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## **Design of a high-resolution and dynamic soil organic carbon monitoring system for agricultural land**

Claire Chenu, Greet Ruyschaert, Eric Ceschia, Axel Don, Fenny Van Egmond,  
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HAL Authorization



**2nd meeting of the Carbon Removals Expert Group** 21-22 June  
**Carbon Farming: mapping of certification methodologies** 2023 Brussels



# Design of a high-resolution and dynamic soil organic carbon monitoring system for agricultural land

Claire Chenu<sup>1</sup>, Greet Ruyschaert<sup>2</sup>, Eric Ceschia<sup>1</sup>, Axel Don<sup>3</sup>, Fenny van Egmond<sup>4</sup>,  
Antonio Bispo<sup>1</sup>, Martin Thorsoe<sup>5</sup>, Suzanne Reynders<sup>1</sup>, Maria Fantappiè<sup>9</sup>

1- INRAE, France

2- ILVO, Belgium

3- Thunen Institute, Germany

4- Wageningen Research, The Netherlands

5- Aarhus University, Denmark

6- CREA, Italy



Introduction

Building blocks

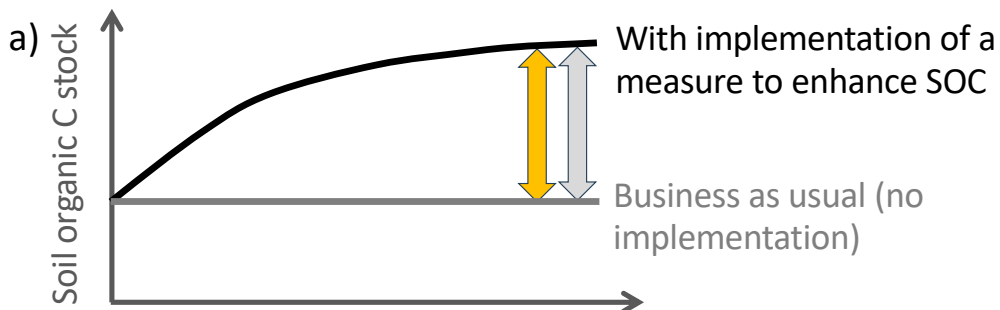
QU.A.L.I.TY

Assemblage

Conclusion



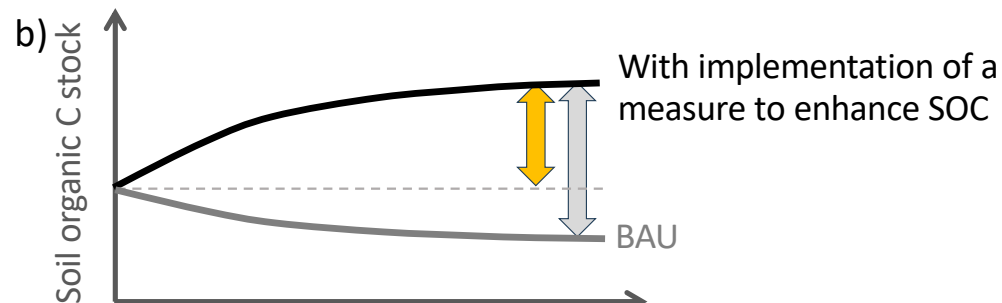
# What is the expected outcome? More Soil Organic Carbon for GHG mitigation for soil health improvement



Time since implementation of a measure to enhance SOC

- ✓ SOC stock accr
- ✓ C sequestration
- ✓ Net C removal

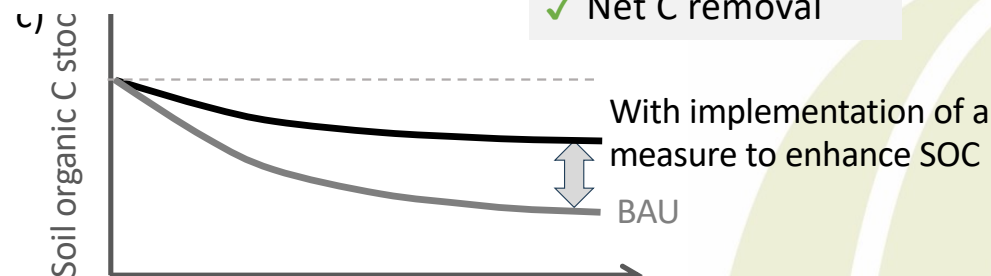
↕ SOC stock accrual    ↕ C sequestration in soil



ice implementation

- ✓ SOC stock accrual
- ✓ C sequestration
- ✓ Net C removal

## GHG balance?



Time since implementation

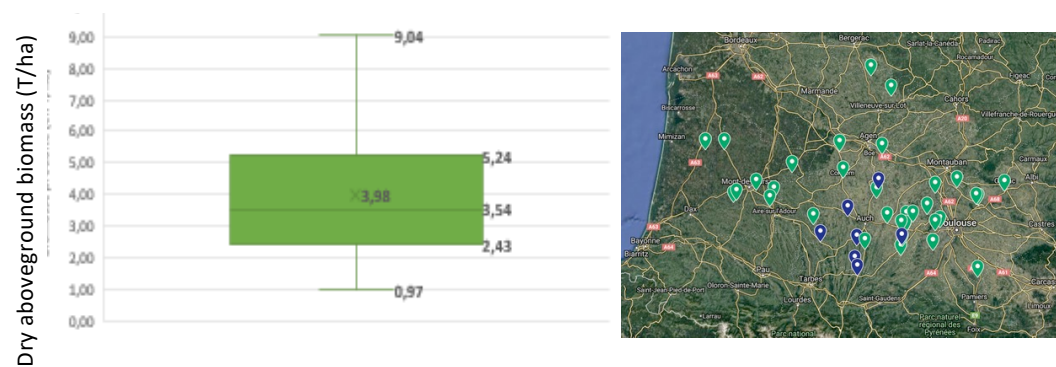
- ✓ SOC stock accrual
- ✗ C sequestration
- ✗ Net C removal

- ➔ Time 0 SOC stock value
- ➔ Business as usual scenario

## Why a results-based MRV system ?

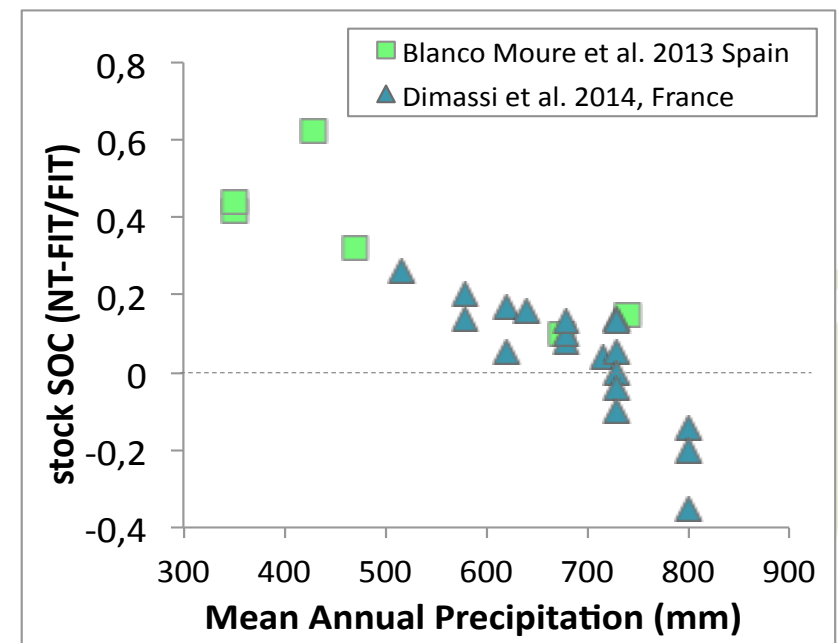
Because additional SOC storage of a given measure depends on the pedoclimatic conditions

### Cover crops



Inter-crop spatial variability : In-situ cover crop biomass measurements at 57 plots in South West France (©E. Cescia, INRAE)

### No-tillage



## Why a “hybrid” MRV system ?



Direct soil sampling and SOC measurement ?

- Sensitivity :
  - Small  $\Delta$  over large stocks
  - Slow changes
  - Spatial variability

=> High costs!

Direct SOC measurement via remote sensing?

- Accuracy and uncertainty
- C contents not stocks

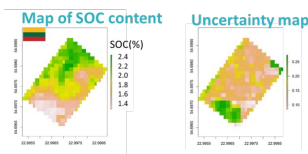
=> Not mature yet for SOC !

Modelling?

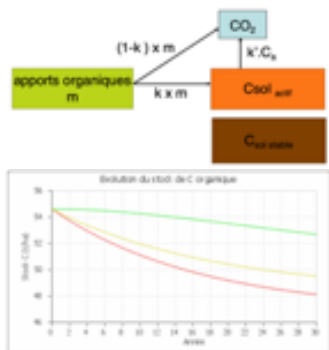
- Detailed input parameters needed
  - Soil texture, type
  - Initial SOC
  - Details on management (e.g, rotation, tillage, fertilisation, etc)

⇒ High administrative burden!

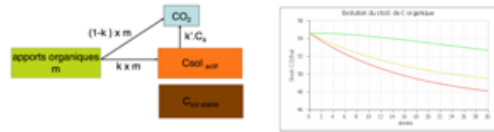
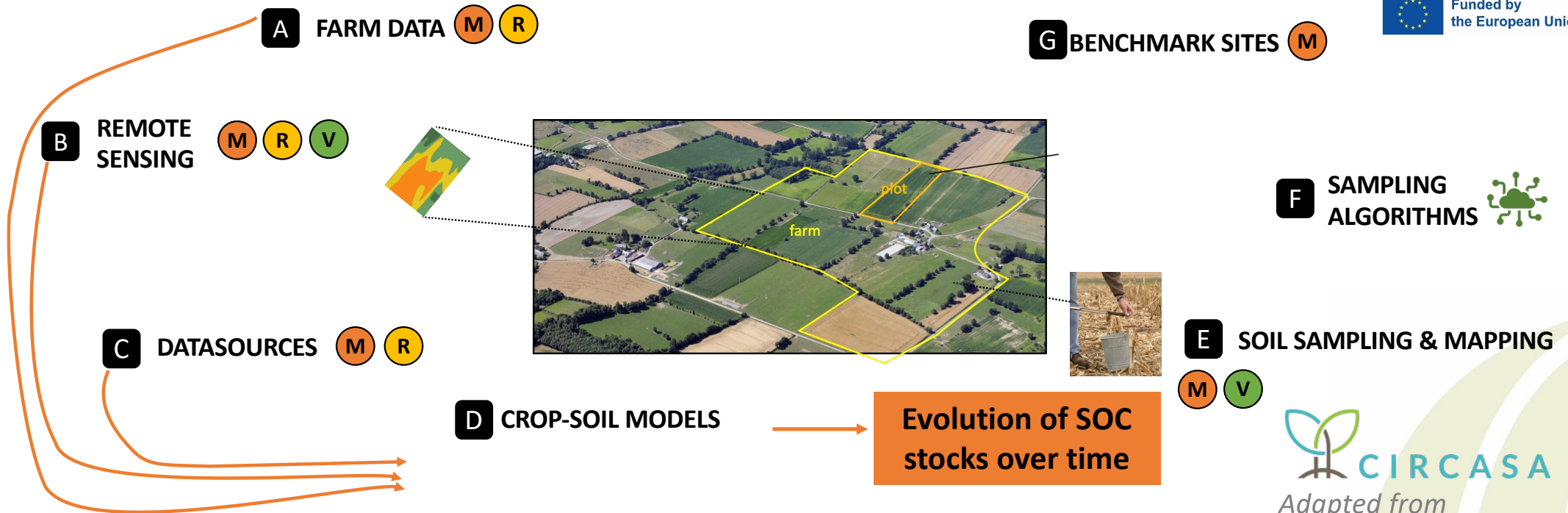
⇒ Explore other info sources



Castaldi et al., 2023



# Example of Soil C Monitoring, Reporting and Verification approach



**CIRCASA**  
Adapted from  
Smith et al. 2020, GCB  
Ruyschaert et al. 2022

APPLY

Eligibility check

**A B**

ENROLL

T0, BAU and Cseq potential

**A C D E**

QUANTIFY

Transparent, robust outcomes

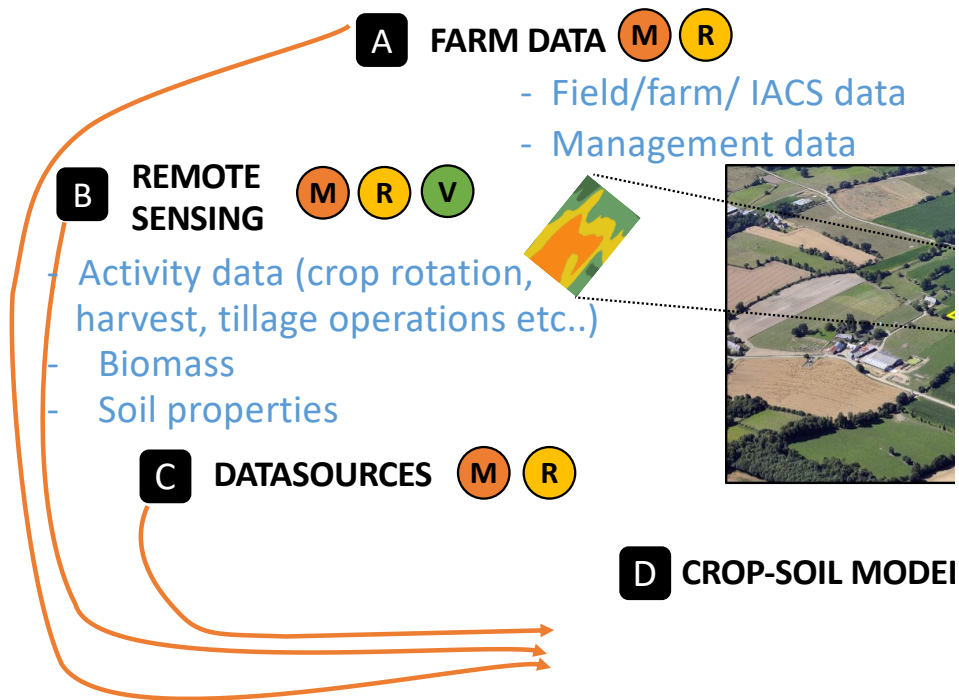
**D E**

VERIFY/REPORT

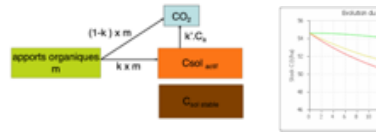
Transparent, verifiable outcomes

**F E D**

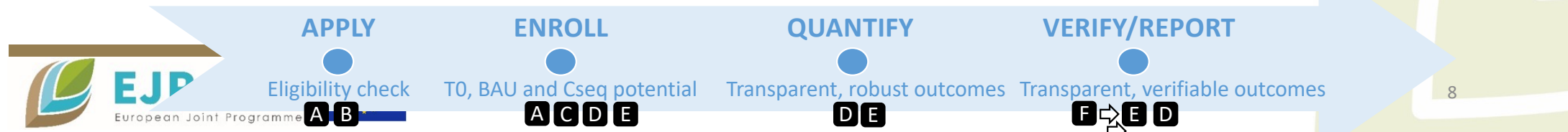
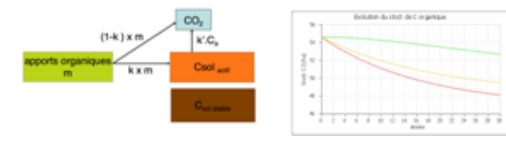
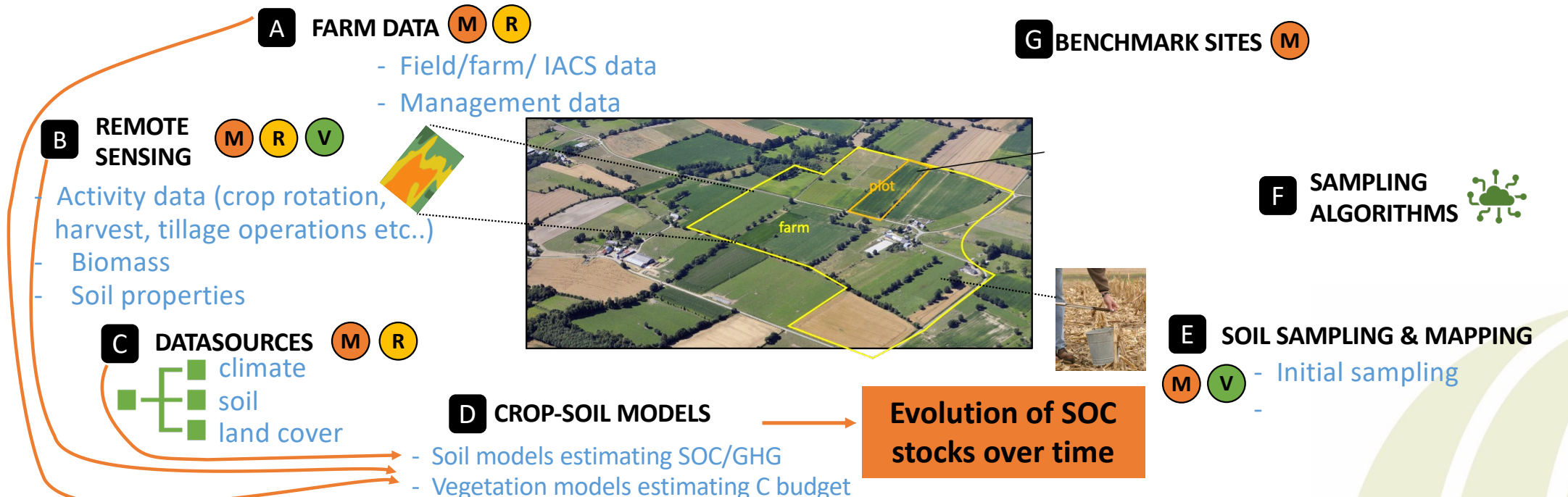
# 1- Eligibility check



- Management options envisioned ?
  - Efficiency / SOC accrual
  - Potential leakage
  - Environmental & biodiversity potential effects
  - Additionality



# 2- Enroll



# 3- Quantify

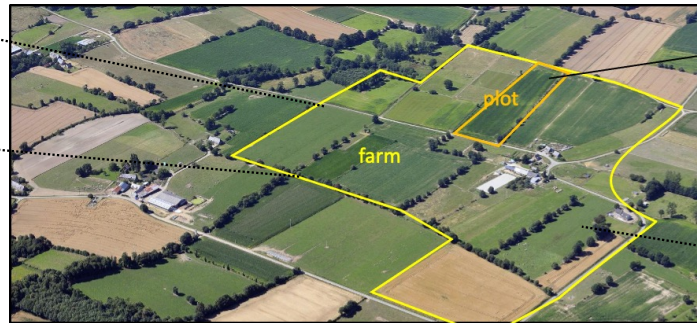
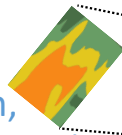
**A FARM DATA** (M) (R)

- Field/farm/ IACS data
- Management data

**G BENCHMARK SITES** (M)

**B REMOTE SENSING** (M) (R) (V)

- Activity data (crop rotation, harvest, tillage operations etc..)
- Biomass
- Soil properties



**F SAMPLING ALGORITHMS**

**C DATASOURCES** (M) (R)

- climate
- soil
- land cover

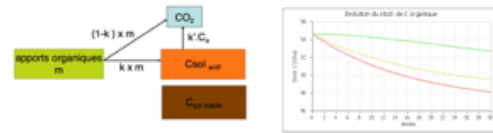
**E SOIL SAMPLING & MAPPING**

- (M) (V) - Initial sampling
- 

**D CROP-SOIL MODELS**

- Soil models estimating SOC/GHG
- Vegetation models estimating C budget

**Evolution of SOC stocks over time**



**APPLY**

Eligibility check

**A B**

**ENROLL**

T0, BAU and Cseq potential

**A C D E**

**QUANTIFY**

Transparent, robust outcomes

**D E**

**VERIFY/REPORT**

Transparent, verifiable outcomes

**F E D**

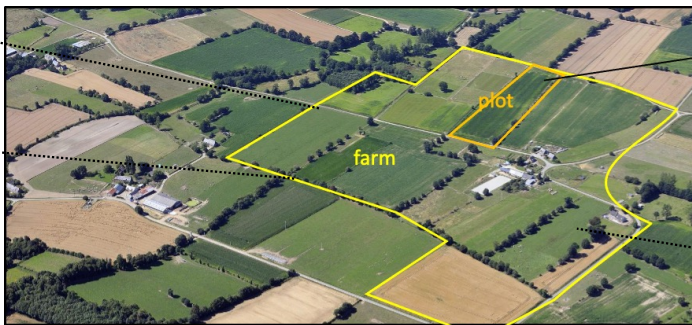
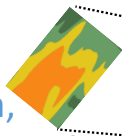
# 5- Verify and Report

**A FARM DATA** (M) (R)

- Field/farm/ IACS data
- Management data

**B REMOTE SENSING** (M) (R) (V)

- Activity data (crop rotation, harvest, tillage operations etc..)
- Biomass
- Soil properties

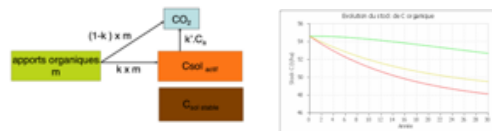


**C DATASOURCES** (M) (R)

- climate
- soil
- land cover

**D CROP-SOIL MODELS**

- Soil models estimating SOC/GHG
- Vegetation models estimating C budget



**G BENCHMARK SITES** (M)

**F SAMPLING ALGORITHMS**

Where, how many, when and how to sample



**E SOIL SAMPLING & MAPPING**

- Initial sampling
- Ground-truthing for V

**Evolution of SOC stocks over time**

APPLY

Eligibility check

**A B**

ENROLL

T0, BAU and Cseq potential

**A C D E**

QUANTIFY

Transparent, robust outcomes

**D E**

VERIFY/REPORT

Transparent, verifiable outcomes

**F → E D**

# Develop MRV methodologies



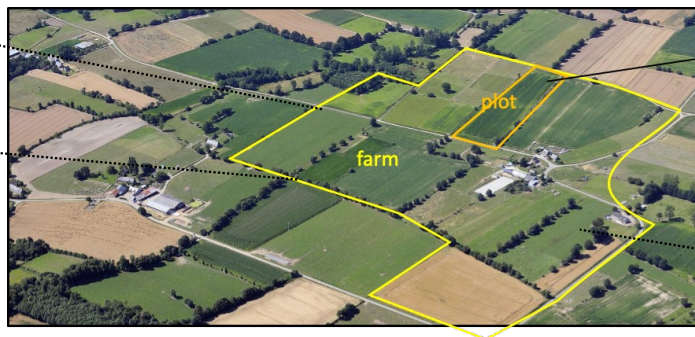
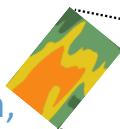
**A FARM DATA** (M) (R)

- Field/farm/ IACS data
- Management data



**B REMOTE SENSING** (M) (R) (V)

- Activity data (crop rotation, harvest, tillage operations etc..)
- Biomass
- Soil properties



**C DATASOURCES** (M) (R)

- climate
- soil
- land cover

**D CROP-SOIL MODELS**

- Soil models estimating SOC/GHG
- Vegetation models estimating C budget

**Evolution of SOC stocks over time**

**G BENCHMARK SITES** (M)

- Test CF practices
- Measure fluxes
- Develop/refine models

**F SAMPLING ALGORITHMS** (M) (V)

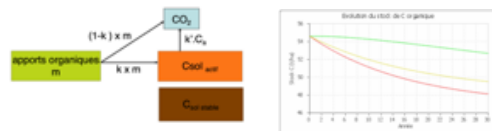
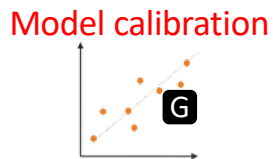
Where, how many, when and how to sample

**E SOIL SAMPLING & MAPPING** (M) (V)

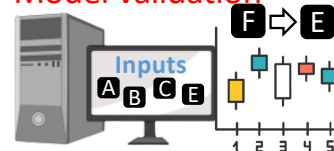
- Initial sampling
- Ground-truthing for V
- Precision sampling M



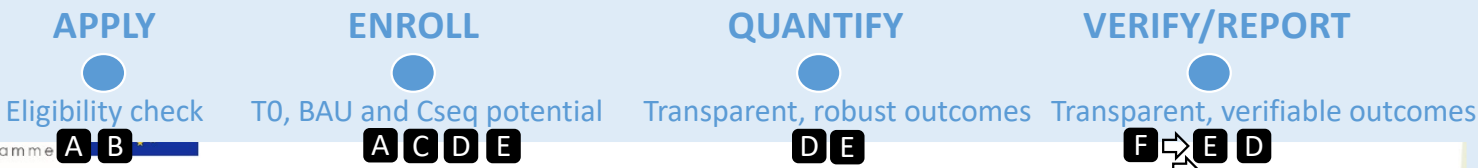
Develop MRV methodologies  
Apply MRV in CF schemes



Model validation



Adapted from  
Smith et al. 2020, GCB  
Ruyschaert et al. 2022



# Example of Soil C Monitoring, Reporting and Verification approach



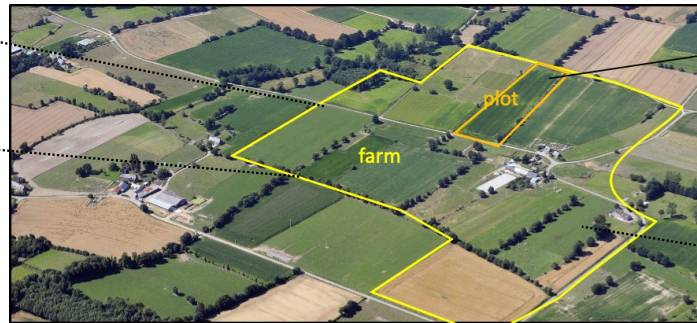
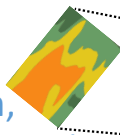
## A FARM DATA (M, R)

- Field/farm/ IACS data
- Management data



## B REMOTE SENSING (M, R, V)

- Activity data (crop rotation, harvest, tillage operations etc..)
- Biomass
- Soil properties



## G BENCHMARK SITES (M)

- Test CF practices
- Measure fluxes
- Develop/refine models

## F SAMPLING ALGORITHMS



Where, how many, when and how to sample

## E SOIL SAMPLING & MAPPING (M, V)

- Initial sampling
- Ground-truthing for V
- Precision sampling M



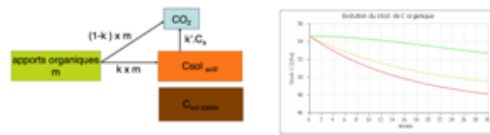
## C DATASOURCES (M, R)

- climate
- soil
- land cover

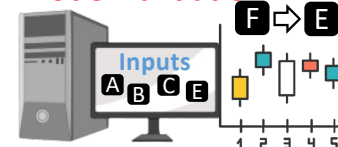
## D CROP-SOIL MODELS

- Soil models estimating SOC/GHG
- Vegetation models estimating C budget

Evolution of SOC stocks over time

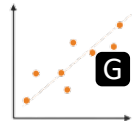


## Model validation



Develop MRV methodologies

## Model calibration



Apply MRV in CF schemes

### APPLY

Eligibility check

A B

### ENROLL

T0, BAU and Cseq potential

A C D E

### QUANTIFY

Transparent, robust outcomes

D E

### VERIFY/REPORT

Transparent, verifiable outcomes

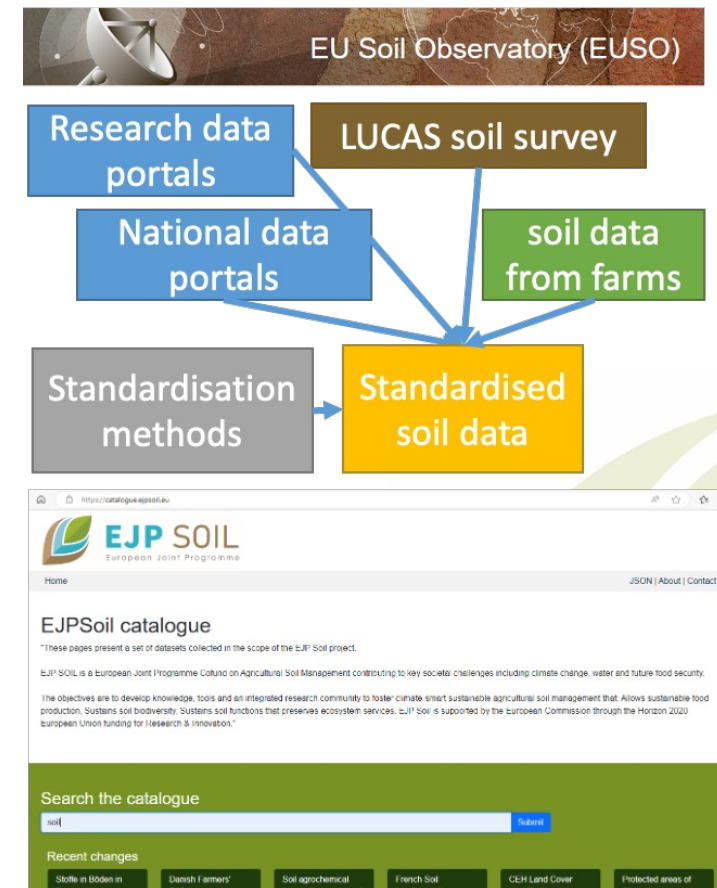
F E D



Adapted from  
Smith et al. 2020, GCB  
Ruyschaert et al. 2022

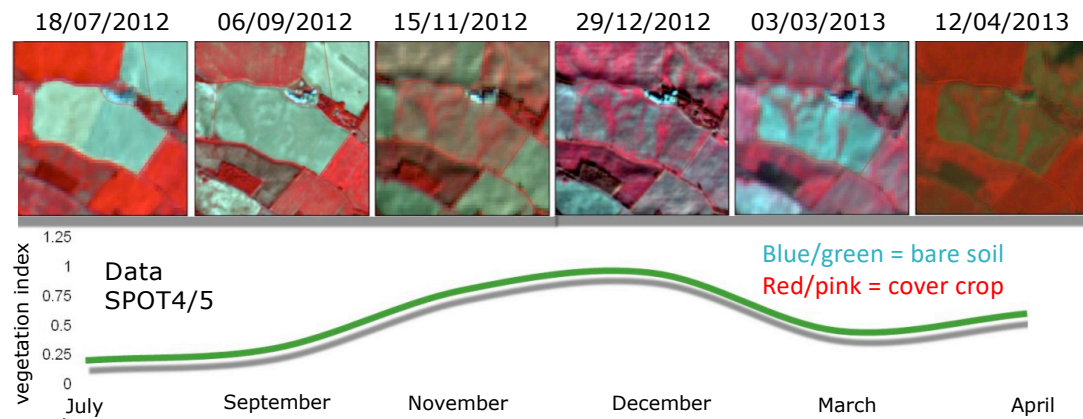
## Hybrid, high resolution, dynamic MRV approach

- **Smart assembly** of building blocks (operational processing chains)
- **Automated inputs to models:** as much as possible
  - **Remote sensing:** crop types, carbon inputs, farm activities, soil properties
  - Link with already **publicly available existing data:** e.g. LPIS, GSAA, LUCAS, national databases, research databases (country dependent)
  - Work on **data harmonisation/standardization and interoperability** (e.g. work EJP SOIL WP6, EUSO, Soil Mission, SoilWise etc)
  - Link with **already recorded farm data** (e.g. lab data, harvest machinery, farm management systems) & with **regional data spaces**, eg farm data sharing platform <https://www.djustconnect.be/en>



# Remote sensing for accurate assessment biomass production and restitution to the soil

High intra plot spatial variability  
cover crop development  
(@E. Cescia, INRAE)



- Classical agronomic models cannot predict spatio-temporal variability in biomass production (& in-situ measurements too expensive) → huge uncertainties on SOC stock changes,
- Previous attempts to assimilate remote sensing data in agronomical models (e.g. STICS, EPIC) failed (too many input data) → not adapted to upscaling

→ Assimilation of remote sensing data in crop models dedicated to upscaling (e.g. SAFYE-CO2) → force the model to estimate accurate biomass production/spatial variability

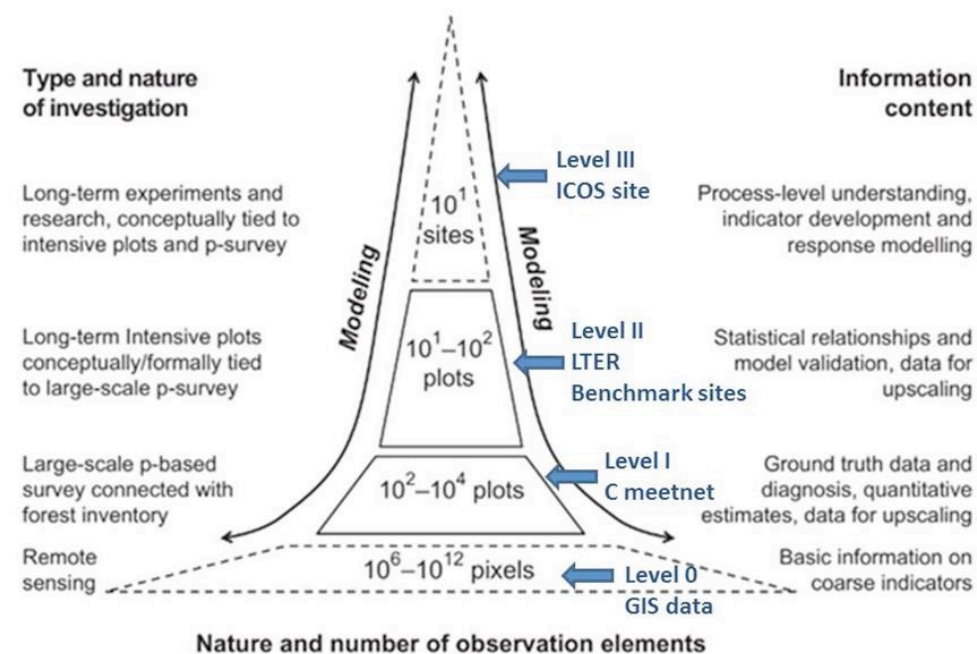
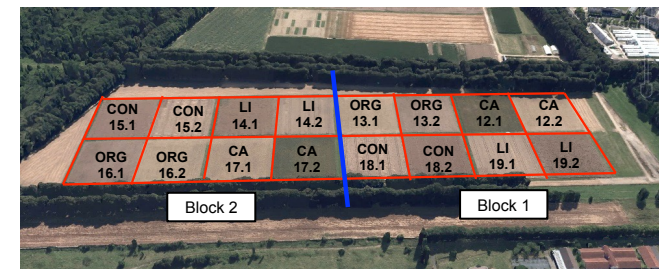
2023-06-21-DG CLIMA experts group meeting

**HYBRID APPROACH NEEDED !**

# Developing MRV methodologies

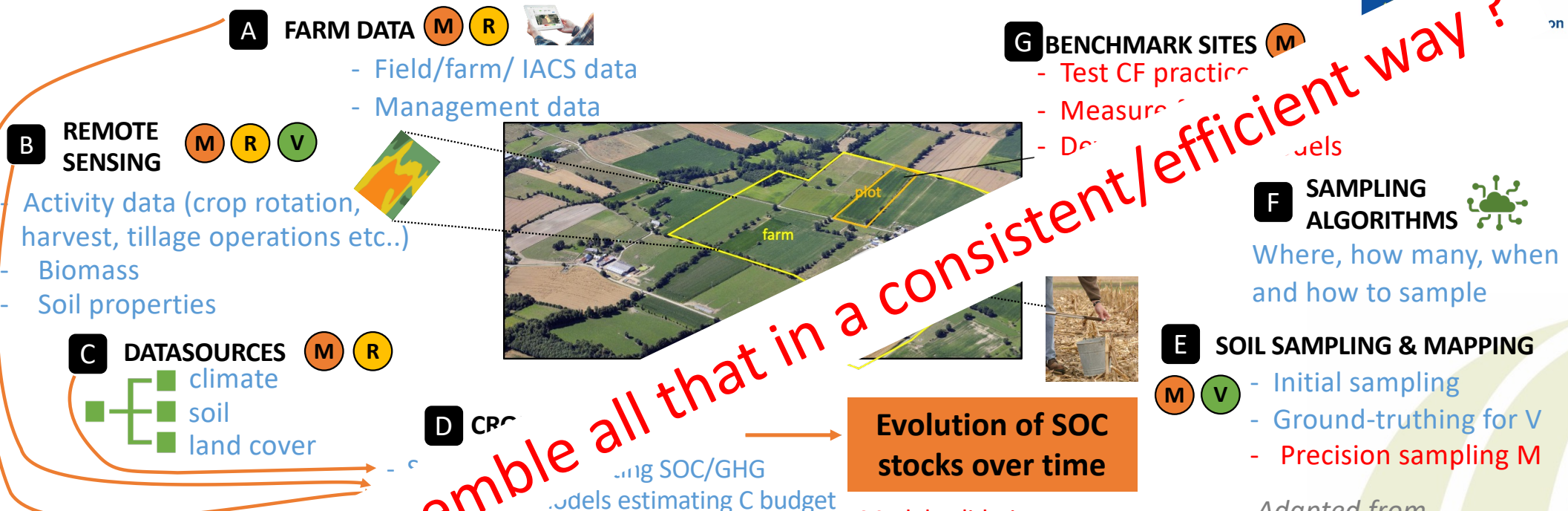
## Importance of benchmark sites!

- Test management options
- Develop and test models (calibration/ validation)
  - Plant C inputs models (remote sensing)
  - Soil carbon models
  - Direct measurements – detailed monitoring and sampling
- Different complementary networks
  - Level I regional/EU carbon monitoring network
  - Level II LTER benchmark sites
  - Level III ICOS sites



*Slutel et al. 2020 adapted from Ferretti & Fisher 2013*

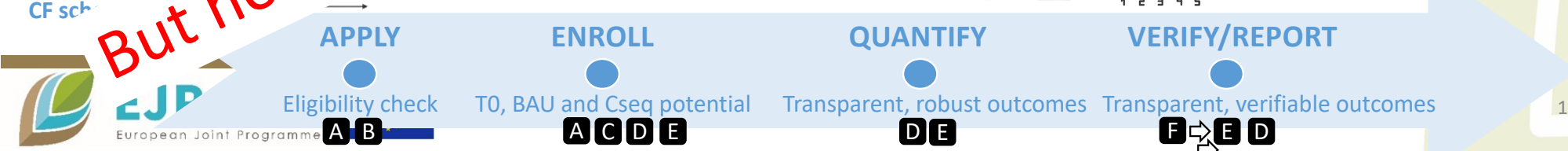
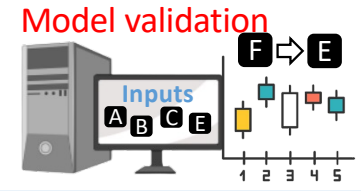
# Example of Soil C Monitoring, Reporting and Verification approach



**But how to assemble all that in a consistent/efficient way?**

Develop MRV methodologies  
Apply MRV in CF schemes

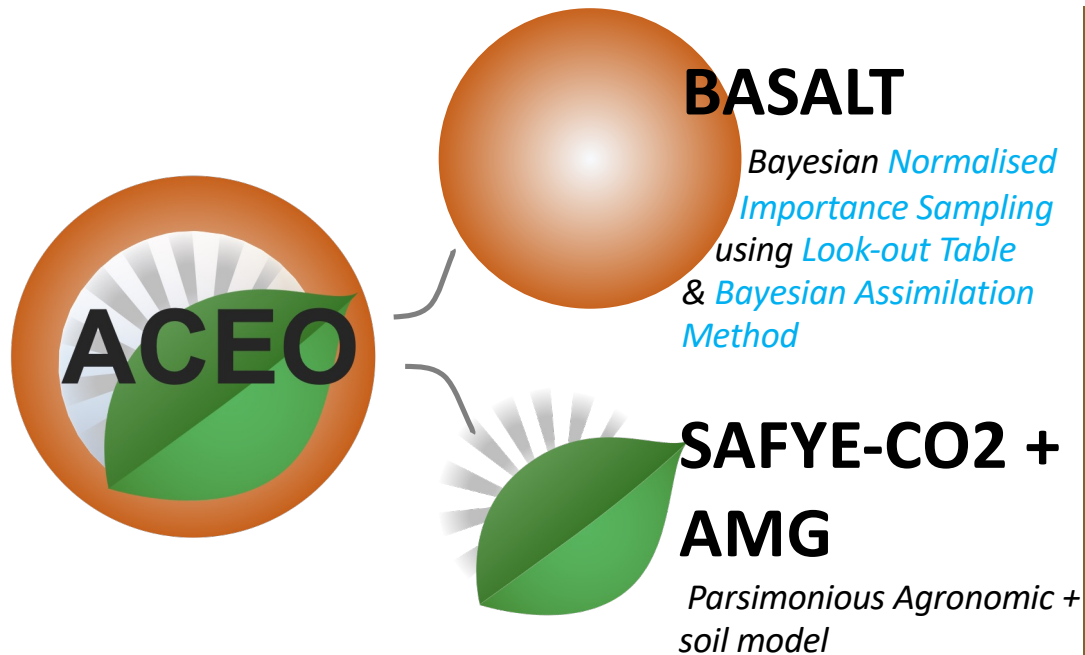
Model validation



Adapted from Smith et al. 2020, GCB Ruyschaert et al. 2022

## Example of operational processing chain for MRV of SOC stock changes

AgriCarbon-EO [ACEO], an end-to-end pre-operational processing chain dedicated to SOC MRV



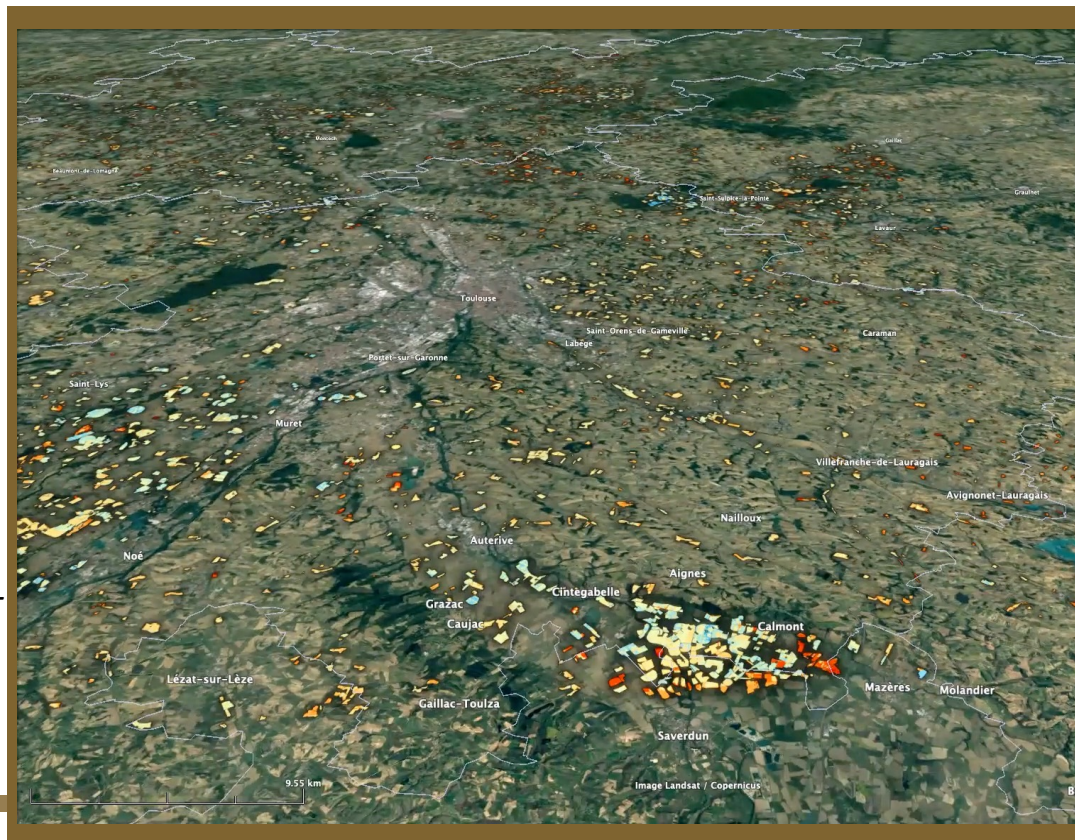
AgriCarbon-EO v1.0.1: Large Scale and High Resolution Simulation of Carbon Fluxes by Assimilation of Sentinel-2 and Landsat-8 Reflectances using a Bayesian approach

Taeken Wijmer<sup>1,2,\*</sup>, Ahmad Al Bitar<sup>1,\*</sup>, Ludovic Arnaud<sup>1</sup>, Remy Fieuzal<sup>1</sup>, and Eric Ceschia<sup>1</sup>



2023-06-21-DG CLIMA experts group meeting

Net annual CO<sub>2</sub> fluxes for Wheat over 110x110 km at 10m resolution (in France) simulation takes 4 hours (downloading images takes 1 day)



<https://egusphere.copernicus.org/preprints/2023/egusphere-2023-48/>

## How can such a system comply to the Regulation on Carbon Removals Certification QU.A.L.I.TY criteria?



### QUANTIFICATION

*Carbon removal activities are measured against a baseline and are net of supply-chain emissions*



### ADDITIONALITY

*Carbon removal activities go beyond standard market practices and what is legally required to the operator*



### LONG-TERM STORAGE

*Certificates clearly account for the duration of carbon storage and distinguish permanent storage from temporary storage*



### SUSTAINABILITY

*Carbon removal activities do not harm the environment or even benefit other environmental objectives such as biodiversity*

- Time 0 measurements/ soil data
- Modelling of the business as usual (standard practice)
  - ⇒C sequestration in soil
- GHG emission estimates (emission factor, modelling)
  - ⇒Negative emissions, climate change mitigation

## How can such a system comply to the Regulation on Carbon Removals Certification QU.A.L.I.TY criteria?



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### SUSTAINABILITY

*Carbon removal activities do not harm the environment or even benefit other environmental objectives such as biodiversity*

- Farm data
- Remote sensing
- Eligibility of the practice  
⇒ "additional" management option

*Accounting for the  
pionners ?*

## How can such a system comply to the Regulation on Carbon Removals Certification QU.A.L.I.TY criteria?



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*Certificates clearly account for the duration of carbon storage and distinguish permanent storage from temporary storage*



### SUSTAINABILITY

*Carbon removal activities do not harm the environment or even benefit other environmental objectives such as biodiversity*

- Remote sensing for C input and activity
- Modelling effects of climate change

# How can such a system comply to the Regulation on Carbon Removals Certification QU.A.L.I.TY criteria?



### QUANTIFICATION

Carbon removal activities are measured against a baseline and are net of supply-chain emissions



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**EJP SOIL** WORK PACKAGE 8 SCIENCE TO POLICY

Save the Date

AN OPEN WEBINAR ON

**SOIL HEALTH INDICATORS**

Friday 12th May 2023  
10:00 - 12:00 CEST  
Online Event

The webinar will present scientific information in support of the needs for the development of the EU Soil Health Law based on some of the research findings of the EJP SOIL.

What is soil health?  
What are the different approaches to setting targets and thresholds?  
How can indicators be categorized and prioritized?  
Why is a holistic approach to indicators important?

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 882695

**EJP SOIL SIREN**  
Inventory of current indicator systems

**EJP SOIL SERENA**  
Common definitions, thresholds inventory/proposal

**EJP SOIL MINOTAUR**  
Prioritizing biodiversity indicators

**EJP SOIL WP6**

WP6: "D6.5 Guidelines for accounting and mapping agricultural soil carbon, fertility and degradation changes at different scales"

• Evaluating ecosystem services provision and biodiversity

**EU MISSIONS**  
SOIL DEAL FOR EUROPE

## Design of a high-resolution and dynamic soil organic carbon monitoring system for agricultural land

- Store more C in soils for ecosystem services and GHG mitigation
- **Mixed carbon farming systems:** practice-based & results-based MRV
- **Adapted to different context of application**
  - National inventories, CAP, agri-food sector (insetting), voluntary markets
- **Hybrid MRV systems** to predict & validate SOC changes and C budget: measurements & modelling & realistic biomass estimates through remote sensing in crop models
- **Automated, modular, large scale but high resolution, uncertainty analysis and low cost**
- **Issues:**
  - The **references:** time 0, BAU simulation, regional standard baseline, specific baselines
  - **Soil data:** spatial resolution, harmonization
  - **Data assimilation & assemblage**

Several projects working on it now !





© C. Chenu

*Thank you for your attention*



EJP SOIL has received funding from the European Union's Horizon 2020 research and innovation programme: Grant agreement No 862695



[www.ejpsoil.eu](http://www.ejpsoil.eu)  
[claire.chenu@inrae.fr](mailto:claire.chenu@inrae.fr)