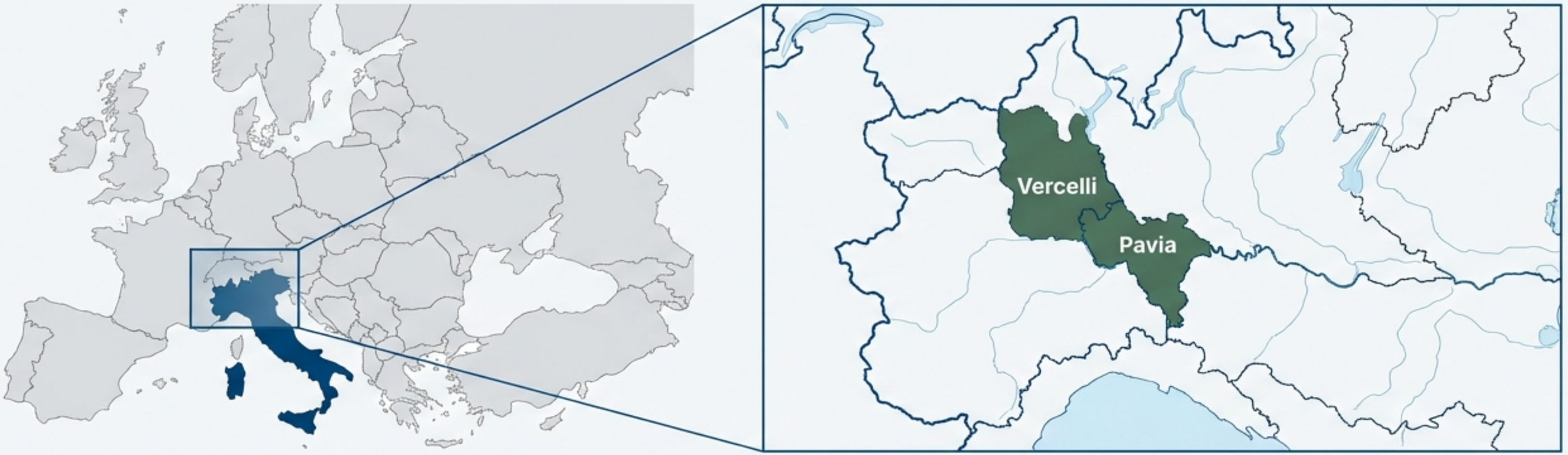
Monitoring Italy's Rice Heartland

Building a Foundation for Climate Resilience with Sentinel Time-Series in Zarr Format

Why the Po Valley Matters: Europe’s Strategic Rice Producer



#1 Italy is the largest rice-producing country in the European Union.

60% Italy exports about 60% of its national rice output, mainly within Europe.

The provinces of Vercelli and Pavia form the core of Europe’s largest contiguous rice-growing area.

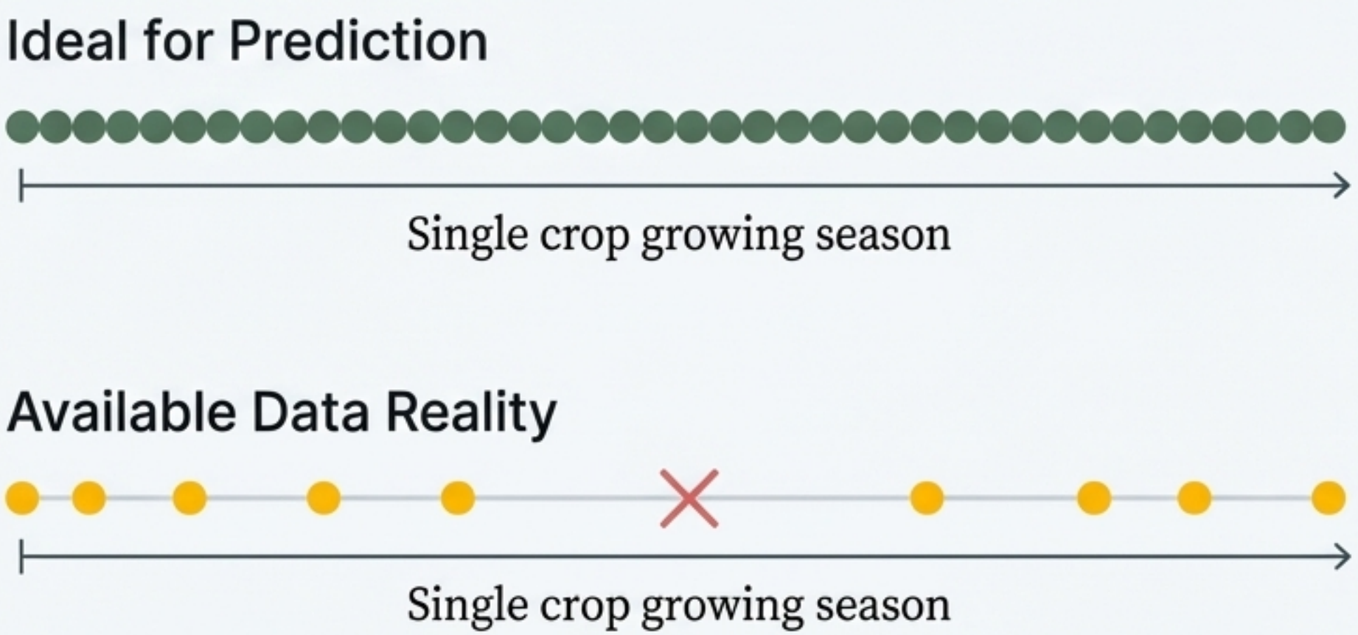
This strategic agri-food sector is increasingly exposed to climatic stress, including droughts, heatwaves, and altered water availability from the Po River, impacting yield stability.

The Original Ambition: An Absolute Yield Prediction Framework

- The initial project was designed to build an early-stage yield prediction framework for rice in Punjab, India.
- **Primary Goal:** To **predict** **absolute crop yield** by linking **dense, multi-sensor Sentinel time-series** to seasonal crop performance at the field scale.

Core Technology: Exploit **Sentinel-1, -2, and -3** data stored in Zarr format to analyze responses to temperature, rainfall, and drought.

The Reality Check: A Data Bottleneck

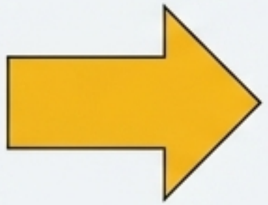


Constraint: The implementation of the original concept was constrained by limited access to suitable, temporally dense Zarr data in the Indian study area.

Exploration: Alternative datasets were explored via the STAC API, identifying more promising data for rice systems in northern Italy.

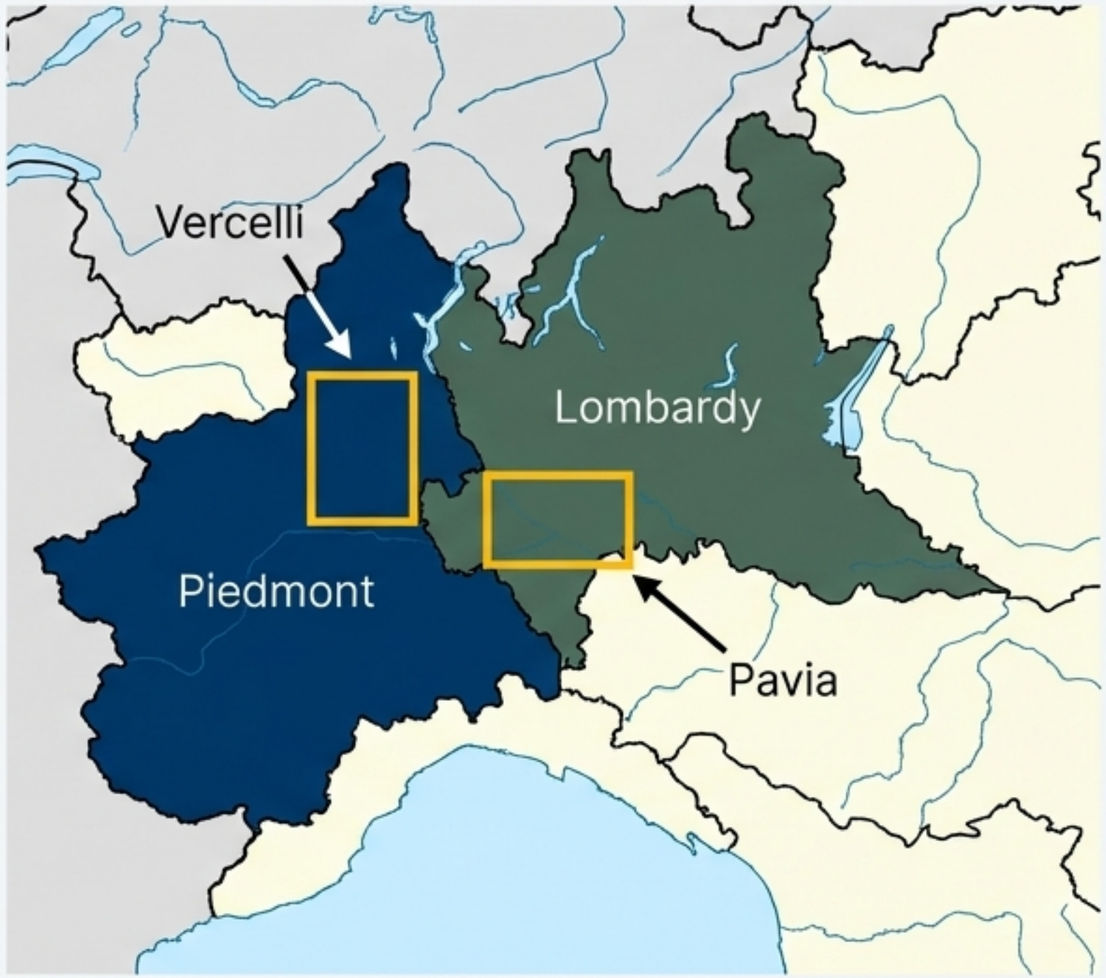
Limitation: The available Italian data, while promising, is still temporally sparse. It is sufficient for comparative analysis but not yet adequate to support a stable, absolute yield-prediction model.

The Strategic Pivot: From Absolute Prediction to Foundational Analysis

FROM: Direct Prediction of Absolute Yield		TO: Relative Yield Analysis & Driver Extraction
• Estimating precise tonnage per hectare. • Requires dense time series and multi-year yield observations.		• Comparing patterns between locations (Vercelli vs. Pavia) and seasons. • Identifying factors that cause differences in relative productivity. • More statistically tractable with available data frequency.

****Key Rationale:** This refined direction preserves the core scientific motivation while adapting to data realities. It concentrates on building a critical foundation—understanding the drivers—before attempting forecasting.

Our New Laboratory: The Rice Fields of Vercelli & Pavia



The study now focuses on two key districts that form the core of Europe's rice production.

Vercelli (Piedmont): Frequently described as the "capital of rice" in Europe.

Pavia (Lombardy): A major producer, home to the Lomellina plain.

Why these locations?

- They are representative of a highly specialized, irrigated rice landscape.
- They are similar cropping systems but differ slightly in hydrological setting, irrigation infrastructure, and local climate.
- This provides a perfect setup for a comparative analysis of how rice systems respond to differing regional climate signals.

Our Refined Research Focus: Extracting Drivers of Crop Performance

Climate & Vegetation Dynamics

Analyze how meteorological variables (temperature, precipitation, drought) influence satellite vegetation and moisture indices (NDVI, EVI, NDWI). Contrast response functions between Vercelli and Pavia.

Phenology & Productivity Signals

Derive phenology metrics from time series (e.g., start of season, date of maximum greenness). Assess how these metrics co-vary with climate anomalies and known constraints (e.g., cold risk, disease pressure).

Technical Advantages of Zarr

Evaluate how the Zarr cloud-native format supports efficient storage and querying of multi-sensor, multi-year Sentinel data for comparative analysis.

A 4-Step Operational Workflow

1.

Identify & Label

Use spatial datasets and imagery to delineate rice farms and fields in Vercelli and Pavia.

2.

Profile & Characterize

Apply crop masking and temporal profiling to derive time-series indicators of crop growth duration and key phenological phases.

3.

Combine & Analyze

Combine multi-sensor Sentinel indices and ancillary climate data to examine vegetation responses to climate variability.

4.

Quantify & Compare

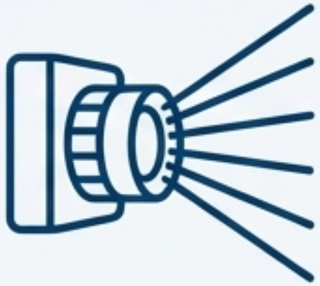
Quantify relative differences in yield proxies and stress indicators between the two regions to identify dominant climatic and management factors.

The Multi-Sensor Toolkit: A Comprehensive View from Space

Sentinel-1 (SAR)

Measures: VV & VH Backscatter, VV/VH Ratio

Primary Role: Captures field flooding, surface moisture, and canopy physical structure. Provides robust information under all weather conditions, critical during cloudy spring months.



Sentinel-2 (Optical)

Measures: NDVI, EVI, NDWI, NDMI

Primary Role: Tracks greenness, canopy health, biomass, and phenological stages. Essential for monitoring growth and deviations linked to weather.

Sentinel-3 (Thermal)

Measures: Land Surface Temperature (LST)

Primary Role: Quantifies thermal stress events during sensitive growth stages, linking heat stress to anomalies in vegetation indices.

Decoding the Signals: What the Satellite Indices Tell Us

Vegetation

NDVI / EVI

(Normalized Difference Vegetation Index / Enhanced Vegetation Index)

How green, healthy, and dense is the plant canopy?

Moisture

NDWI / NDMI

(Normalized Difference Water Index / Moisture Index)

How much water is present in the soil and within the plant leaves?

Structure

VV / VH Backscatter

(Sentinel-1 Radar)

What is the physical structure of the field? Is it flooded? How developed is the canopy?

Stress

LST

(Land Surface Temperature)

How much heat stress is the crop experiencing?

The Technical Engine: The Power of Cloud-Native Zarr

The Zarr format is the technical backbone that makes this analysis feasible and scalable.

Cloud-Native

Designed for efficient storage and access in cloud environments.

Fast Time-Series Queries

Optimized chunking allows for rapid extraction of pixel-wise time series, crucial for climate-vegetation studies.

Scalable & Efficient

Reduces I/O latency and processing costs compared to traditional file formats, strengthening the case for scaling the framework to other European rice areas.

Core Deliverables: Building Foundational Assets for Rice Monitoring

1. 

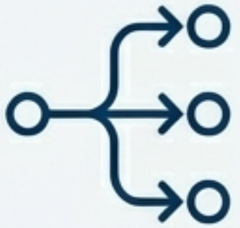
A Harmonized, Analysis-Ready Dataset

A unique, cloud-native Zarr data cube containing multi-sensor, multi-year Sentinel data for Europe's most important rice region.

2. 

Robust Driver Analysis & Feature Representations

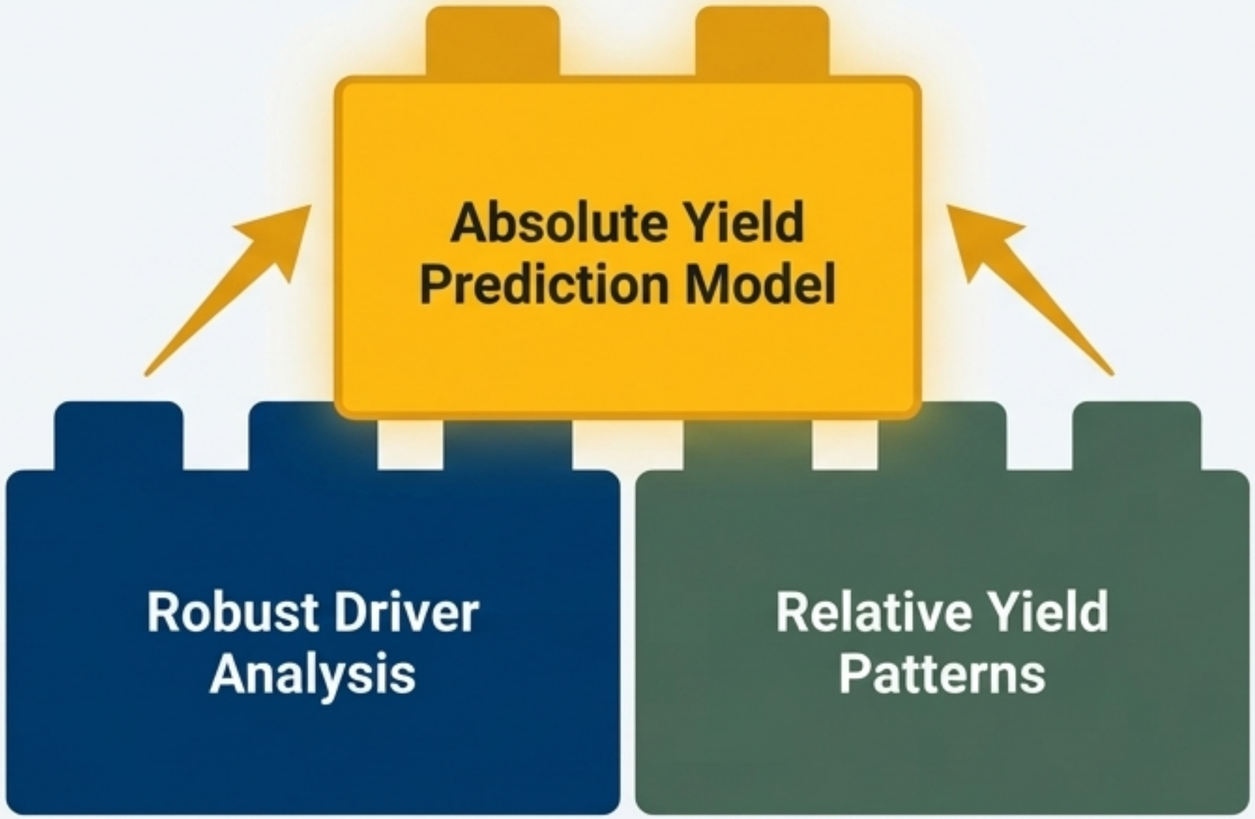
Statistically validated links between climate events (temperature, water stress) and crop canopy response in Vercelli and Pavia. A ranked set of candidate predictors for future models.

3. 

A Scalable, Transferable Workflow

An analytical framework that can be applied to other European rice areas and extended into full predictive models as longer climate and production records become available.

The Vision Revisited: Paving the Way for Prediction



The ultimate goal of creating a **stable, absolute yield prediction model** remains.

This study provides the indispensable **scientific foundation.** By first identifying and quantifying the dominant climatic and management-related drivers, we are building the statistically robust relationships required for future machine learning models.

This foundational work transforms a “black box” prediction challenge into a more **transparent, explainable modeling task.**

From Ambition to Adaptation: A Resilient Framework for a Vital Crop

By strategically adapting our approach to data realities, this project establishes a robust, scalable foundation for monitoring Europe's rice heartland. We are delivering immediate insights into climate–crop dynamics and building the essential components for future predictive systems, ensuring our work contributes meaningfully to regional food security and climate resilience.