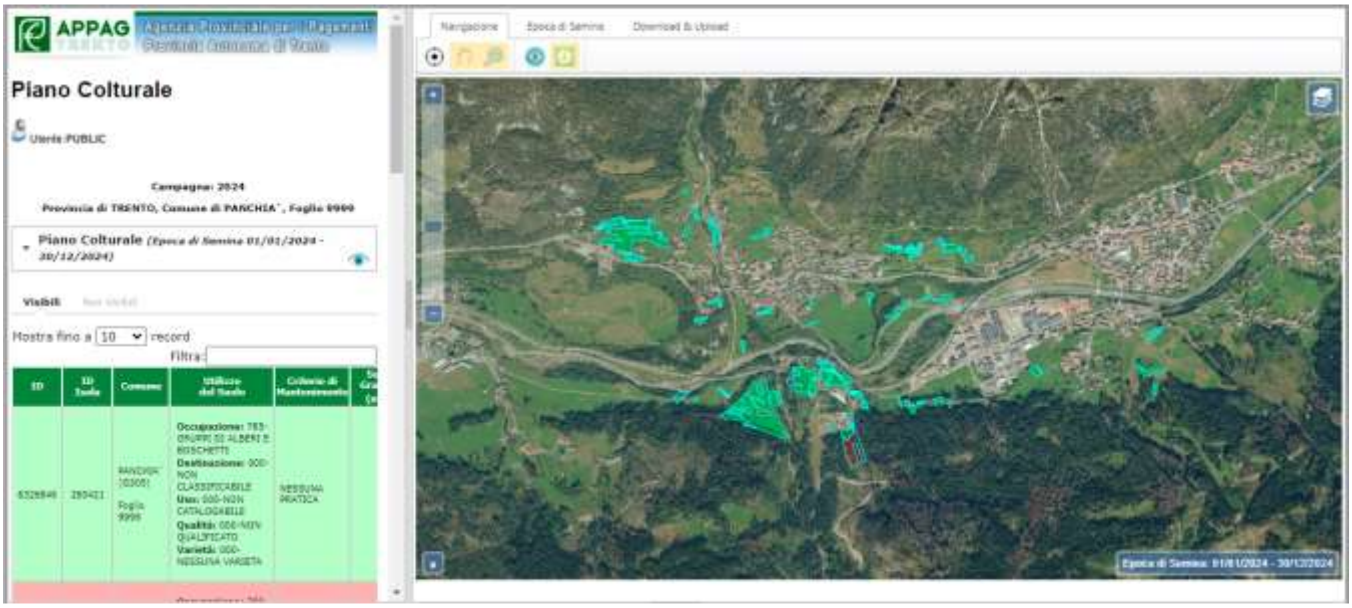
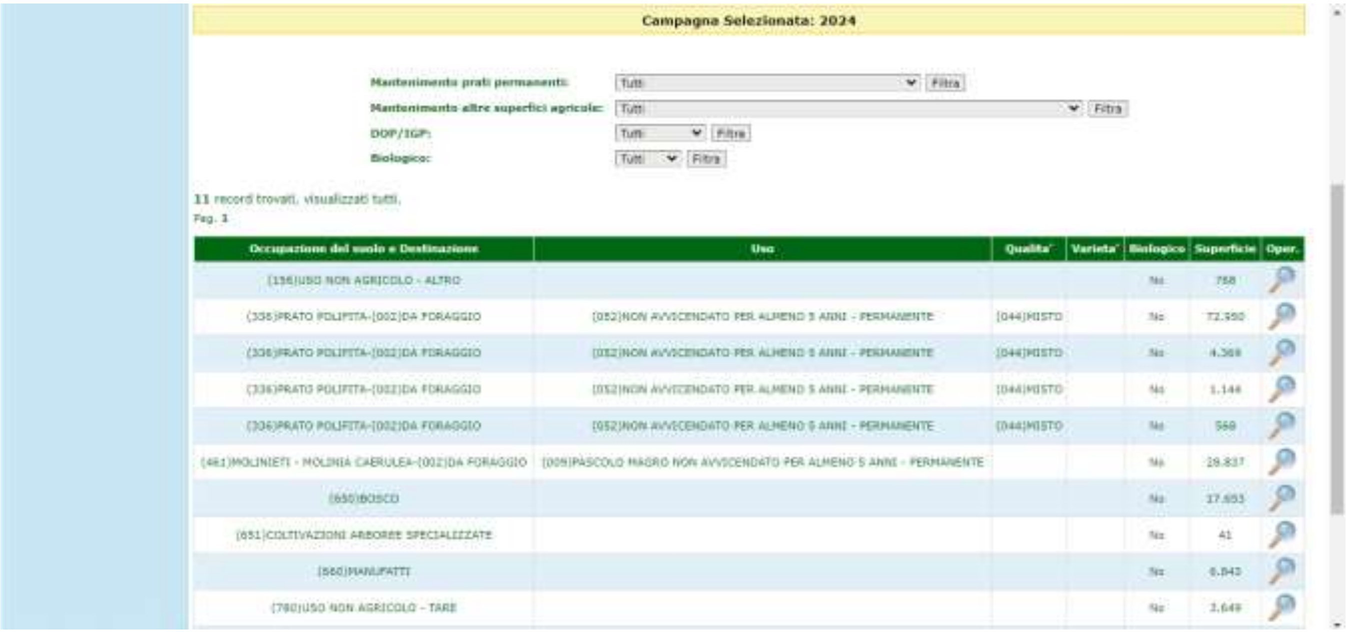


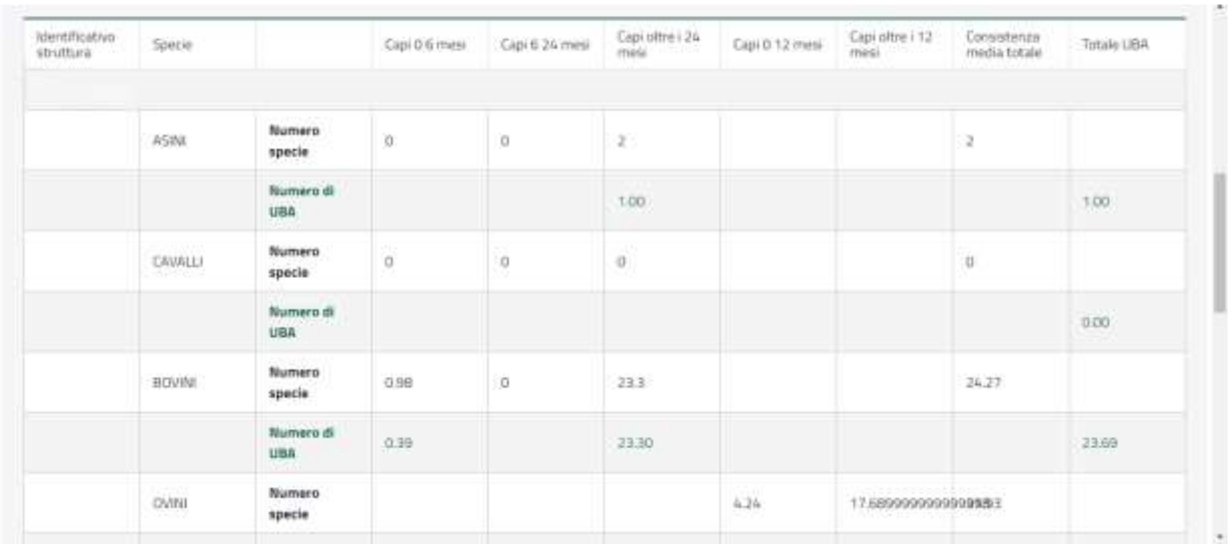
Figure 13 Company graphic crop plan



Occupazione del suolo e Destinazione	Uso	Qualita'	Varieta'	Biologico	Superficie	Oper.
(156)USO NON AGRICOLO - ALTRO				No	758	
(336)PRATO POLIFITA-(002)DA FORAGGIO	(052)NON AVVICENDATO PER ALMENO 5 ANNI - PERMANENTE	(044)MISTO		No	72.950	
(336)PRATO POLIFITA-(002)DA FORAGGIO	(052)NON AVVICENDATO PER ALMENO 5 ANNI - PERMANENTE	(044)MISTO		No	4.369	
(336)PRATO POLIFITA-(002)DA FORAGGIO	(052)NON AVVICENDATO PER ALMENO 5 ANNI - PERMANENTE	(044)MISTO		No	1.144	
(336)PRATO POLIFITA-(002)DA FORAGGIO	(052)NON AVVICENDATO PER ALMENO 5 ANNI - PERMANENTE	(044)MISTO		No	569	
(461)MOLINIETI - MOLINIA CAERULEA-(002)DA FORAGGIO	(009)PASCOLO MAGRO NON AVVICENDATO PER ALMENO 5 ANNI - PERMANENTE			No	28.837	
(650)BOSCO				No	17.653	
(651)COLTIVAZIONI ARBOREE SPECIALIZZATE				No	41	
(660)MANUFATTI				No	6.843	
(780)USO NON AGRICOLO - TARE				No	3.649	

Figure 14 Land use. The farmer declares the destination of each parcel, i.e. non-agricultural use, forage meadow, forest, specialized tree crops etc

- Livestock database: it provides information on factories/farms, herds, animals, movements and slaughterings. The constant updating of data makes it possible to create a dynamic register that provides real-time information on the livestock population of Trentino;



Identificativo struttura	Specie		Capi 0 6 mesi	Capi 6 24 mesi	Capi oltre i 24 mesi	Capi 0 12 mesi	Capi oltre i 12 mesi	Consistenza media totale	Totale UBA
	ASINI	**Numero specie**	0	0	2			2	
		Numero di UBA			1.00				1.00
	CAVALLI	**Numero specie**	0	0	0			0	
		Numero di UBA							0.00
	BOVINI	**Numero specie**	0.98	0	23.3			24.27	
		Numero di UBA	0.39		23.30				23.69
	OVINI	**Numero specie**				4.24	17.689999999999998		

Figure 15 Livestock population of a company: type of livestock, age, total livestock units (LU)

ALLEVAMENTI

	Specie	Identificativo della struttura	Comune della struttura	Codice fiscale proprietario	Codice fiscale detentore	Tipologia di allevamento	Tipo produzione	Orientamento produttivo
›	BOVINI		PANCHIA'			-	ALLEVAMENTO	LATTE
›	CAVALLI		PANCHIA'			-	ALLEVAMENTO	Q
›	OVINI		PANCHIA'			STABULATO O INTENSIVO	ALLEVAMENTO	CARNE
›	ASINI		PANCHIA'			-	ALLEVAMENTO	Q
›	OVINI		PANCHIA'			ALL'APERTO O ESTENSIVO	ALLEVAMENTO	MISTO
›	BOVINI		VILLE DI FIEMME			STABULATO O INTENSIVO	ALLEVAMENTO	LATTE
›	OVINI		PANCHIA'			ALL'APERTO O ESTENSIVO	ALLEVAMENTO	MISTO

Figure 16 Livestock population of a company: type of livestock, location, type of breeding (intensive or loose stabling), type of production

- Provincial register of pastures: it collects and manages all the information on Trentino's pastures. Each pasture is georeferenced and the grazing areas pertaining to the mountain pasture certified. The maintenance and management of pasture areas has a strong environmental and landscape value by favoring the conservation of biodiversity, ecosystems, the environment, the landscape and historical and cultural traditions.

The provincial pasture register consists of three separate georeferenced databases: the pasture register, the alpine pasture register and the grazing register.

1. In the Pasture Land Register, each pasture is identified by one or more grazing units referable to a single property and each pasture is described in a separate sheet.
2. In the alpine pasture register, on the other hand, alpine pastures are listed and described as buildings functionally linked to a pasture.
3. In the grazing register, the pasture areas are delimited and classified by photo-interpretation, according to the tare criterion (no tare - tare 20% - tare 50% - tare 70%), and included in each individual pasture unit.

5. Climate impact projection on soil, crops, livestock, and biodiversity

Climate change has profound and wide-ranging effects on agriculture, impacting various processes within agro-environmental systems (AES), including soil health, cropping systems, livestock production, and biodiversity, both directly and indirectly. Over the past few decades, research has increasingly focused on projecting the impacts of climate change on these critical components. Researchers have used forecasted climate data and integrated simulation models to evaluate these impacts across diverse scenarios. These models have been extensively applied in numerous studies to predict the effects of climate change on these interconnected systems under different conditions. The results have been regularly reviewed and evaluated by national and international organizations, notably by the IPCC, which offers policy-relevant scientific insights into the impacts of and adaptations to climate change.

Activities specifically related to the task T4.4 will address the following two objectives:

1. **Assess the Vulnerability of Agricultural Activities and Biodiversity to Projected Climate Impacts**: This objective focuses on using the indicators from Task 4.1 and projections from Task 4.3 to evaluate how different agricultural practices and biodiversity will be affected by climate change. The goal is to identify key areas of vulnerability within agriculture and biodiversity that may require attention or adaptation.
2. **Develop and Benchmark Adaptation Strategies for Enhancing Agricultural Resilience**: This objective aims to identify, evaluate, and benchmark effective adaptation strategies and practices that can be implemented to mitigate the negative impacts of climate change on agriculture and biodiversity. The goal is to provide actionable recommendations for improving the resilience of agricultural systems in the face of climate change.

To address these objectives this chapter contributes to the design phase methodologies and plans developed in the task at the current stage of the project. The proposed method summarises a framework for assessing projected climate change impact in AES, within the context of the AgriDataValue (ADV) project. The approach follows the steps of an environmental impact assessment as outlined by the Food and Agriculture Organization of the United Nations (FAO) (2020) [14]. These steps are as follows, sourcing the indicators and their projection, mapping each indicator to AES impacted, delineating scope to ADV, literature-based benchmarking, and development of impact projections and adaptation strategies as presented in Figure 17.

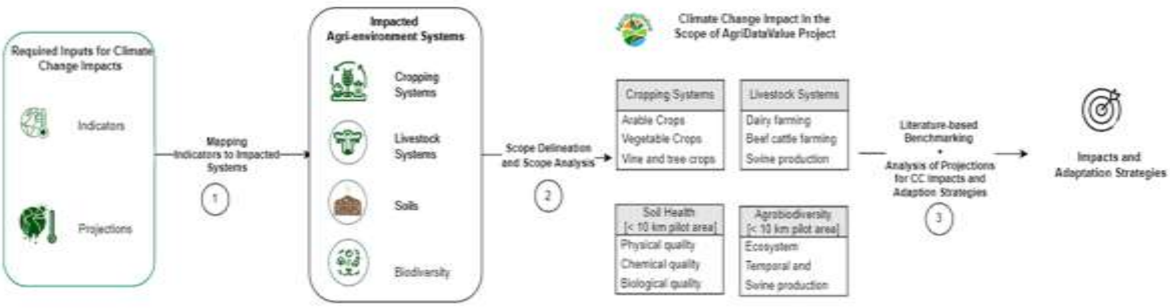


Figure 17 Schematic representation of activity roadmap of T4.4 activities to develop climate change impact projection and adaptation strategies

5.1 Overview of Requirements for Climate Impact Projection in Agri-environment Systems

Candidate Indicators: T4.1 developed a comprehensive set of indicators to assess the impact of climate change on agricultural systems. Historical data, sourced from the Landsat and Sentinel Archives, going back to 1985, were used to generate these indicators. They include key metrics such as land cover classification, land surface temperature, evapotranspiration, soil composition, the normalized difference water index, and more. These indicators serve as a baseline for understanding how agricultural systems have responded to environmental changes over time and set the foundation for future projections.

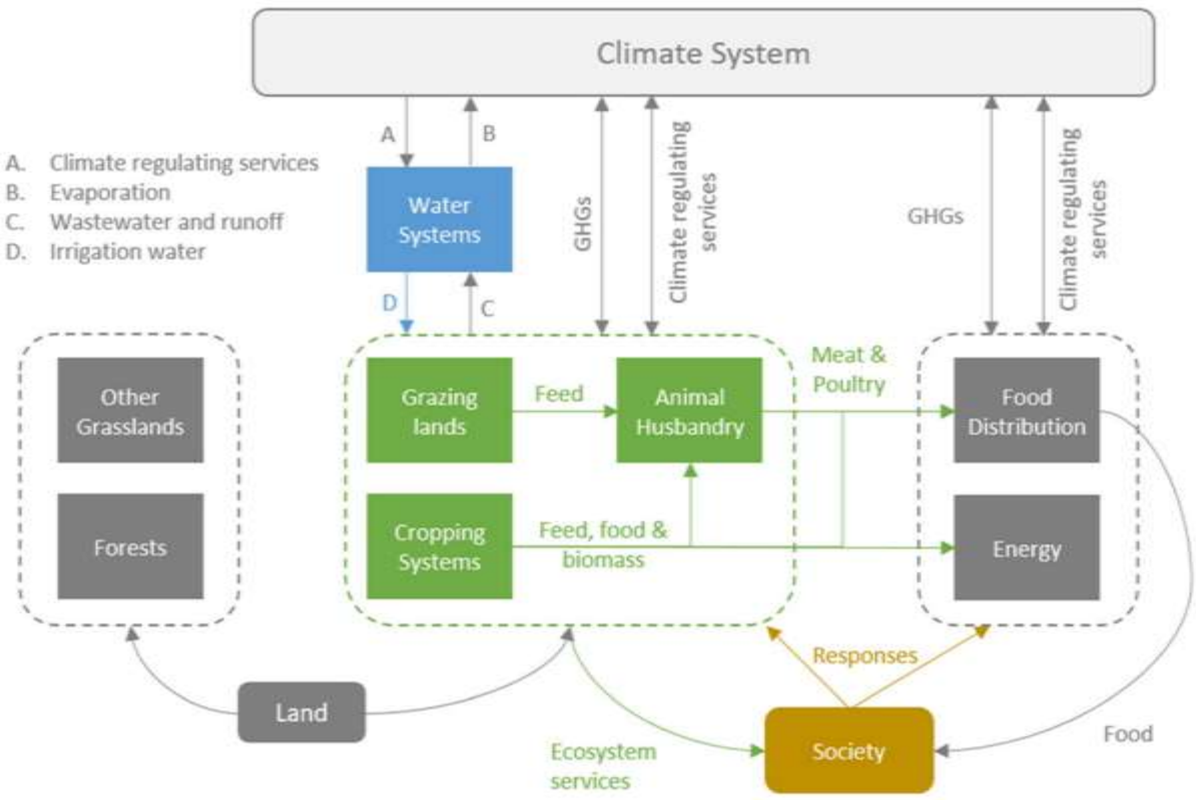


Figure 18 Conceptual diagram of potential indicators of climate impacts on agricultural systems (adapted from Hatfield et al., 2020)

Indicator Projections: building upon these historical indicators T4.3 will generate projections using CMIP6 models for the years 2030, 2050, and 2070 under two scenarios: SSP2-4.5 and SSP5-8.5. These projections include indicators like air temperature, soil water storage capacity, precipitation, drought frequency, and snowfall flux, covering both short-term (2025-2030) and long-term (2030-2070) periods. Short-term projections focus on specific metrics such as near-surface air temperature, wind speed, and humidity, while the long-term projections encompass a broader range of 23 indicators. These projections will be downscaled to 1km and 10 km resolutions to allow us to project climate change impacts on specific components of agricultural systems within the ADV pilot study areas.

Impacted Components of Agriculture: Agricultural systems are multi-faceted and complex because of the range of plant and animal commodities, and environments affected by the interactions between climate and management. Key components of AES considered for assessment of climate change in agricultural systems included cropping systems, livestock systems, soil health, and (agro)-biodiversity. Cropping systems will face challenges related to shifts in growing seasons, water availability, and crop productivity, leading to changes in crop types, planting schedules, and overall agricultural practices. Livestock systems will be affected by increased heat stress, altering feed availability and quality, and affecting animal health, growth rates, and reproduction. Soil health, a crucial foundation for sustainable agriculture, could degrade due to erosion, nutrient depletion, and changes in moisture retention, threatening long-term productivity. Agrobiodiversity, which supports the resilience of agricultural ecosystems, may decline as climate change alters habitats, reduces species diversity, and disrupts the balance of organisms essential for pest control, pollination, and nutrient cycling. Together, these impacts highlight the need for adaptive strategies to protect the sustainability and productivity of agricultural systems.

5.2 Mapping of Candidate Indicators to Impacted Agri-environment Systems

To effectively assess the impact of climate change on agricultural systems, a detailed mapping of candidate indicators to the affected agri-environment systems is essential. This mapping aligns historical and projection indicators with specific components such as cropping systems, livestock systems, soil health, and agrobiodiversity. For cropping systems, indicators related to land cover classification, temperature variations, and water availability are crucial, as they directly influence crop yield, growth cycles, and irrigation needs. In livestock systems, indicators like heat stress and water availability impact animal health and productivity. Soil health is assessed through indicators such as soil composition, erosion, and moisture levels, which are fundamental for maintaining soil fertility and structure. Agrobiodiversity is mapped using indicators related to land cover changes, species diversity, and ecosystem health, ensuring that the diversity of crops, livestock breeds, and wild species is monitored. This systematic approach provides a comprehensive framework for understanding and adapting to climate change impacts across all relevant components of agricultural systems. In Table 1. A literature-based mapping of candidate indicators generated in T4.1 is mapped with potential impacts on the identified components of agricultural systems.

Table 1 Mapping Climate Indicators to Impacts on Soil, Cropping Systems, Livestock Systems, Biodiversity, and Potential Adaptations

Indicator	Soil	Cropping Systems	Livestock Systems	Biodiversity
Historical Indicators				
Land cover classification	Soil erosion and degradation	Land use changes impacting crop types	Habitat loss affecting grazing lands	Habitat changes affecting species composition
Land Surface Temperature	Soil moisture loss	Crop stress due to increased heat	Heat stress on livestock	Thermal stress affecting ecosystems
Temperature condition index	Soil moisture variation	Crop yield prediction	Livestock health	Species migration patterns
Heat stress index	Soil degradation	Crop failure due to heat stress	Increased mortality in livestock	Reduction in species population
Vegetation health index	Soil fertility changes	Crop productivity	Grazing area quality	Plant species health
Evapotranspiration	Soil moisture depletion	Irrigation needs for crops	Water availability for livestock	Water stress affecting plant species
Normalized difference water index	Soil moisture and erosion	Water availability for crops	Water resources for livestock	Wetland habitat health
Temperature vegetation dryness index	Soil aridity	Drought impact on crops	Impact on water resources for livestock	Vegetation loss
Normalized burn ratio	Post-fire soil recovery	Fire impact on croplands	Fire impact on grazing lands	Habitat destruction

Historical flood mapping	Soil erosion and nutrient loss	Flood impact on cropland	Livestock loss due to floods	Loss of habitat for aquatic species
Soil composition	Soil fertility	Crop suitability	Pasture quality	Habitat suitability
Normalized snow index (snow area, extent)	Soil insulation and moisture retention	Impact on growing seasons	Water availability for livestock	Snow-dependent species' habitats
Climate Future Projections				
Air temperature	Soil temperature changes affecting structure	Crop growth cycles	Heat stress on livestock	Altered habitat ranges
Capacity of soil to store water	Soil water retention capacity	Irrigation needs	Water resource management	Impact on wetland ecosystems
Daily maximum near-surface air temperature	Soil thermal dynamics	Crop stress	Heatwaves affecting livestock	Species heat tolerance
Daily minimum near-surface air temperature	Soil freeze-thaw cycles	Growing season length	Cold stress on livestock	Shift in cold-adapted species
Evapotranspiration including sublimation	Soil moisture and salinity	Irrigation requirements	Water availability	Water cycle changes affecting species
Moisture in upper portion of soil column	Soil moisture dynamics	Crop water needs	Pasture quality	Impact on plant growth
Near-surface air temperature	Soil temperature fluctuations	Crop yield	Temperature stress on livestock	Habitat shifts
Near-surface relative humidity	Soil moisture balance	Crop diseases	Livestock respiratory health	Humidity-dependent species
Precipitation	Soil erosion and nutrient leaching	Crop yield and water needs	Water resources for livestock	Impact on ecosystems
Snowfall flux	Soil insulation and moisture content	Snowmelt timing affecting water for crops	Water availability	Habitat conditions for snow-dependent species
Cold spells duration	Soil freeze impacts	Crop loss	Cold stress on livestock	Impact on cold-adapted species
Number of frost days (Tmin < 0°C)	Soil frost impact on structure	Frost damage to crops	Cold-related livestock mortality	Impact on frost-sensitive species
Number of ice days (Tmax < 0°C)	Soil freeze	Crop damage	Cold stress	Ice cover affecting species
Number of hot days (T > 35°C)	Soil moisture evaporation	Heat stress on crops	Heat stress on livestock	Heat stress on species
Number of very hot days (T > 45°C)	Severe soil moisture loss	Crop failure risk	Severe heat stress on livestock	High mortality rates in heat-sensitive species
Number of consecutive dry days	Soil drought and desertification	Drought stress on crops	Water scarcity for livestock	Desertification affecting ecosystems
Drought frequency and severity	Long-term soil degradation	Crop yield reduction	Long-term water scarcity for livestock	Loss of drought-sensitive species
Number of days with precipitation above 20 mm	Soil erosion and nutrient loss	Waterlogging impacting crops	Livestock loss due to flooding	Flooding affecting habitats
Number of days with precipitation above 50 mm	Severe soil erosion	Flood risk to crops	Severe flood risk to livestock	Extreme flood risk to ecosystems
Growing season length	Soil preparation for planting	Crop yield	Grazing availability	Impact on seasonal species
Average largest 1-day and 5-day precipitation	Soil erosion	Flood risk to crops	Livestock safety during extreme events	Habitat flooding

Flood Risk and Flood Depth	Soil and nutrient loss	Crop loss due to flooding	Livestock displacement	Ecosystem disruption
Landslide	Soil stability	Destruction of cropland	Loss of grazing land	Habitat destruction
Short Term Future Projections				
Near-surface specific humidity	Soil moisture balance	Crop health	Respiratory health in livestock	Humidity-sensitive species
Precipitation	Soil erosion, moisture balance	Crop yield	Water resources	Impact on ecosystems
Surface downwelling longwave radiation	Soil warming	Crop growth cycles	Temperature regulation for livestock	Energy balance in ecosystems
Surface downwelling shortwave radiation	Soil heating	Photosynthesis in crops	Thermal comfort for livestock	Solar radiation affecting plant growth
Daily mean near-surface wind speed	Soil erosion and drying	Wind stress on crops	Respiratory issues in livestock	Wind patterns affecting species
Daily near-surface air temperature	Soil temperature fluctuations	Crop health and yield	Livestock comfort and health	Habitat temperature dynamics
Daily minimum near-surface air temperature	Soil cooling	Frost risk to crops	Cold stress on livestock	Cold-tolerant species
Daily maximum near-surface air temperature	Soil heating	Heat stress on crops	Heat stress on livestock	Habitat overheating

5.3 Benchmarking Adaptation Practice and Mechanism

In the literature, it is noted that changes in global temperatures can profoundly impact the occurrence of pathogens in agricultural and natural ecosystems, increasing the risk of exposure to new pests and pathogens [24]. In the context of the ADV project, the benchmarking activity for mapping the impact of global climate change on the agri-environment system (AES) will focus on developing models that would affect the natural habitat of the environment. One of the critical threats affecting the AES from global warming is the projected increase in the abundance of many fungal soil-borne plant pathogens, with significant consequences for primary productivity of cropping systems. Warming temperatures are attributed to the development of new strains of pathogens that are better adapted and more virulent. The severity of Fusarium head blight of wheat is likely to increase due to the shift from the milder Fusarium culmorum that prefers cool and wet conditions to the more aggressive Fusarium graminearum that prefers warm and humid conditions [15]. Similarly, more aggressive and temperature-tolerant novel strains of Puccinia striiformis have replaced older strains and are causing major outbreaks of wheat rust in the United States, Australia and Europe [16, 17]. Warming temperatures can increase the range of many pathogens that are currently limited by requirements for overwintering, such as wheat stem rust caused by Puccinia graminis f. sp. tritici [18]. On the other hand, over a period of 30 years with a steady rise in summer temperatures, local extinction of Triphragmium ulmarie, the rust pathogen that infects Filipendula ulmaria (meadowsweet), was observed. Other pathogens, such as Phytophthora infestans, are predicted to be little impacted by warming temperatures due to their lower thermal preferences [19]. In Figure 19, one of the methodology published for the evaluation of new disease triangle is presented.

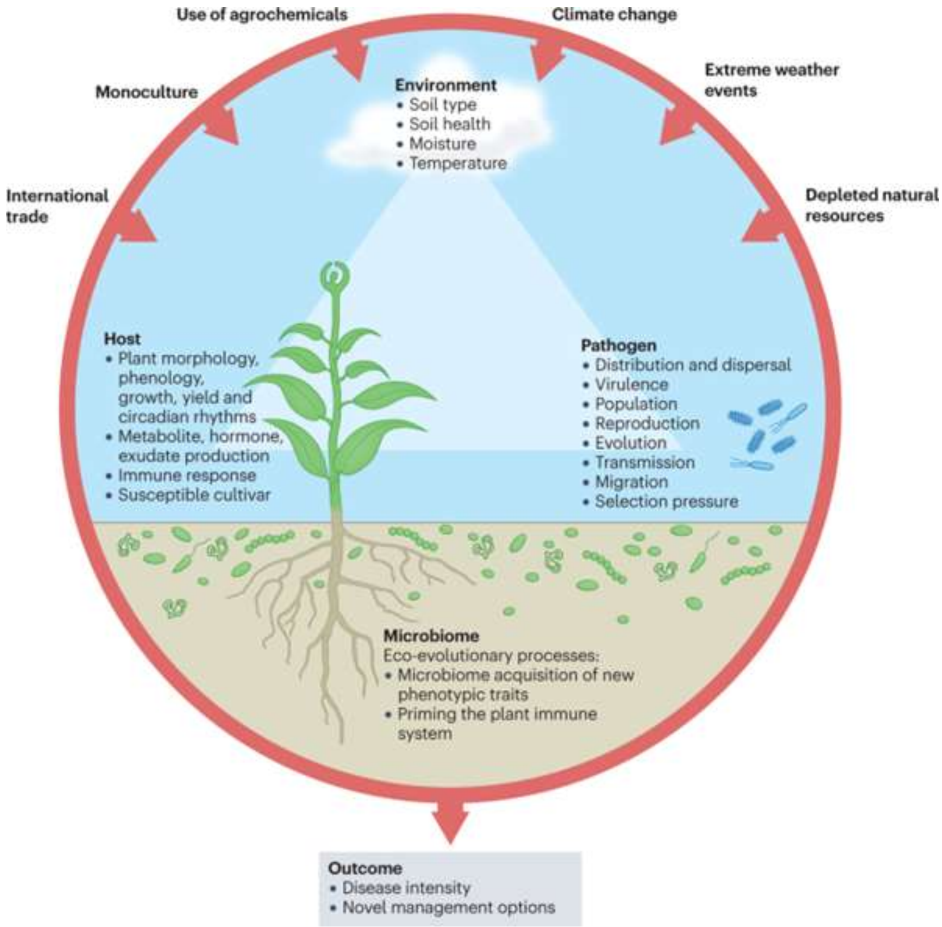


Figure 19 A new angle in the disease triangle paradigm that considers the plant microbiome as a pivotal factor influencing plant disease [18]

The impacts of drought on infection rates of pathogens and disease severity vary dramatically [19]. For example, diseases such as pea root rot (caused by Aphanomyces euteiches), onion white rot (Sclerotium cepivorum), wheat take-all (Gaeumannomyces graminis var. tritici), wheat crown rot (Fusarium spp.), brassica black leg (Leptosphaeria maculans) and grapevine black foot (Ilyonectria/Dactylonectria spp.) increase in severity with the increase in the length and frequency of drought. On the other hand, drought reduced the severity of kiwifruit sclerotinia rot (S. sclerotiorum) and radiata pine red needle cast (Phytophthora pluvialis) [19]. Similar results were reported for the bacterial pathogen Xylella fastidiosa of grape [20]. In general, necrotrophs will accelerate drought-induced tree mortality by depleting tree resources as a result of repair and compartmentalization processes, whereas biotroph-caused diseases are expected to be less severe in drought because of the strong connection between pathogen performance and tree nutritional status. However, if biotrophs are able to invade stressed trees, they are expected to cause more severe drought-dependent impacts on trees because they deplete carbohydrate reserves important for tree drought tolerance [21]. In the context of ADV, it is vital to ensure the indicators and the climate projections that are being developed are appropriately analysed for undertaking benchmarking of climate resilient models.

Complementing the impact of climate on the cropping system, it is also noted that the livestock and soil system are also being affected by climate change. In Figure 20, the risks affecting the livestock and soil composition being affected by climate change is noted.

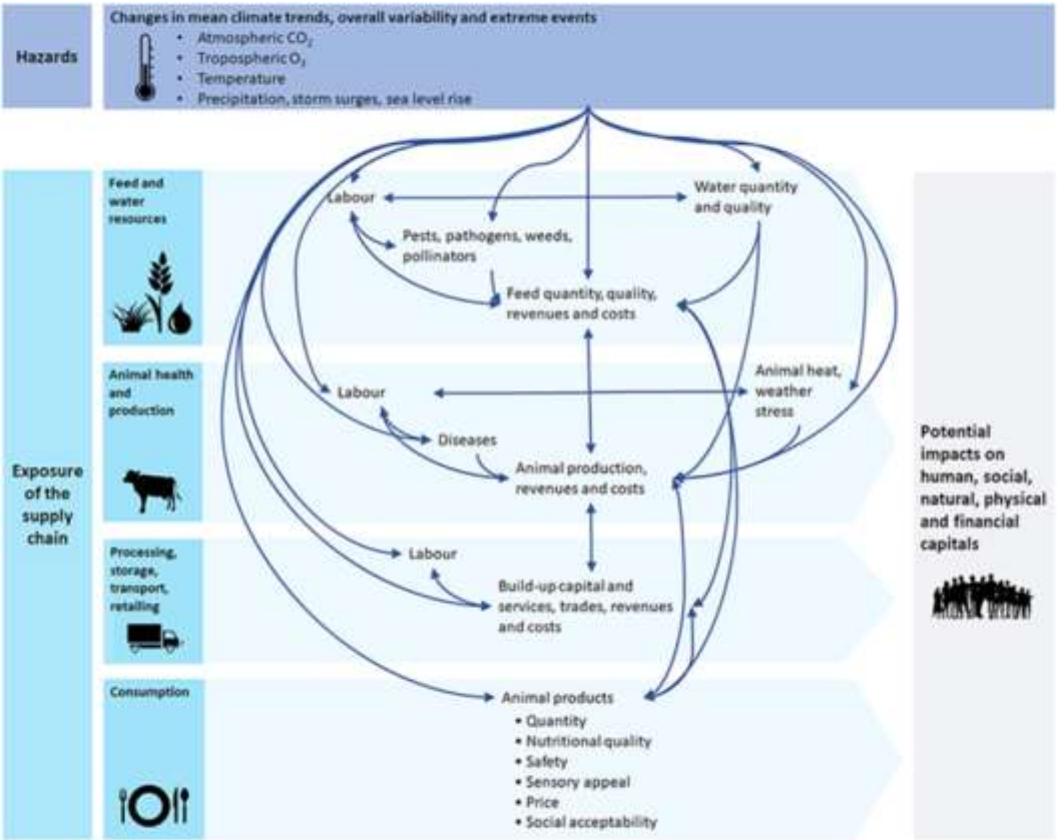


Figure 20 Risks affecting the livestock and soil composition emanating from climate change

The potential impacts of climate change on current livestock systems worldwide are a major concern, and yet the topic is covered to a limited extent in global reports such as the ones produced by the Intergovernmental Panel on Climate Change [23]. In the literature, the risk of climate-related impacts along the land-based livestock food supply chain has been published by Goode et al. Although a quantification of the net impacts of climate change on the livestock sector is beyond the reach of our current understanding, there is strong evidence that there will be impacts throughout the supply chain, from farm production to processing operations, storage, transport, retailing and human consumption. The risks of climate-related impacts are highly context-specific but expected to be higher in environments that are already hot and have limited socio-economic and institutional resources for adaptation. Large uncertainties remain as to climate futures and the exposure and responses of the interlinked human and natural systems to climatic changes over time. Consequently, adaptation choices will need to account for a wide range of possible futures, including those with low probability but large consequences. The approach to be adopted in ADV for the evaluation and the benchmarking of climate resilient models will rely on the established models to quantify the threat to food security.

6. Conclusion, ways forward, and next steps

This document, as Version V1 of the final deliverable, establishes a comprehensive framework for understanding the impacts of climate change on agriculture in Europe. It underscores the urgent need for adaptive strategies to ensure the sustainability and resilience of agricultural systems. By detailing the algorithms and procedures for evaluating agro-climatic indicators, soil health, and the Common Agricultural Policy (CAP) 2023-2027, this version provides a solid foundation for future analysis and action.

The document highlights the significant threats posed by climate change, including altered growing seasons, increased pest and disease distribution, and soil degradation. It emphasizes the importance of evaluating agro-climatic indicators such as temperature, precipitation, and soil moisture, which are crucial for informed decision-making in agriculture. Additionally, it stresses the need for soil health and conservation practices to mitigate the adverse effects of climate change. The new CAP framework is discussed in detail, showcasing its role in promoting sustainable agricultural practices and supporting farmers in adapting to climate change. The document also outlines the use of historical data and future projections to understand and anticipate climate impacts, providing a basis for developing effective adaptation strategies.

Version 2 (V2) of this deliverable will focus on the detailed collection and presentation of the information captured and processed by the partners responsible for the various pilots. While this document addresses in a general way the importance of data in the agroclimatic context, as well as the recommended methodology for their capture, the key characteristics that they must meet and the potential impact both in the short and long term, V2 will focus on a more specific and applied analysis in each of the pilots.

In V2, pilot partners will be asked to submit a thorough analysis on the practical applicability of the data in their specific cases. This will include the justification of the methodological approach used, the quality and homogeneity of the data obtained, as well as the evaluation of its relevance. In addition, it will be possible to check how these data have an optimal influence on the modelling of agroclimatic variables, with special emphasis on practical results and suggested adaptations for implementation at a practical level.

The ultimate goal of this second version of the deliverable is to demonstrate, with concrete examples, how the information presented can be effectively applied in each pilot. This will allow the usefulness of the data in optimizing agricultural practices and improving resilience to short- and long-term climate change to be assessed. Through this approach, it is expected to provide valuable feedback that contributes to the continuous improvement of agroclimatic models and their ability to adapt efficiently to variable conditions.

As we move towards Version V2 of the final deliverable, the focus will shift from explaining methodologies to producing and analyzing the actual indicators discussed in this document. Once the historical data and future projections are received, they will be used to assess the vulnerability of AES components. Further, the refinement of adaptation strategies and benchmarking of best practices will continue, providing actionable recommendations to enhance agricultural resilience. These efforts aim to guide policy decisions and adaptation strategies to mitigate climate impacts on AES within the ADV project framework. APPAG can help validate data provided by other partners by comparing them with its own databases (exclusively related to the Trentino region), which are constantly updated through on-site inspections and farmers' declarations. APPAG's graphic data about land use dates back to 2018-2019 and is a good reference for identifying the change in land use in the last few years. The livestock and pastures registers can help in identifying the ratio between livestock units and hectares, thereby helping to measure the impact of breeding on the environment.

The integration of these indicators into decision-making tools for farmers, policymakers, and researchers will be a key step forward. Developing user-friendly interfaces and platforms will facilitate access to and interpretation of the data, enabling stakeholders to make informed decisions. Formulating and implementing specific adaptation strategies based on the produced indicators will be crucial for optimizing farming practices, conserving biodiversity, and managing water and carbon footprints. Continuous monitoring and evaluation will be essential to assess the effectiveness of these strategies and make necessary adjustments. Engaging with stakeholders and providing training and capacity-building programs will enhance the practical application of the findings, ensuring that the project remains dynamic and responsive to emerging challenges and opportunities.

By following these steps, Version V2 will not only provide a detailed analysis of climate impacts on agriculture but also offer actionable insights and tools to enhance resilience and sustainability in the face of climate change. This iterative approach ensures that the project continues to evolve and adapt, addressing the needs of the agricultural sector in a changing climate.

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