An advanced study

Storing 4 per 1000 carbon in soils: the potential in France

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Context and rationale

- The objective of carbon neutrality in 2050
- Two pillars
  - Drastically reduce GHG emissions
  - Increase C sinks (biomass, soils)
- A scientific controversy about the potential for additional C storage in soils (4 per 1000 initiative)

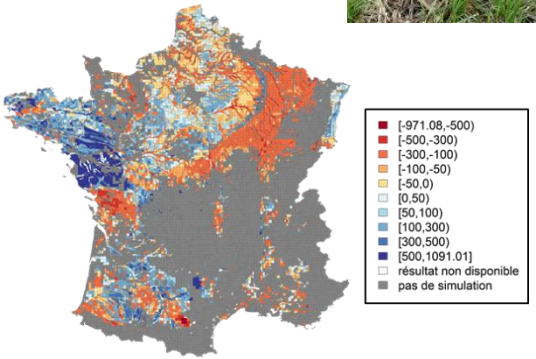
Context and rationale

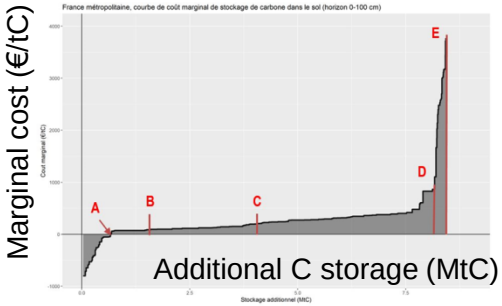
- The 4 per 1000 initiative
- At the early beginning of the initiative a very simple calculation:
  - Soils contain about 2400 Gt C at the global scale
  - Anthropogenic emissions of CO_2 (fossil fuel consumption and deforestation) amount about 9.4 Gt C per year
  - 9.4/2400 ≈ 0,004 → an increase of the soil C stock of 4‰ per year would theoretically compensate CO_2 emissions
- Numerous political and scientific controversies about this initiative
- A need for an accurate assessment of the potential additional C storage in soils, but a lack of methodology and a lack of economical approaches

→ INRA was appointed by the French ministry of Agriculture and the French Environment and Energy management Agency (Ademe) to carry out an advanced study on this topic at the national scale

Objectives

- To identify soil C storing practices
- To assess and map the potential for additional carbon storage in soils following their implementation
- To assess their implementation cost
- To propose an optimal cost-efficient strategy for additional soil C storage at the national scale





Scope

- Mainland France only
- No land use change (no afforestation, no artificialisation of agricultural areas)
- No production systems modification or relocation
- No change in demand or food regimes

=> only management practices readily implementable

General organisation

The advanced study was carried out during two years (2017-2019), under the umbrella of the DEPE-INRA, following its charter and basic principles:

- Two scientific leaders
- A multidisciplinary panel of 28 experts (soil scientists, agronomists, economists, modellers)
- A project team (including two non-permanent junior scientists for modelling)
- An advisory board and a technical committee

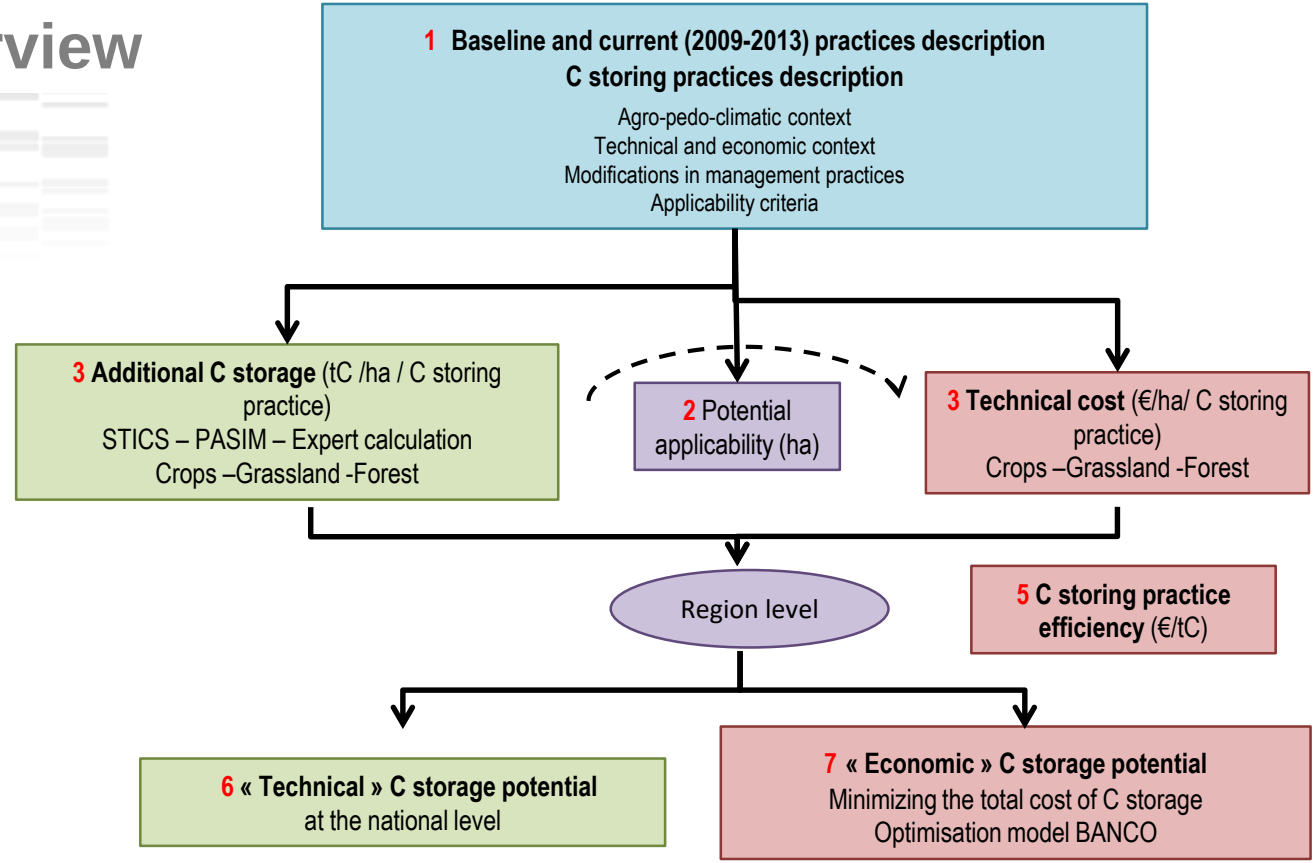
Denis Angers (AAC canada)
Jérôme Balesdent (INRA)
Isabelle Basile-Doelsch (INRA)
Claire Chenu (Agroparistech)
Rémi Cardinael (Cirad)
Eric Ceschia (INRA)
Joel Darroussin (INRA)
Sabine Houot (INRA)
Safya Menasseri (Agrocampus)
Delphine Mézière (INRA)
Thierry Morvan (INRA)
Jean Roger-Estrade (Agroparistech)
Valérie Viaud (INRA)
Olivier Thérond (INRA)

François Gastal (INRA)
Anne Isabelle Graux (INRA)
Katja Klumpp (INRA)

Laurent Augusto (INRA)
Lauric Cecillon (IRSTEA)
Laurent Saint André (INRA)
Julie Constantin (INRA)
Bertrand Guenet (CNRS)
Manuel Martin (INRA)

Valentin Bellassen (INRA)
Philippe Delacote (INRA)
Nathalie Delame (INRA)
Elodie Letort (INRA)
Claire Mosnier (INRA)

Method : overview



Method

Nine soil C storing practices were selected, based on a literature review

- no-tillage
- expansion of cover crops (longer and more frequent cover crops)
- new C inputs (not already spread on agricultural soils under current management practices)
- expansion of temporary grasslands (instead of silage maize)
- agroforestry
- hedges
- moderate intensification of extensive grasslands (+50kgN/ha)
- animal grazing instead of mowing
- grass cover of vineyard

For each selected practice, its potential applicability was calculated considering technical constraints (ex no reduced tillage for sugar beet, no cover crop for intercrop period < 2 months, no agroforestry if soil depth < 1m or plot size < 1ha…)

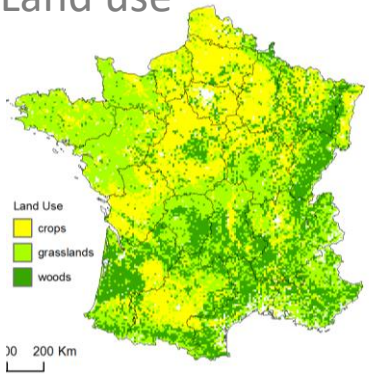
Method

The additional C storage following the implementation of C storing practices was assessed using a modelling approach at a fine spatial-scale resolution (≈1 km^2)

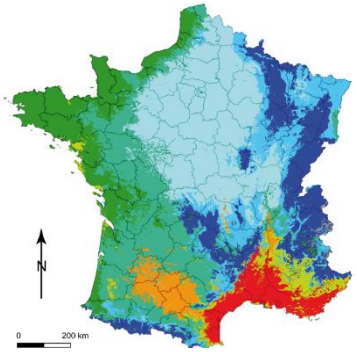
Each grid cell was characterized by its:

- dominant land-use
- local climate
- dominant soil type
- dominant cropping system (crop rotation and current farming practices)
- initial soil C stock value

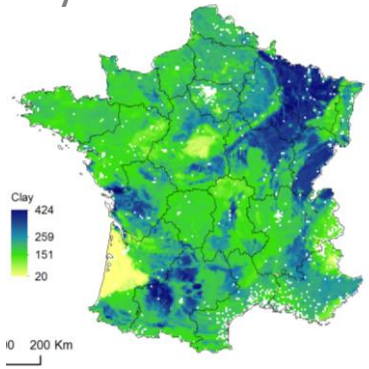
Land use



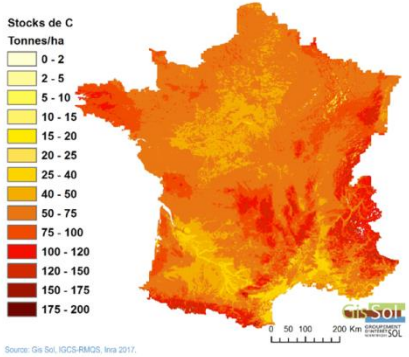
Climate



Clay content



Initial soil C stock value



Method

Two models were used for simulations

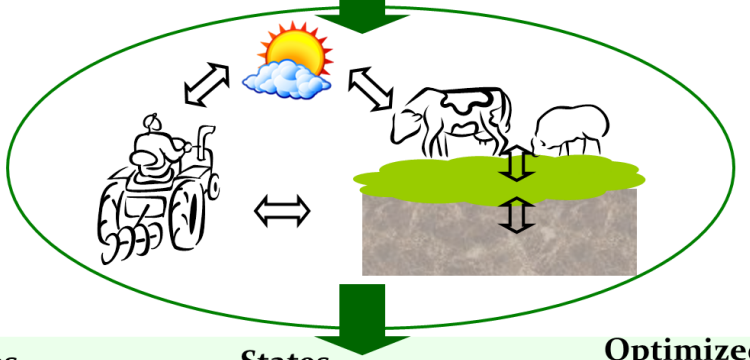
- STICS for arable crops
- PaSim for permanent grasslands

Both models include an explicit representation of the C cycle

INPUT

Climate	Soil	Vegetation	Herbivores	Management
• Radiation • Precipitation • Temperature • Vapour pressure • Wind speed • CO_2 • NH_3	• Texture • Density • Water profile • Depth	• Multi or monospecies • With or without legumes	• Type (heifers, suckler or dairy cows, sheeps) • LW, BCS, age, $MP_{pot,max}$ at turnout to grass	• Mowing • N fertilization • Grazing • Tillage

PaSim



OUTPUT

Fluxes	States	Optimized management
• GHG (CO_2, N_2O, CH_4) • C, N, H_2O & energy fluxes •…	• Forage provision • MP, LW and BCS • SOM • SWC …	• Mowing • N fertilization • Grazing • Irrigation • complementation

Method

For each grid cell, changes in soil C stock were simulated for a period of 30 years

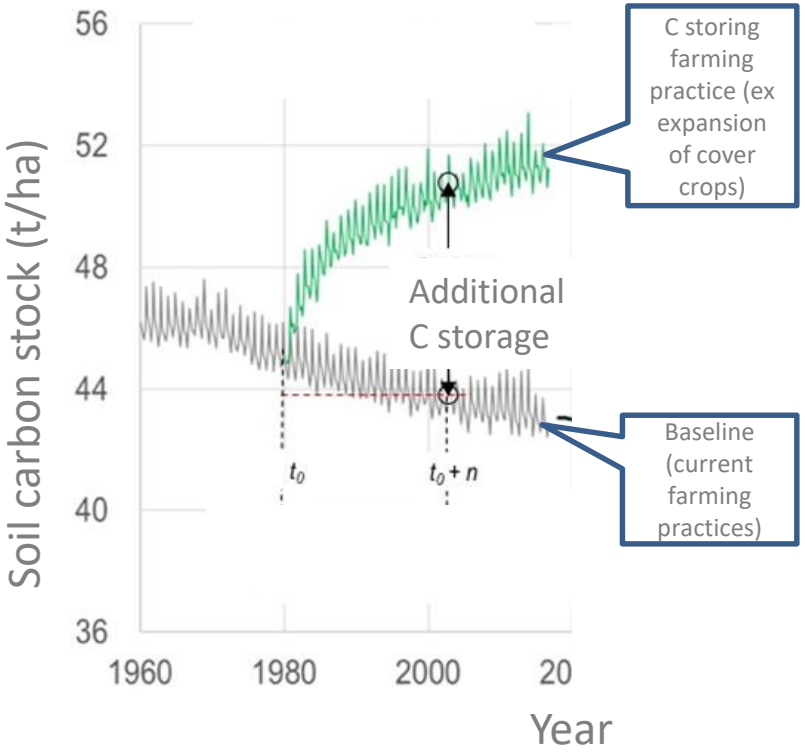
- under current management practices (= baseline)
- under C storing management practices (ex expansion of cover crops)

The additional C storage was calculated as the difference between the simulated soil C stock under C storing practices and the simulated soil C stock under current management practices

Simulations were performed under current climatic conditions for a 30 years period. New simulations are currently run under a second climatic scenario (RCP 8.5, 2040-2070)

Simulations were performed for the 0-30cm horizon, and then extrapolated to the whole soil profile

For each C storing practice, a complete greenhouse gases budget was calculated



Implementation cost assesment

« additional cost » = « cost » C storing practice – « cost » current practice

Cost = loss or gain for the farmer

- **Δ overheads**
  - Δ inputs (fertilizer, feedstuff, …)
  - Δ crop management operations (labour, machinery, fuel)
  - Dedicated investments (e.g. tree planting)
- **Δ revenue**
  - Δ yield
  - New revenue (e.g. sale of wood)
  - Change in land allocation (e.g. crop area substituted with trees or hedges)
- Excluding « optional subsidies »
  - E.g. CAP payments, AEM, regional subsidies
- Constant annuity with a 4.5% discount rate (CGDD)

Cost were calculated for each C storing practice and each French region

Cost-effective allocation of the additional C storage effort

Which C storing practices implementing? And where? To reach a global C storage target at the lowest price?

Cost for farmer (region, practice) €/ha/yr
Additional C storage (region, practice) tC/ha/yr
Potential applicability (region, practice) ha
Compatibility (practice, practice')

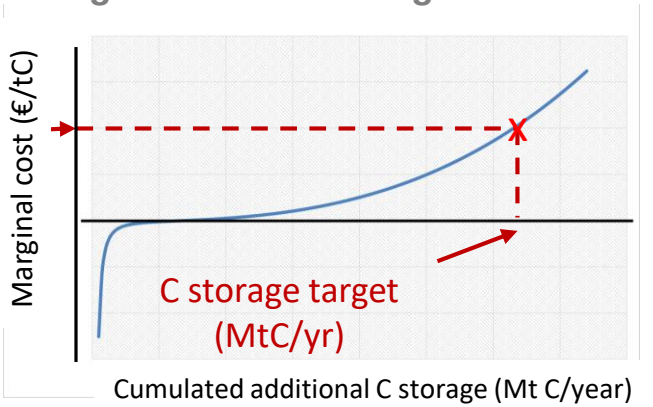
STICS, PASIM, litterature …
Experts

BANCO

National additional C storage target

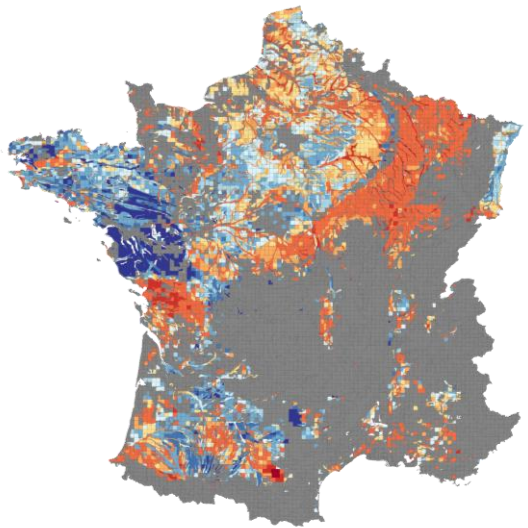
Uptake level (region, practice) (ha)
Marginal C storage cost (€/tC/yr)
Total C storage cost (€/yr)

Marginal carbon storage cost curve



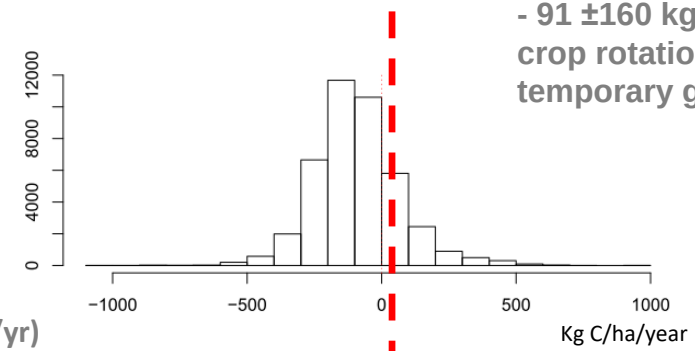
Example of results: baseline

Carbon storage under current farming practices (baseline) for croplands (arable crops and temporary grasslands)

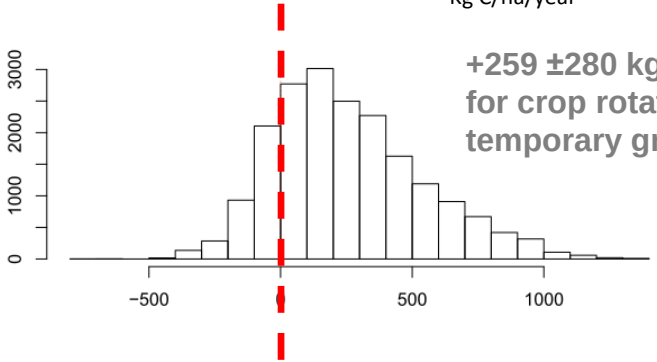


C storage (in kg C/ha/yr)

- [-971.08,-500)
- [-500,-300)
- [-300,-100)
- [-100,-50)
- [-50,0)
- [0,50)
- [50,100)
- [100,300)
- [300,500)
- [500,1091.01]
- résultat non disponible
- pas de simulation



- 91 ±160 kg C/ha/yr for crop rotations without temporary grasslands

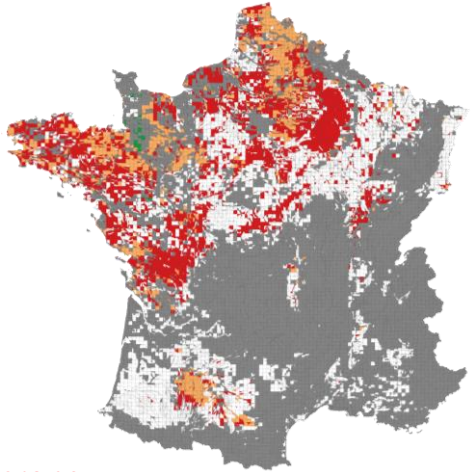


+259 ±280 kg C/ha/yr for crop rotations with temporary grasslands

Example of results: expansion of cover crops

Percentage of intercrop periods with a cover crop during the crop rotation

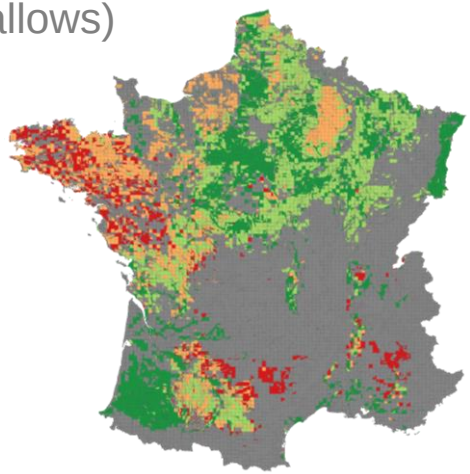
In the baseline (current farming practices, mostly during winter)



Cover crops :
9.3 Mha in 2009-2013 (baseline)

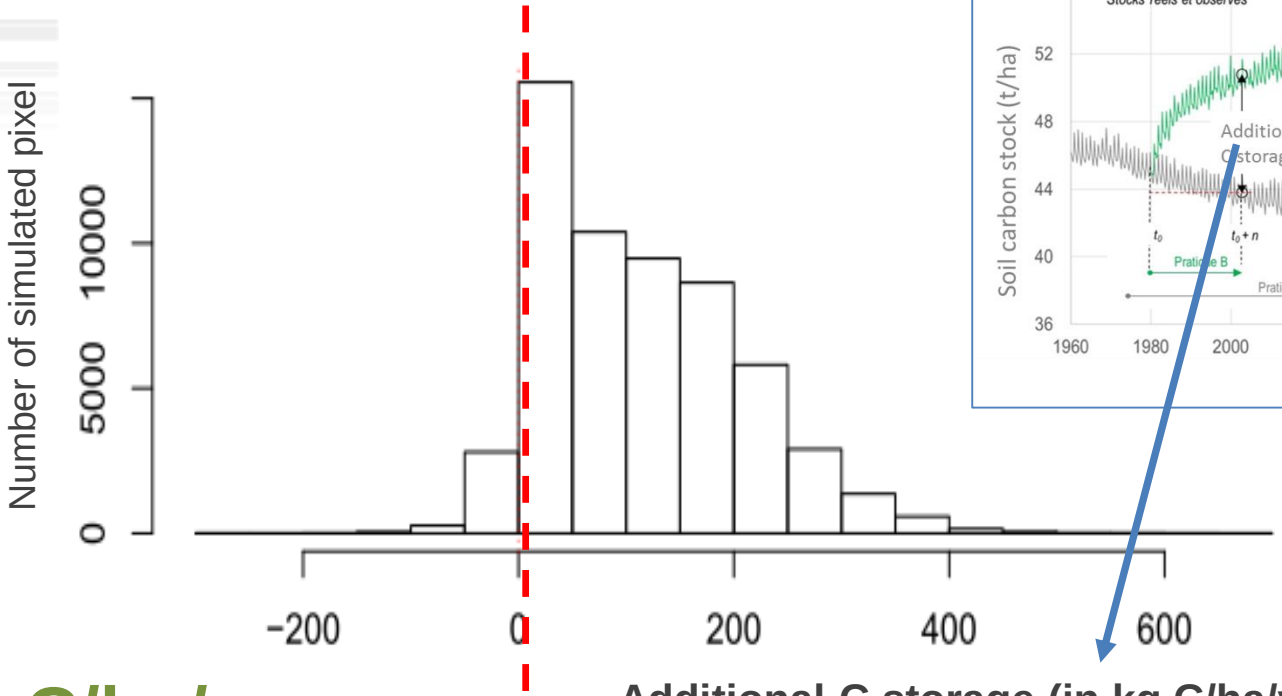
- 2%-25%
- 25%-50%
- 50%-75%
- 75%-97%

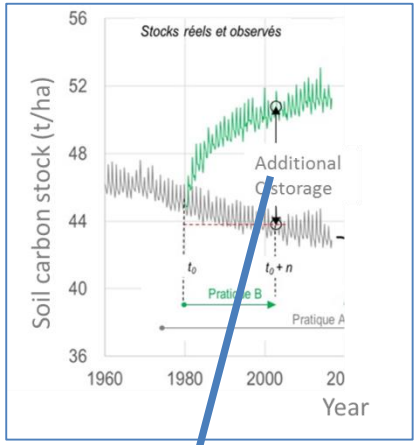
In the scenario with expansion of cover crops (CC during winter and summer fallows)



Potential applicability : 16.6 Mha (96.1% of the cropland area)

Additional carbon storage provided by the expansion of cover crops

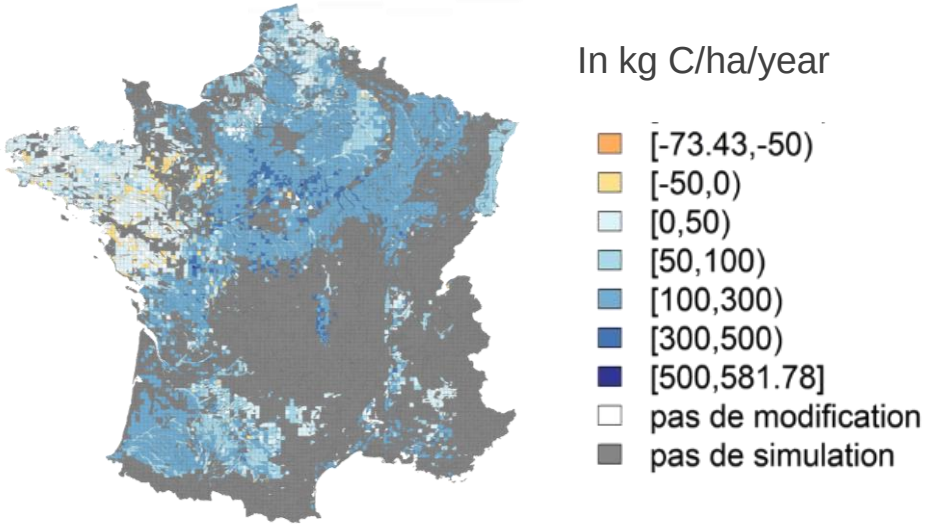




Average additional C storage

+126 ± 93 kg C/ha/yr

Map of the additional C storage provided by the expansion of cover crops



- Less additional carbon storage provided by cover crops in the western part of France;
  - Due to crop rotations already including perennial temporary grasslands, which provide less opportunities for incorporating cover crops
- By contrast, more additional carbon storage in arable cropping systems of the Parisian Basin and South-western France

Many other environmental benefits (ecosystem services) including other net climate mitigation effects (surface albedo increase, decrease in surface heat fluxes…) ➔ not accounted for !

Aggregated results for all C-storing practices

	Additional C storage 0-30 cm soil layer	Potential applicability	Potential additional C storage at the national level 0-30 cm soil layer	Relative yearly increase of soil C stocks (=949 Mt C for cropland soils in mainland France)
	Kg C/ha/an	Mha	Mt C/year	‰ /year
Arable cropping systems				
Expansion of cover crops	+126	16.03	+2.019	
No tillage	+60	11.29	+0.677	
New carbon inputs	+61	4.21	+0.257	
Expansion of temporary grasslands	+114	6.63	+0.756	
Agroforestry	+207	5.33	+1.102	
Hedges	+17	8.83	+0.150	
Total for croplands			+4.960	+5.2 ‰

!!! Carbon storage limited in time ➔ e.g.for cover crop new equilibrium reached after 50 years !!!

Aggregated results for all C-storing practices

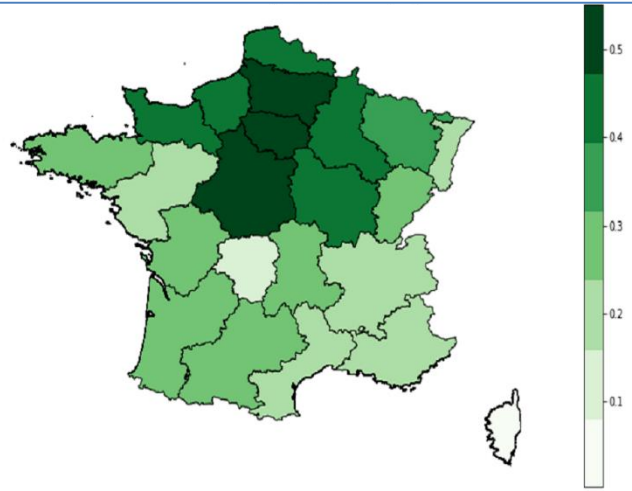
	Additional C storage Horizon 0-30 cm	Potential applicability	Potential additional C storage at the national level Horizon 0-30 cm	Relative yearly increase of the soil C stock
	Kg C/ha/year	Mha	Mt C/year	‰ /year
Permanent grasslands				
Moderate intensification of extensive grasslands	+176	3.94	+0.694	
Grazing instead of mowing	+265	0.09	+0.023	
Total for permanent grasslands			+0.720	+0.9 ‰
Vineyard				
Grass cover	+182	0,56	+0.103	
Total for vineyard			+0.103	+3.7 ‰
Total for French agricultural soils (without forests)			**5,78**	**+3,3 ‰**

- A potential for additional C storage of about 5.78 Mt C/year (in the 0-30cm soil layer)

- This represents an annual increase of
  - +5,2 ‰ for croplands
  - +0,9 ‰ for grasslands
  - +3,3 ‰ for all agricultural soils

- This potential is mainly found in arable soils (86% of the total potential), partly because initial soil C stocks are low

Additional C storage potential (in tC/ha/yr

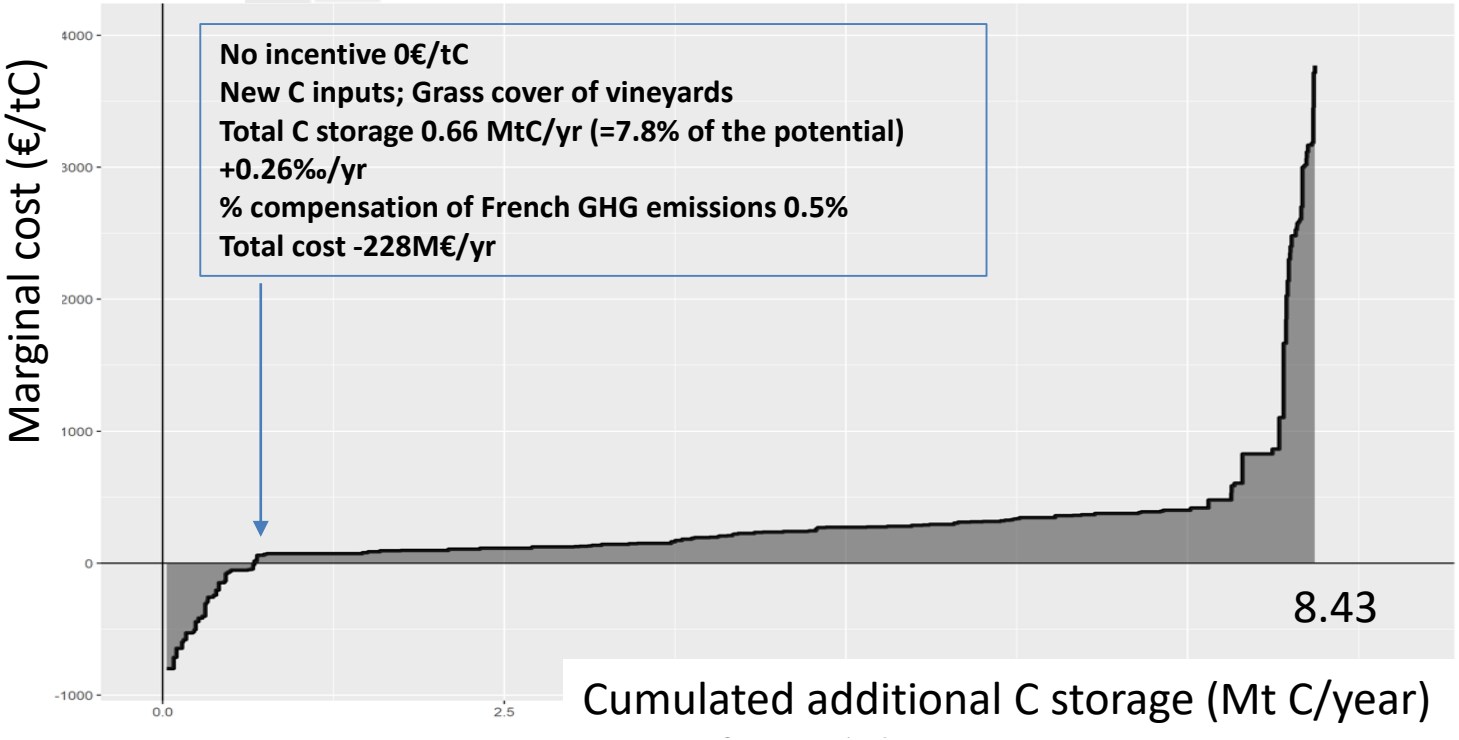


- Extrapolated to the whole soil profile (5,78 → 8,43 MtC = 31MtCO_2e), this additional C storage would compensate 6,8% of national GHG emissions (458 MtCO_2e)

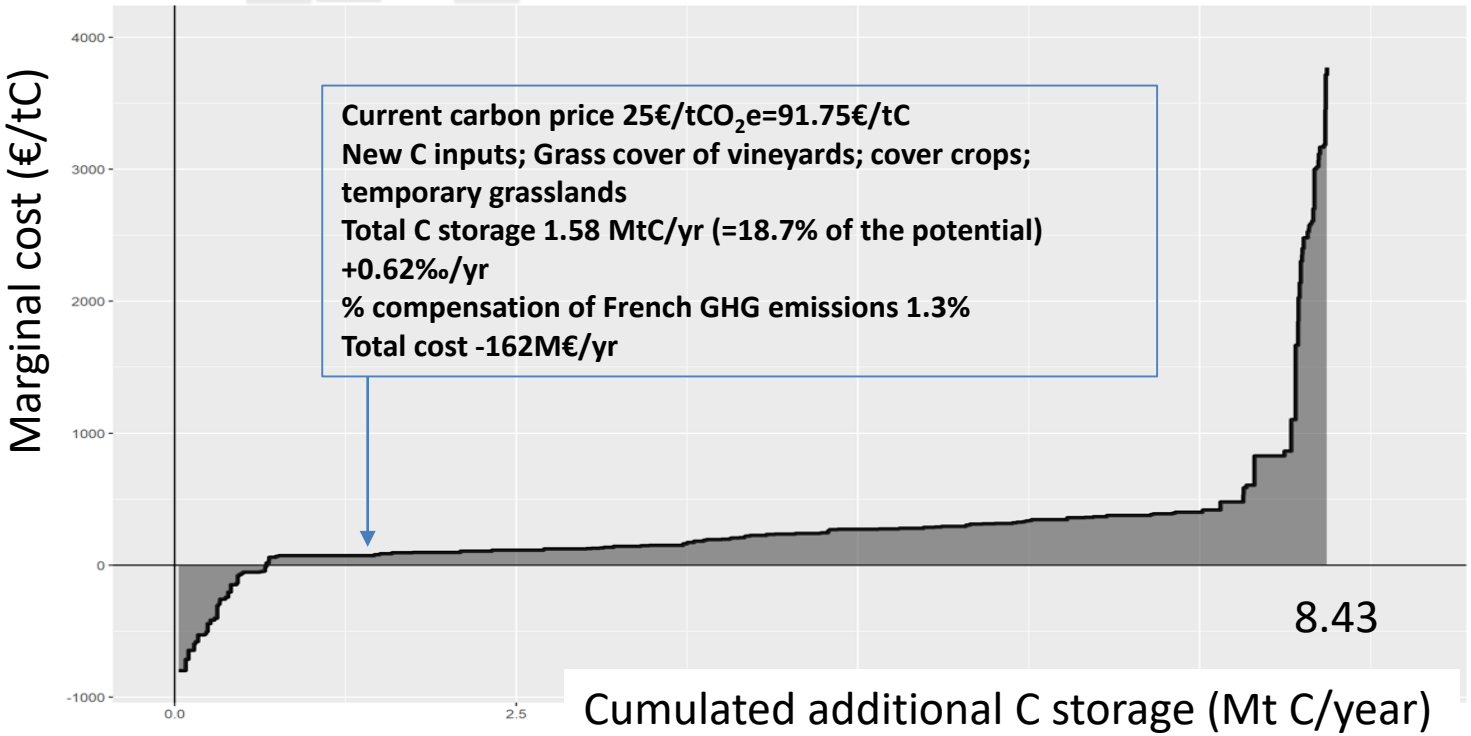
Costs

C storing practice	Potential applicability (Mha)	Cost for farmer (€/ha/year)	Storage cost (€/tC)	Storage cost (€/tCO_2)
New carbon inputs	**4,21**	**-52** (-117; -8)	**-494** (-1 192; -134)	**-135** (-325; -37)
Grass cover of vineyards permanent	**0,15**	**-26** (-27; -22)	**-56** (-44; -77)	**-15** (-21; -11)
In winter	**0,41**	**-15** (15; 15)	**-51** (-51)	**-14** (-14)
Expansion of cover crops	**16,03**	**39** (12; 147)	**180** (69; 1 104)	**49** (19; 301)
Moderate intensification of extensive grasslands	**3,94**	**28** (12; 38)	**130** (60, 1 189)	**35** (16;324)
Grazing instead of mowing	**0,09**	**73** (-85; 146)	**203** (-2 791; 518)	**55** (-761; 141)
Expansion of temporary grasslands	**6,63**	**91** (-40; 263)	**473** (-242; 1 667)	**129** (-66; 455)
Agroforestry	**5,33**	**118** (63; 179)	**302** (195; 386)	**82** (53; 105)
Hedges	**8,83**	**73** (54; 87)	**2 322** (2 013; 3 618)	**633** (549; 987)

Marginal carbon storage cost curve

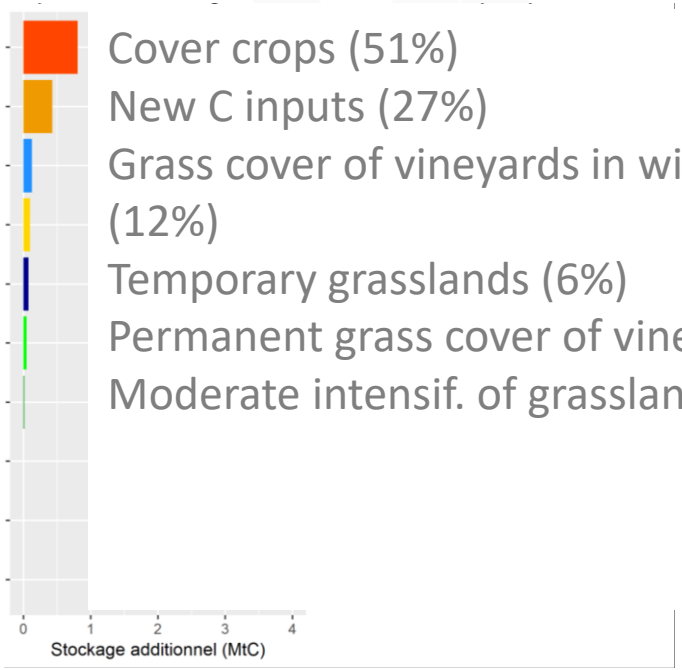


Marginal carbon storage cost curve



Current carbon price 91,75 €/tC = 25 €/tCO2e

Contribution of C storing practices

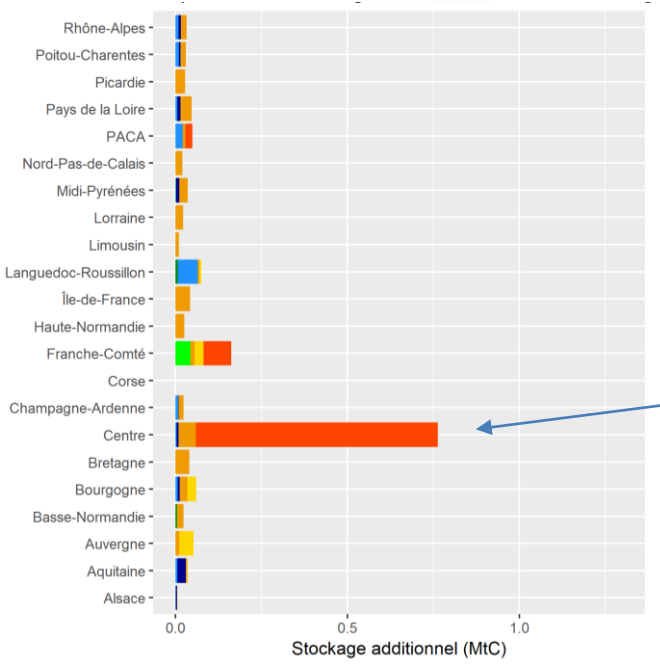


- Total C storage: 1.58 MtC/yr = -5,8 $MtCO_2e$/yr
- 97% in croplands and vineyard
- % compensation of total French emissions: 1.3%
- Total cost = -162 M€/yr = gain

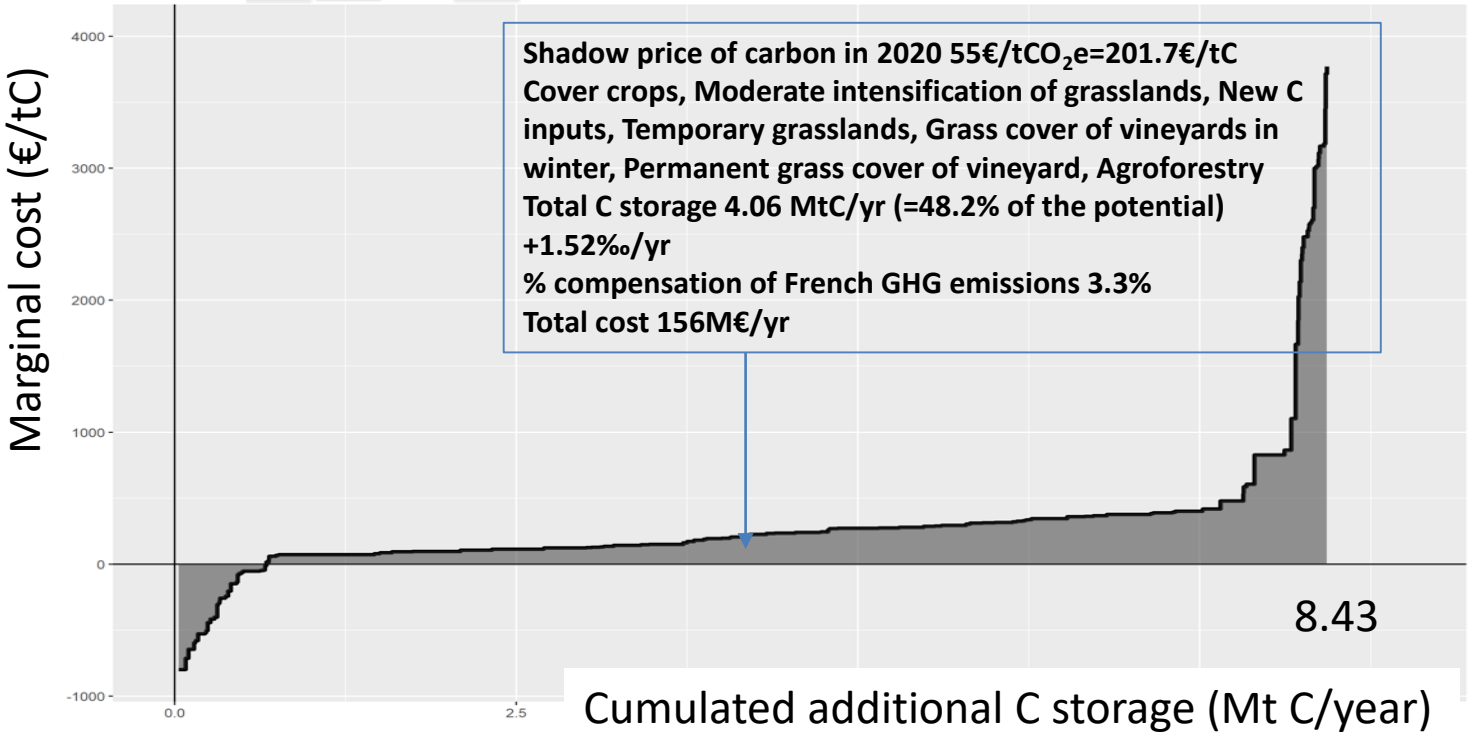
Current carbon price 91,75 €/tC = 25 €/tCO2e

Contribution of French regions

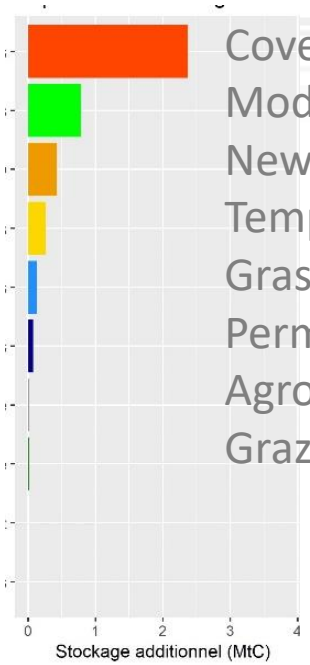
The main contributing region is « Centre-Val de Loire », an intensive cropland area



Marginal carbon storage cost curve



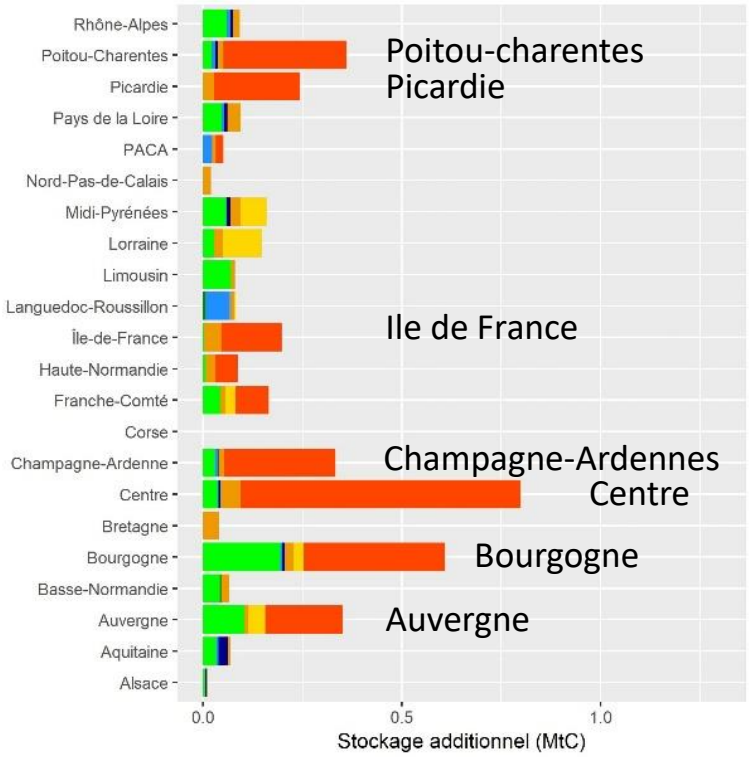
Shadow price of carbon in 2020 (201,7 €/tC = 55 €/tCO_2e)



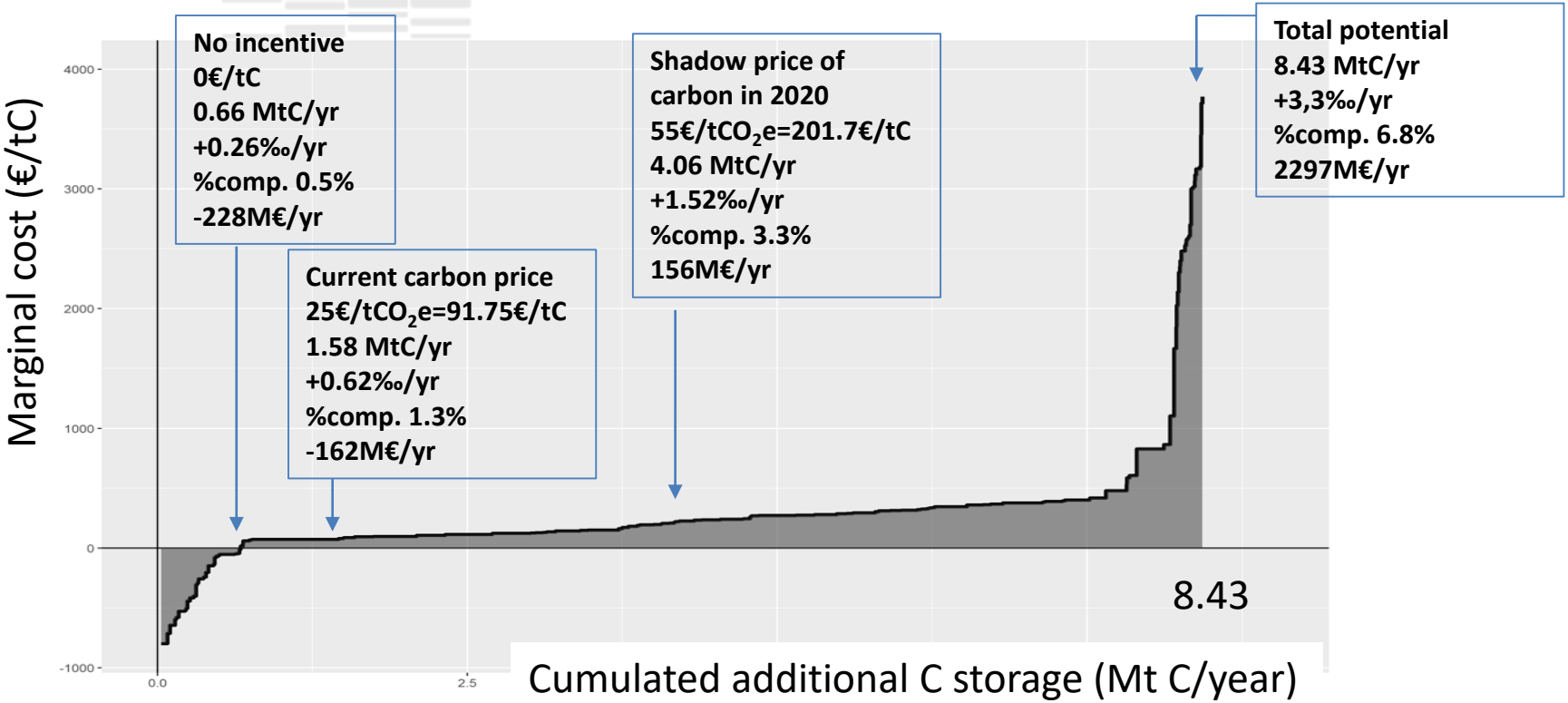
Cover crops (58%)
Moderate intensification of grasslands (19%)
New C inputs (11%)
Temporary grasslands (6%)
Grass cover of vineyards in winter
Permanent grass cover of vineyard
Agroforestry
Grazing instead of mowing

- Total C storage: 4.06 MtC/yr = 14.9 MtCO_2e/yr
- % compensation of total French emissions: 3.3%
- Total cost = 156 M€/yr

Shadow price of carbon in 2020 (201,7 €/tC = 55 €/tCO_2e)



Marginal carbon storage cost curve



Summary

- A potential for additional C storage of about 5,78 Mt C/year (in the 0-30cm soil layer)
- This represents a relative increase of +3,3‰ for agricultural soils (+ 5,2‰ if only arable soils are considered)
- This potential is mainly found in arable soils (86% of the total potential), partly because initial soil C stocks are low
- Extrapolated to the whole soil profile, this additional C storage would compensate 6,8% of national GHG emissions
- About half of this potential is at a lower cost than the shadow price of carbon
- The optimal combination of C storing practices depends on the regional context