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**Agroscope**

# How measures for greenhouse gas mitigation in agriculture are implemented strongly determines cost-effectiveness

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[1] Climate and Agriculture, Agroscope
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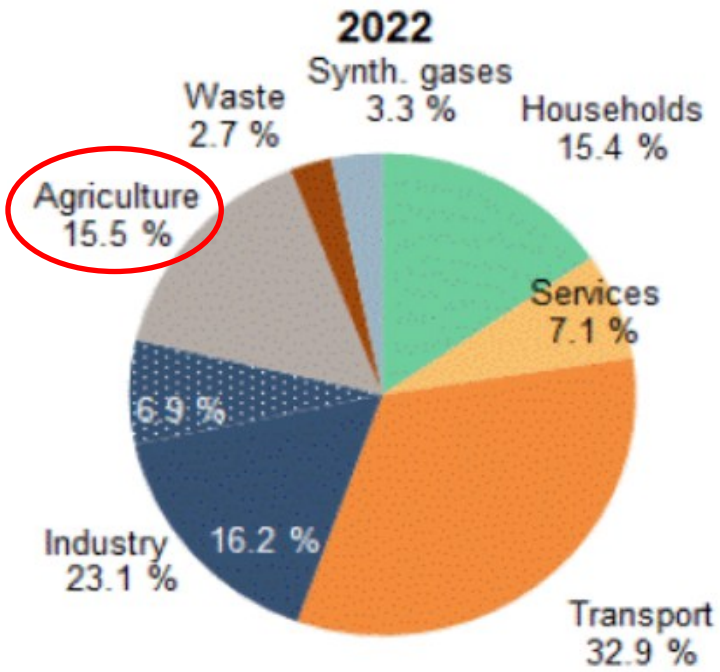
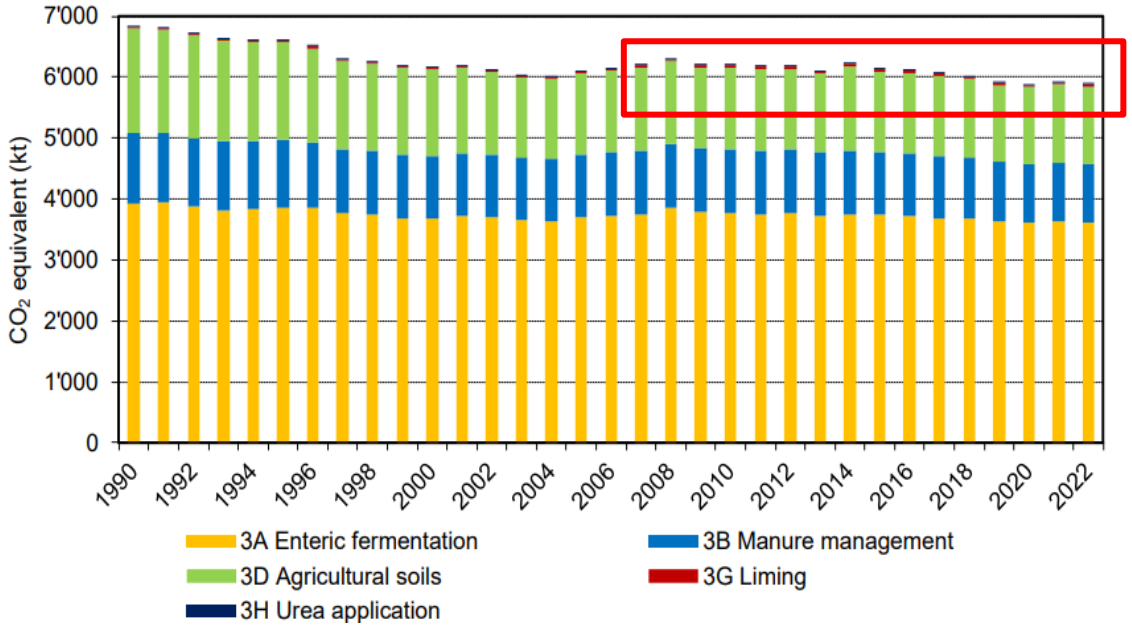
# Background

- Swiss agricultural greenhouse gas (GHG) emissions accounted for 15.5% of the total emissions (in 2022)
- Agricultural emissions have been reduced by 14% (in 2022), but the reduction is stagnating now




**Agricultural GHG in CO2 equivalent**

Switzerland's greenhouse gas inventory
Switzerland's Greenhouse Gas Inventory 1990–2022, National Inventory Document 2024



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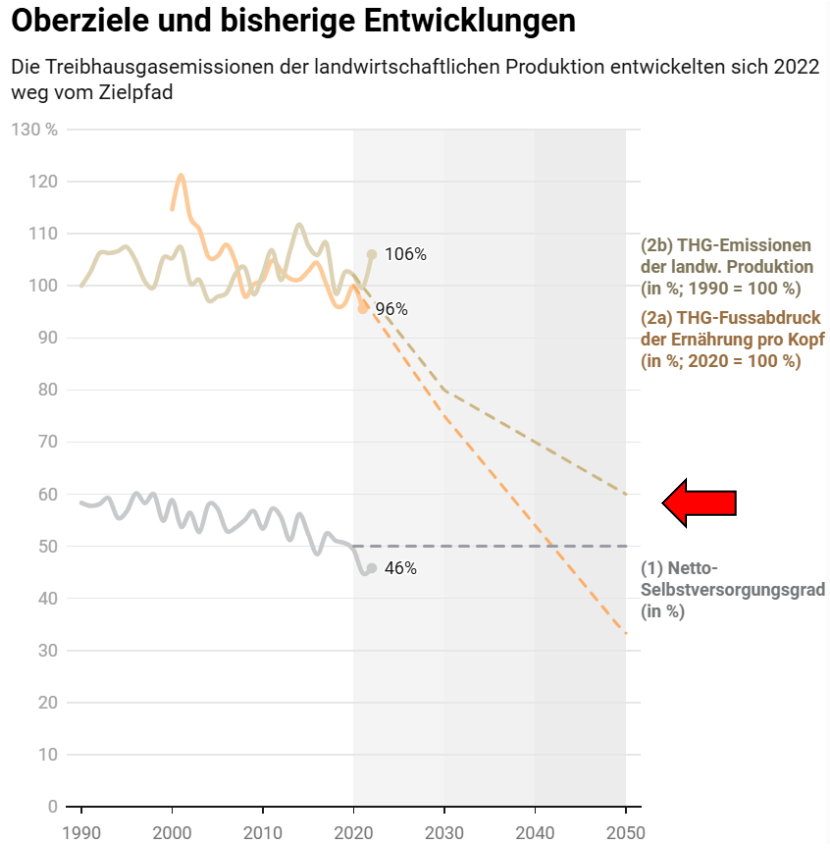
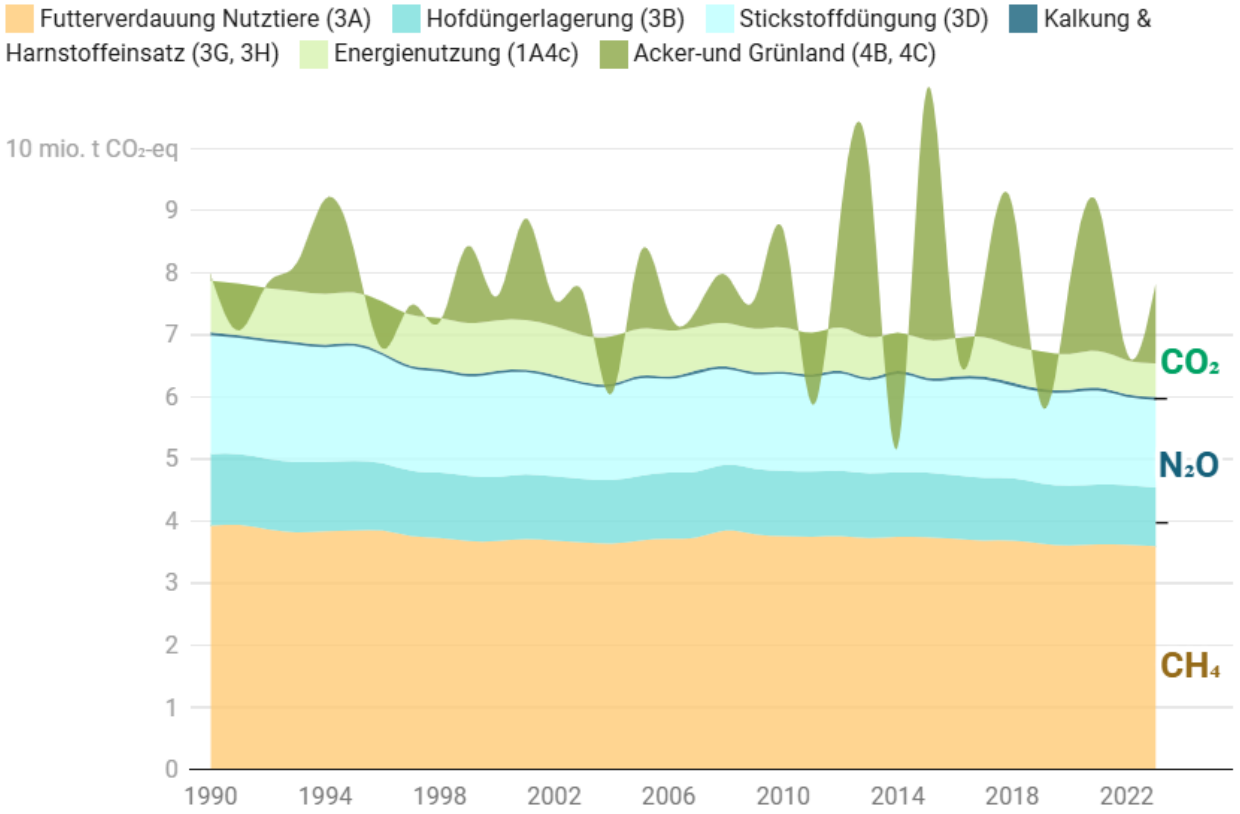
# Background

- Swiss agricultural greenhouse gas (GHG) emissions accounted for 15.5% of the total emissions (in 2022)
- Agricultural emissions have been reduced by 14% (in 2022), but the reduction is stagnating now
- Reduction of GHG emissions from domestic agricultural production by 40% compared to 1990
- New promising measures are urgently needed, and these measures should be comprehensive




Agriculture and Food Climate Strategy 2050




Landwirtschaft im Klimawandel

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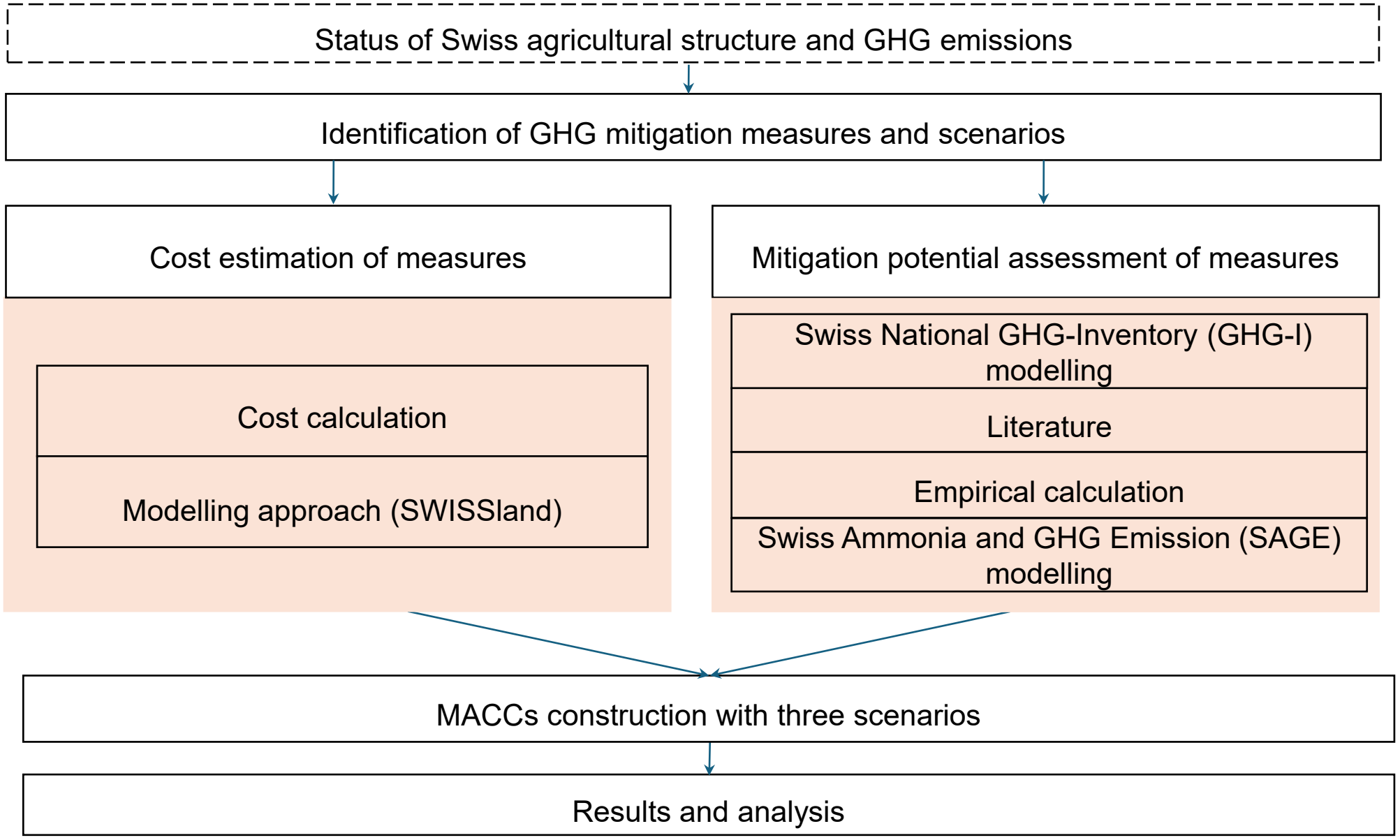
# Objectives

- Identify potential **measures** and up to three implementation **scenarios** (i.e., different assumptions for application of measures)
- Estimate the **cost** of each measure and scenario for farmers, and upscale to national-level
- Assess the **mitigation potential** of each measure at the national scale (Swiss National GHG-Inventory Model)
- **Integrate** costs and potentials of all measures in marginal abatement cost curves (**MACCs**). Group results by costs per ton of mitigated $CO_2$ and present them in three MACCs (i.e., for the most **probable** scenario, a **low-cost** and a **high-cost** scenario)

# Overview of the methodological approach



# Measure identification

- **Approach: Literature search, discussion with experts and policy makers**
- **Criteria: Mitigation potential, social acceptance, farmers' operational difficulty, policy support**

| Function | Measures | Approach |
|---|---|---|
| $CH_4$ reduction<br>$N_2O$ reduction<br>$CO_2$ reduction<br>C-sequestration → $CO_2e$ | 1. Biogas plants ($CH_4$+$N_2O$)<br>2. Increasing lactation number<br>3. Methane-reducing feed additives<br>4. Nitrification inhibitor<br>5. Slurry covers<br>6. More grain legumes<br>7. Trailing hose/shoes for slurry spreading<br>8. Precision nitrogen fertilization<br>9. Nitrogen optimized feeding<br>10. Rewetting organic soils ($CO_2$+$N_2O$)<br>11. Biochar | Technical approaches |
| | 12. Agroforestry (C-sequestration+$CH_4$+$N_2O$) | Structural approaches |

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# Example1: Scenarios for the measure “Agroforestry”

- Plant fruit/nut trees on suitable meadows and pastures for C-sequestration in biomass ($CO_2$ removal)
- Reduced fodder production due to reduced grass area, leads to lower livestock numbers and $CH_4$/$N_2O$ emissions

## Assumptions

Tree density (per ha): Walnut: 30; Apple: 50; Cherry: 50; tree longevity: 60 years (convert to biochar)

| | |
|---|---|
| Scenario 1 | Reduction in grass production by **10% per ha**, and **average revenue** from fruit and nut yield |
| Scenario 2 | Reduction in grass production by **30% per ha**, and **average revenue** from fruit and nut yield |
| Scenario 3 | Reduction in grass production by **10% per ha**, and **optimistic revenue** from fruit and nut yield |

Simulations: Eva Winter with SWISSland and Swiss Ammonia and GHG Emission (SAGE) models

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# Example2: Scenarios for measure “Grain Legumes”

- Legumes require no N fertilizer and therefore their cultivation leads to less $N_2O$ emissions
- Legumes could partly replace temporary grassland and fodder maize

## Assumptions

| | | | |
|---|---|---|---|
| Scenario 1 (S1) | Area expansion based on **agronomic potential** (conventional farming)<br>soybean (+48,710 ha)<br>dry bean (+44,095 ha)<br>pea (+8,706 ha) | temporary grassland (-73,901 ha)<br>fodder maize (-27,610 ha) | References:<br>Keller et al., 2024;<br>Ramseyer et al., 2021 |
| Scenario 2 (S2) | Area expansion based on **market demand** (organic farming)<br>soybean (+4,000 ha)<br>pea (+15,000 ha) | temporary grassland (-13,832 ha)<br>fodder maize (-5,168 ha) | |
| Scenario 3 (S3) | Area expansion according to **regional survey** (organic farming)<br>soybean (+16,615 ha) | temporary grassland (-12,096 ha)<br>fodder maize (-4,519 ha) | |

Keller, B., Oppliger, C., Chassot, M., Ammann, J., Hund, A., Walter, A., 2024. Swiss agriculture can become more sustainable and self-sufficient by shifting from forage to grain legume production. Communications Earth & Environment 5, 40.
Ramseyer, N., Steiner, B., Vonlanthen, I., Brugger, D., 2021. Potential ausgewählter Ackerkulturen in der Schweiz -- Bericht zur aktuellen Lage im Ackerbau und den möglichen Entwicklungen. Geschäftsbereich Pflanzenbau.



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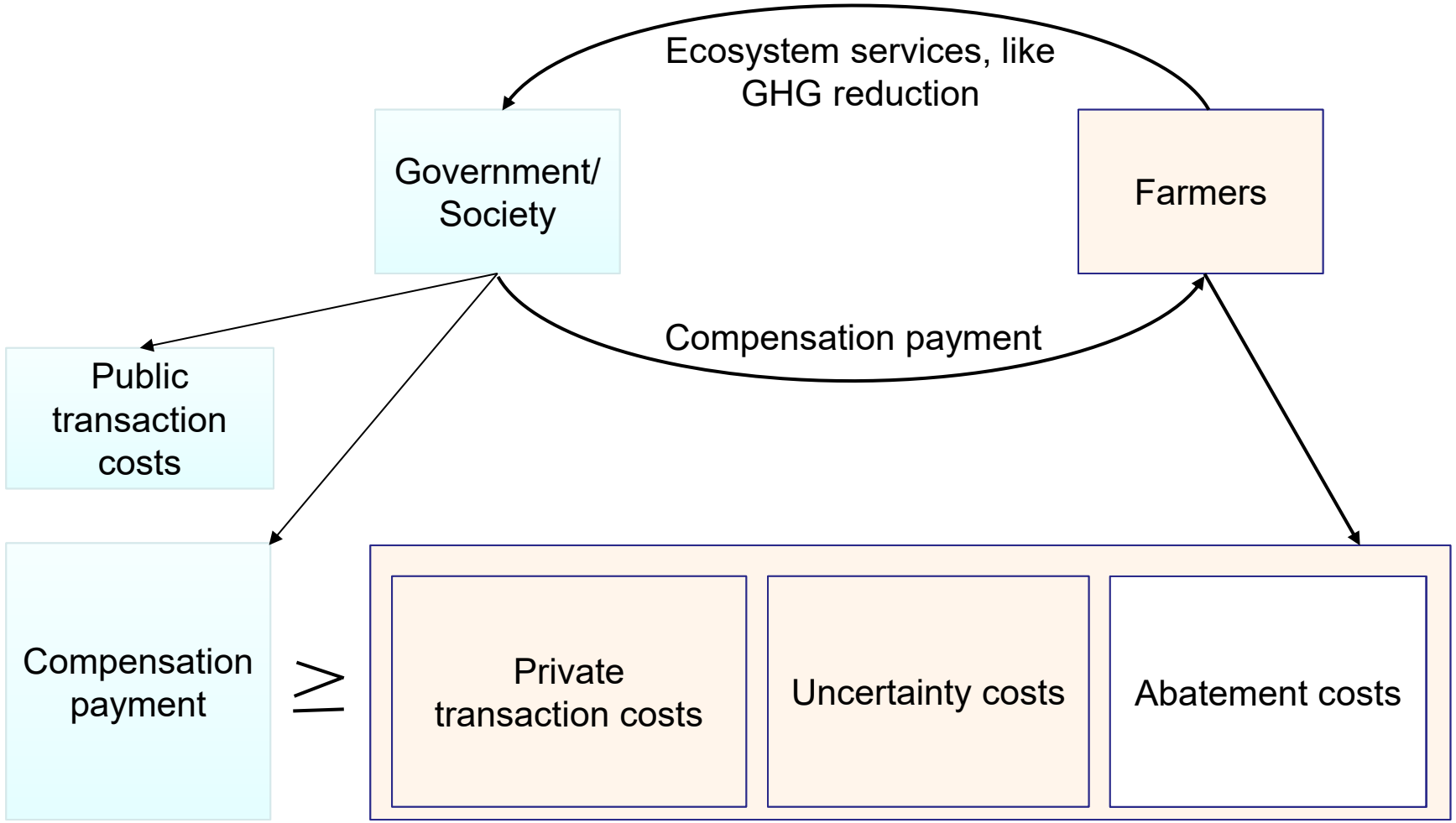
# Cost of measures

**Costs involved in direct payment programs**






Mettepenningen E, Verspecht A, Van Huylenbroeck G. Measuring private transaction costs of European agri-environmental schemes. Journal of Environmental Planning and Management. 2009 Jul 1;52(5):649-67.

# Cost of measures: Average annual costs

Abatement costs

Establishment costs ($c_{em}$)

Maintenance costs ($c_{mt}$)

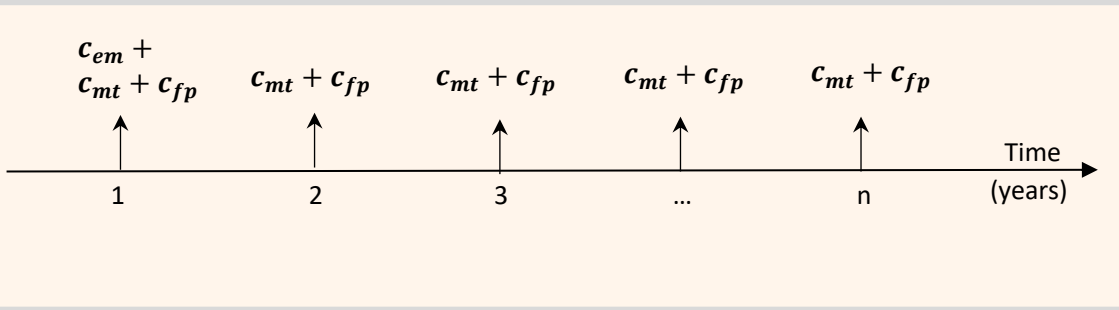
Foregone profits ($c_{fp}$)

**Measures**

Agroforestry
Slurry cover
Trailing hose
Biogas plants
…

Biochar
More legumes
Nitrification inhibitors
Feed additives
N-optimized feeding
…

- $c_{em}$, $c_{mt}$ and $c_{fp}$ occur at different time points




**Cost formulas:**

$$c_a = c_{em} \cdot \frac{r}{1-(1+r)^{-n}} + c_{mt} + c_{fp}$$

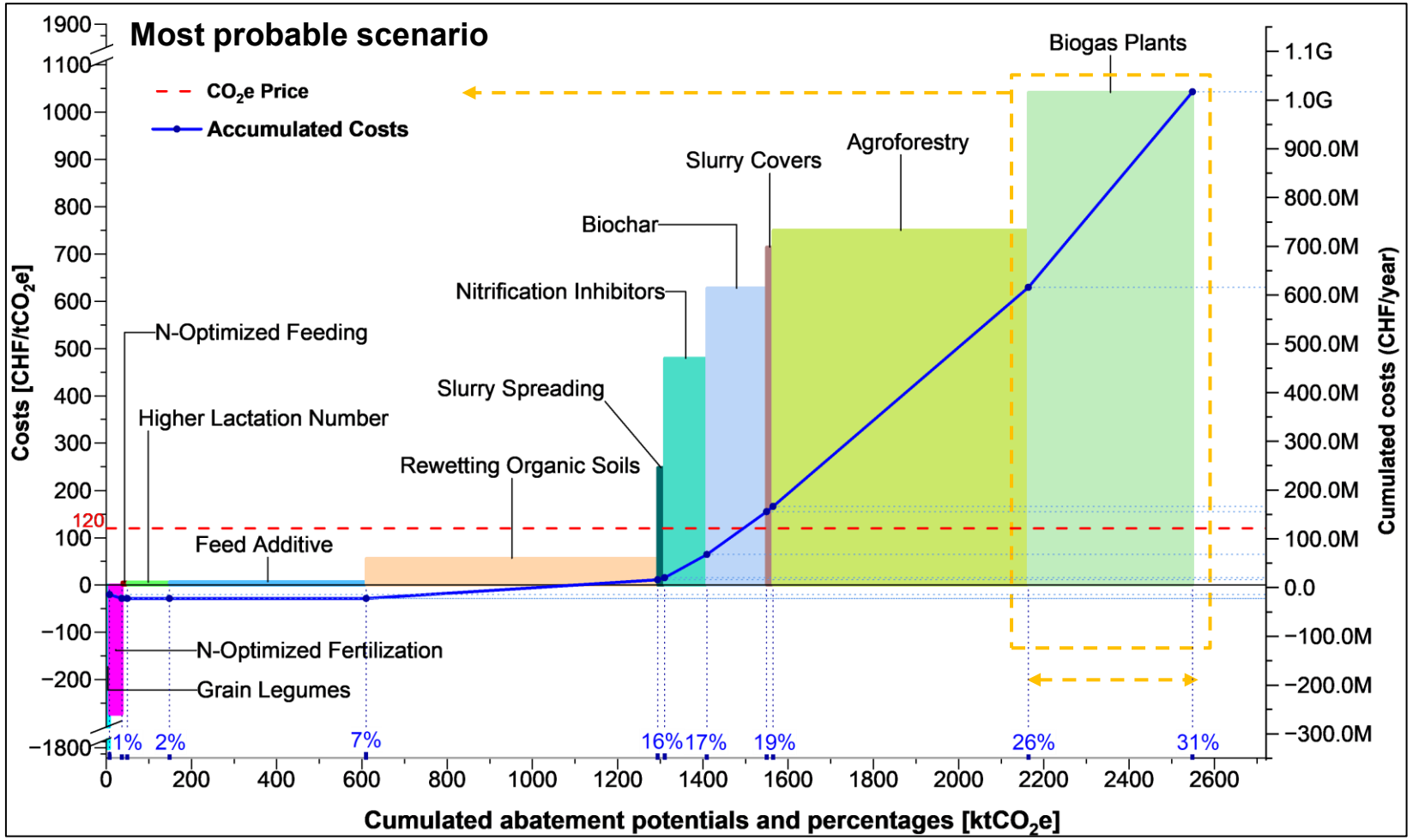
$c_a$: Average annual costs
$r$: Discounting rate
$n$: Number of years of measure life

$$c_a = c_{fp}$$

$c_a$: Average annual costs
$c_{fp}$: Foregone profits

# Results: MACCs with three scenarios

Cost per measure (CHF/tCO$_2$e)




Cumulative cost per year

**Example:**

Measure of “Biogas Plants”

Cost: 1042 CHF/tCO$_2$e

Potential: 385 ktCO$_2$e/year

From left to right: Cumulative GHG emission reduction potential

From left to right: Cumulative GHG emission reduction percentage (% compared to 1990 level)



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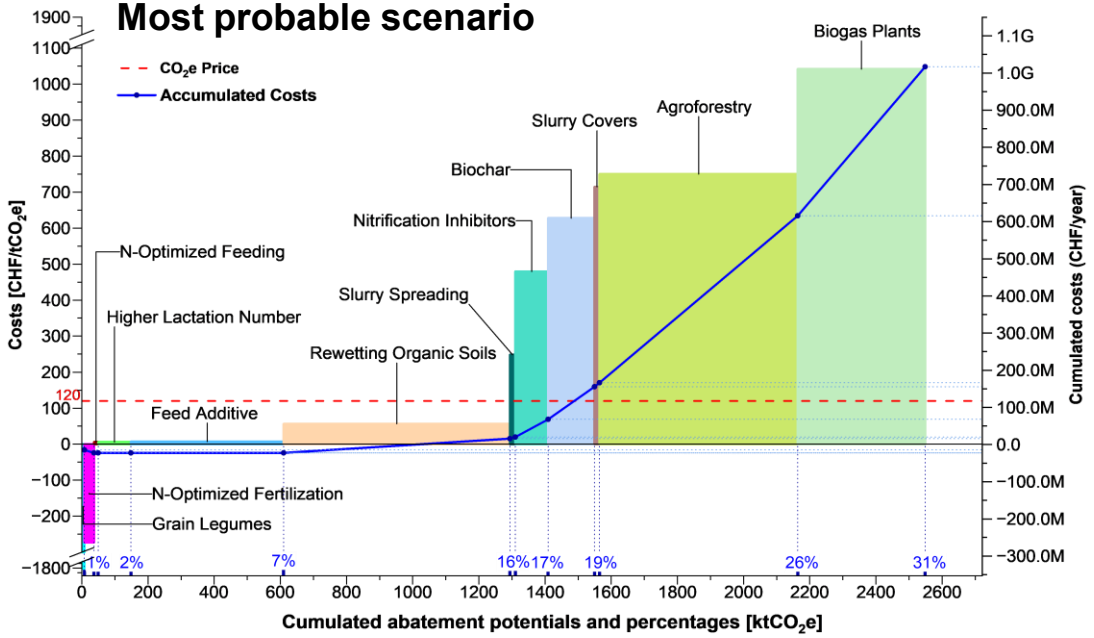
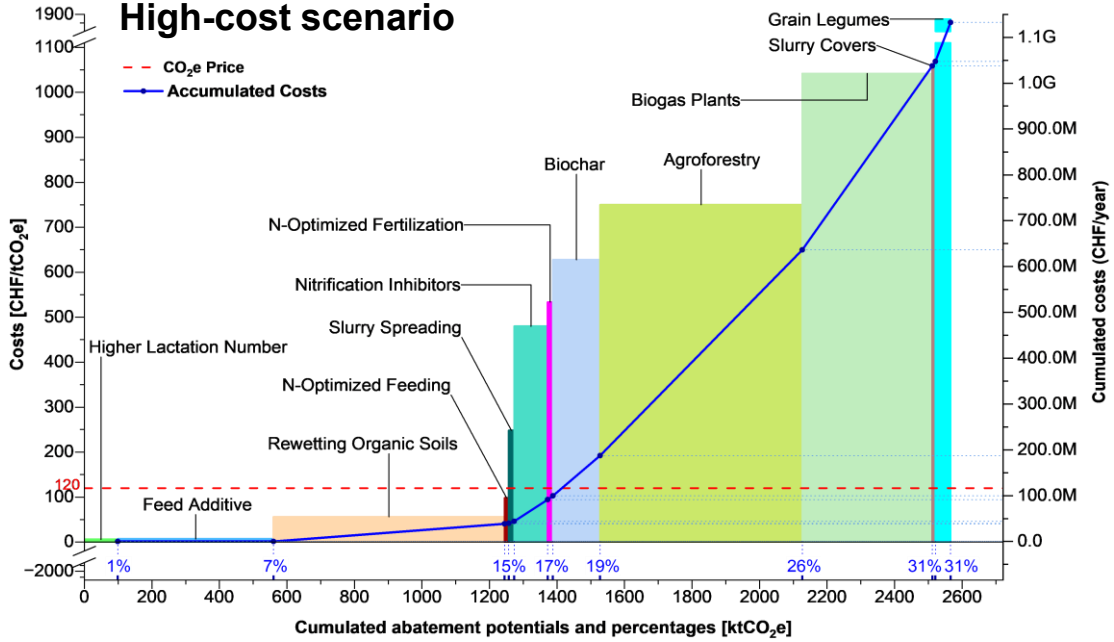
# Results: MACCs with three scenarios

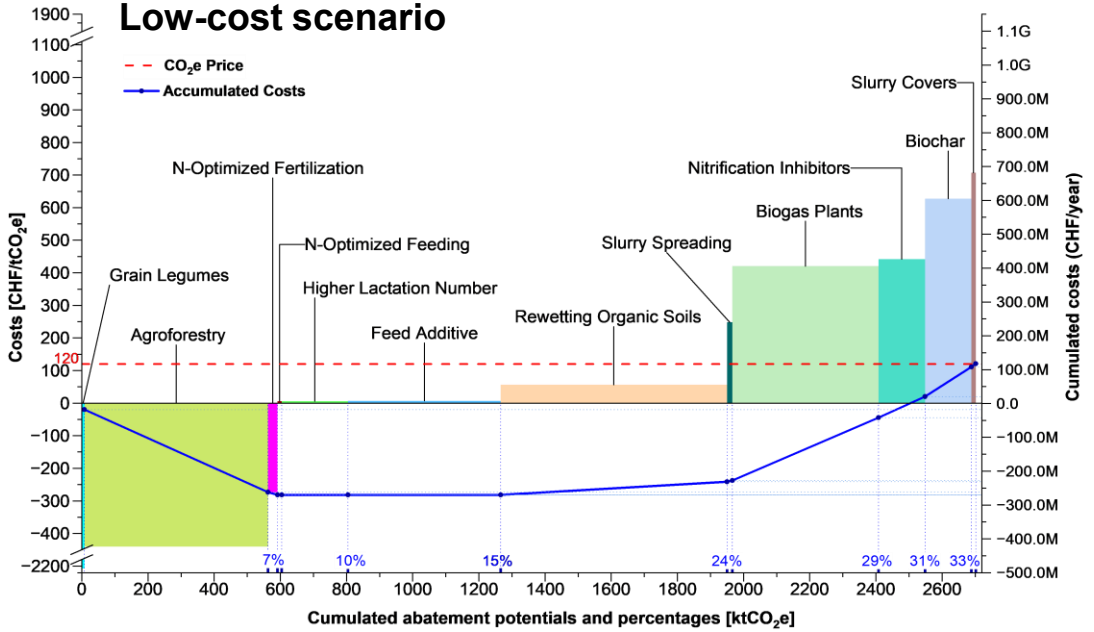
## Most probable scenario




## High-cost scenario



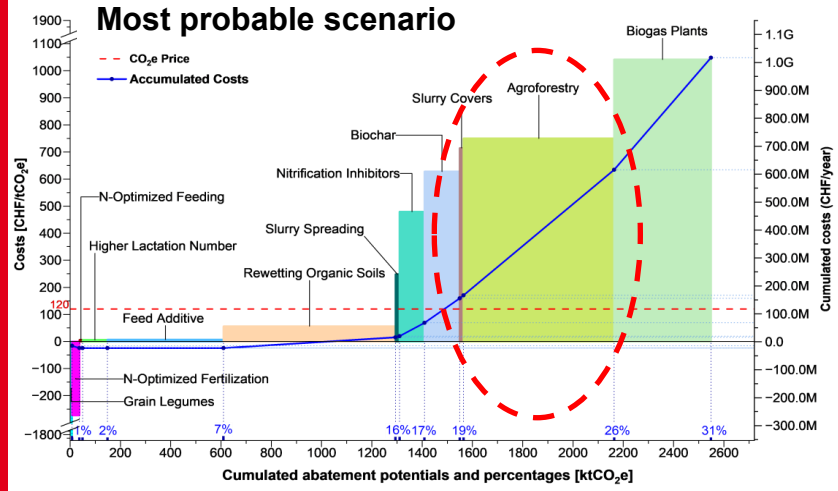

## Low-cost scenario

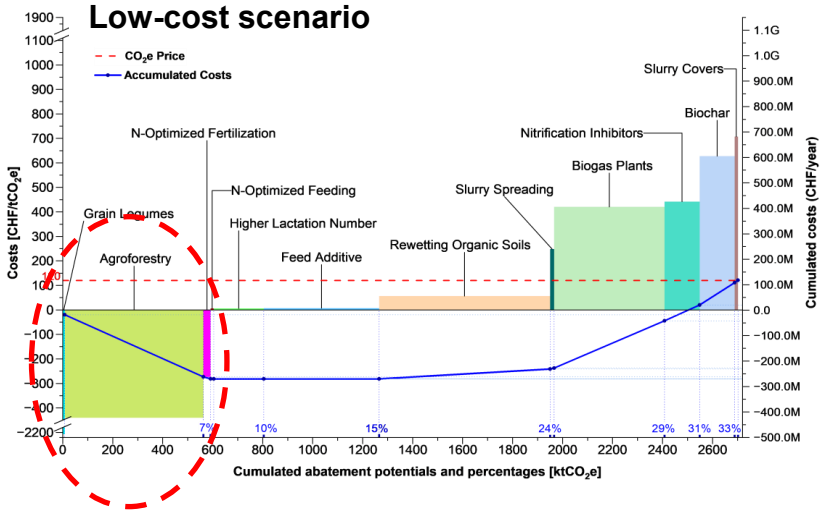


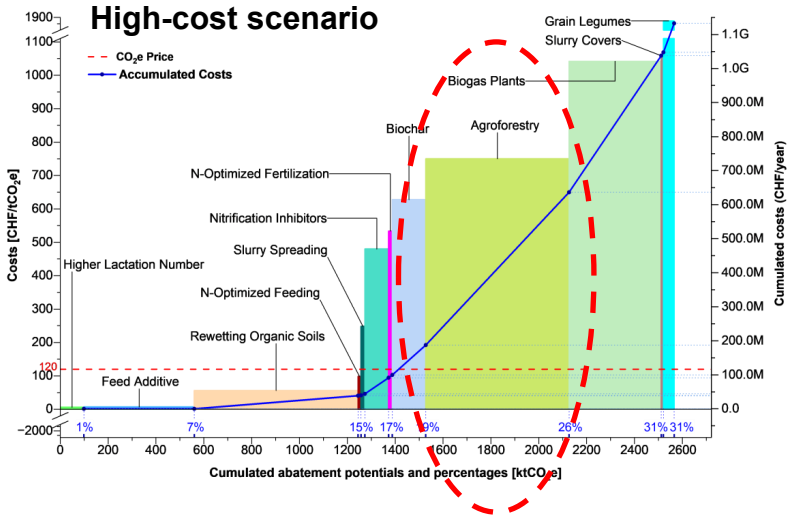

| Results from MACCs | | Probable scenario | Low-cost scenario | High-cost scenario |
|---|---|---|---|---|
| All twelve measures | Emission reductions (kt CO2e) | 2548 (31%) | 2701 (33%) | 2566 (31%) |
| | Costs (Mio CHF) | 1017 | 118 | 1133 |
| Cost-effective measures | Number of measures | 6 | 7 | 4 |
| | Emission reductions (kt CO2e) | 1294 (16%) | 1950 (24%) | 1257 (15%) |
| | Costs (Mio CHF ) | 16 | -231 | 40 |
| Neutral-cost measures | Number | 2 | 2 | 1 |
| | Emission reductions (kt CO2e) | 112 (1%) | 213 (3%) | 99 (1%) |
| Negative-cost measures | Number | 2 | 3 | 0 |
| | Emission reductions (kt CO2e) | 37 (0,45%) | 592 (7%) | 0 (0%) |

# Assumptions change the ranking of measures in MACCs and need to be transparently communicated

## Example1: Agroforestry (Represented bar colour: )

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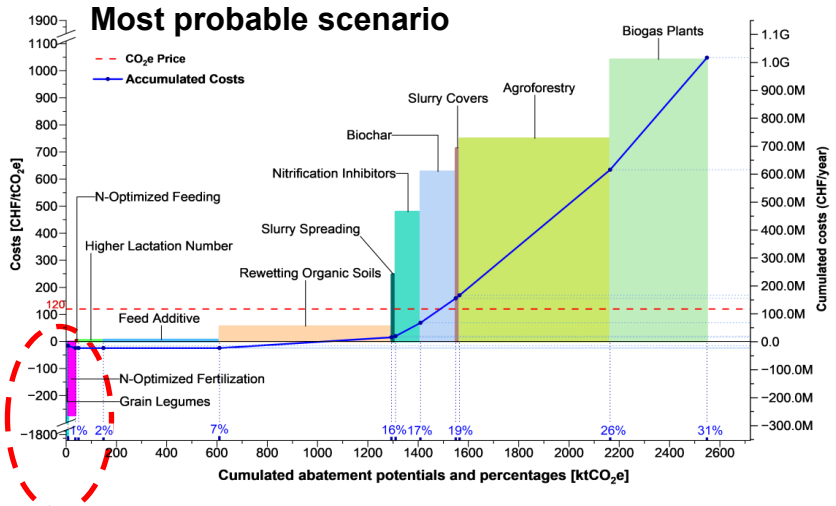
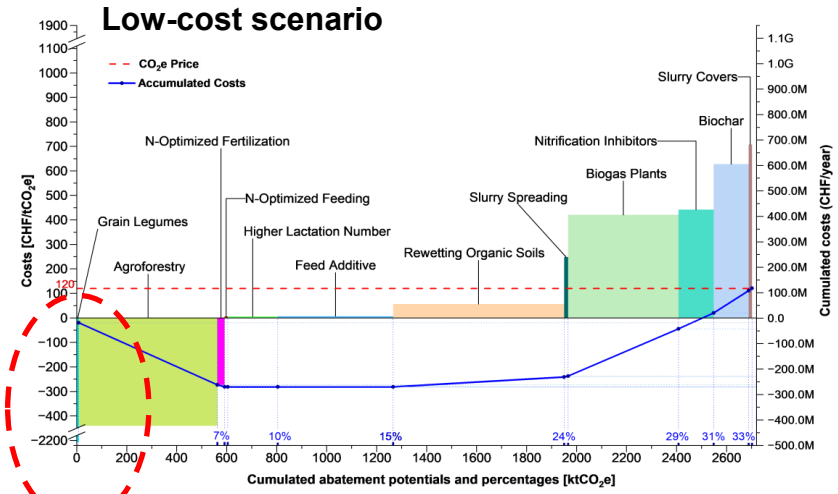
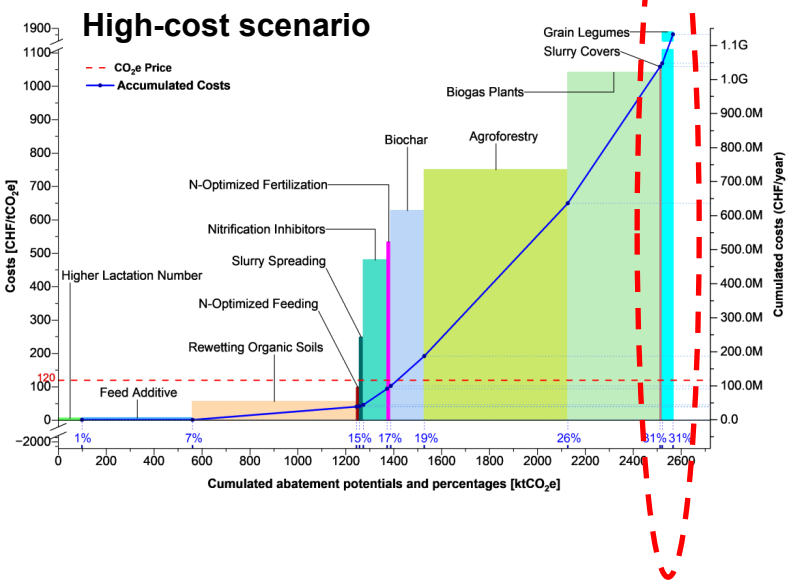
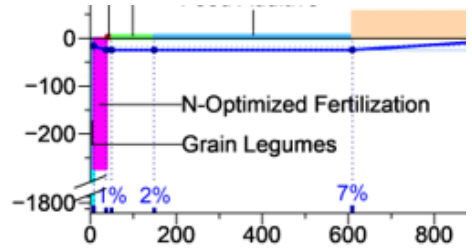
# Assumptions change the ranking of measures in MACCs and need to be transparently communicated

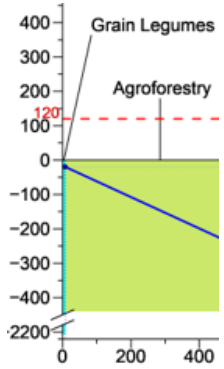
## Example: Grain Legumes (Represented bar colour: )



# Conclusions part 1

- A **31-33%** emission reduction could be reached with a cost of **118-1,133 Mio CHF** per year. Cost-effective measures can achieve a **15%-24%** emission reduction.

- How measures are implemented leads to strong **uncertainty** in MACCs, especially regarding the **costs**. Transparent communication is important for policy makers.

- The existence of cost neutral and cost negative measures suggests that there are **other barriers** that currently prevent the uptake of measures.

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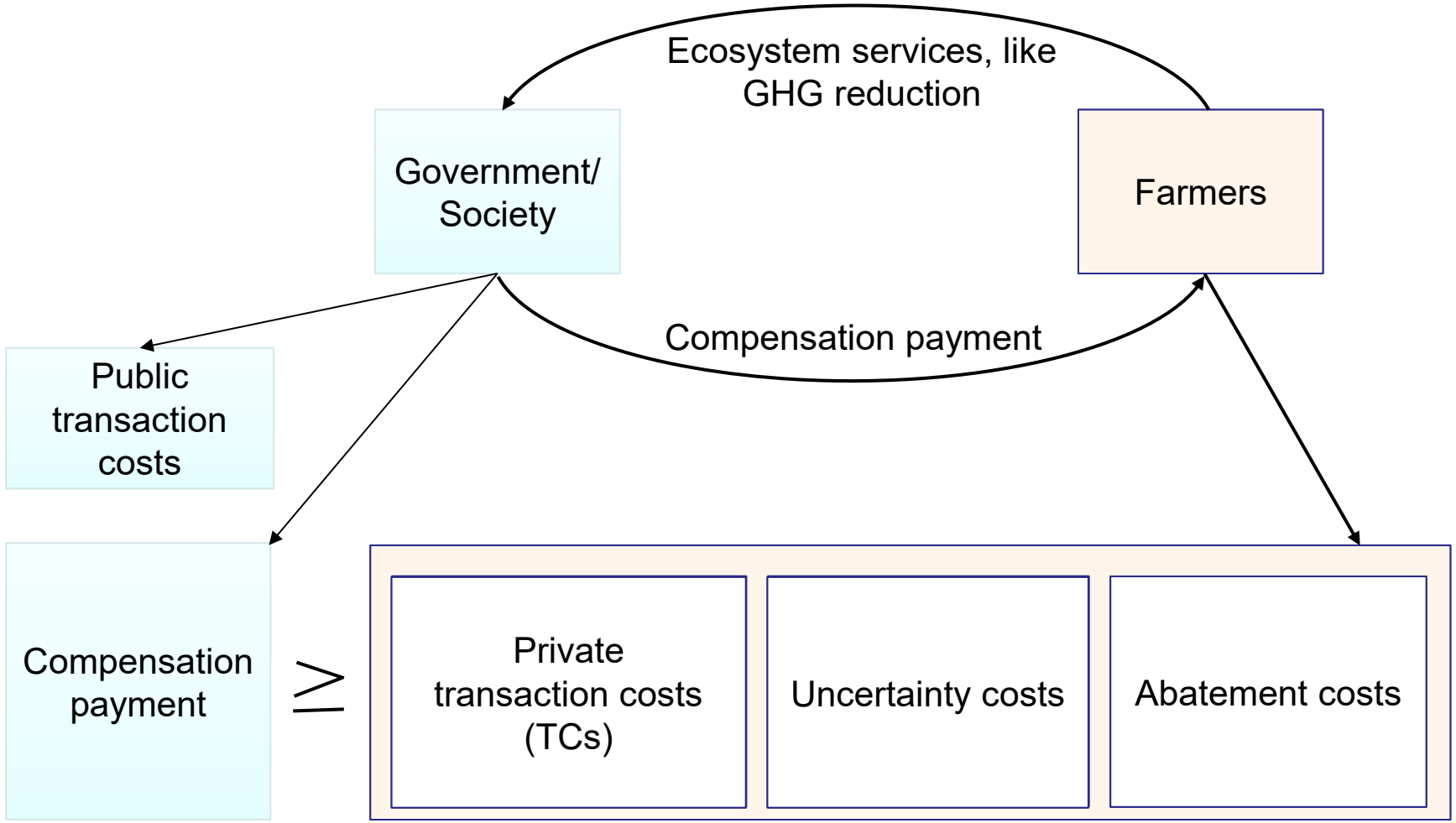
Hao, Z., Bretscher, D., Kay, S., Mack, G., Winter, E., Keel, S. G., "How measures for greenhouse gas mitigation in agriculture are implemented strongly determines cost-effectiveness". (Revision submission to "Journal of Environmental Management", preprint: link)

# Follow-up study: Cost perspective extension



# Follow-up study: Cost scenarios

| Cost scenario (CS) | Cost design | Explanation for the last incremental cost component |
|---|---|---|
| CS1 | Baseline | Production costs of measures only |
| CS2 | Baseline<br>+ Subsidies | Consider subsidies for some measures |
| CS3 | Baseline<br>+ Private TCs1 | Private TCs assigned as fixed % of production costs |
| CS4 | Baseline<br>+ Private TCs2 | Private TCs assigned using measure-specific methods, distinguishing permanent and operational measures especially |
| CS5 | Baseline<br>+ Private TCs1<br>+ Uncertainty costs1 | Uncertainty costs assigned as random values, within a fixed % range of production costs |
| CS6 | Baseline<br>+ Private TCs2<br>+ Uncertainty costs2 | Uncertainty costs assigned as random values, within different % ranges of production costs for permanent and operational measures |

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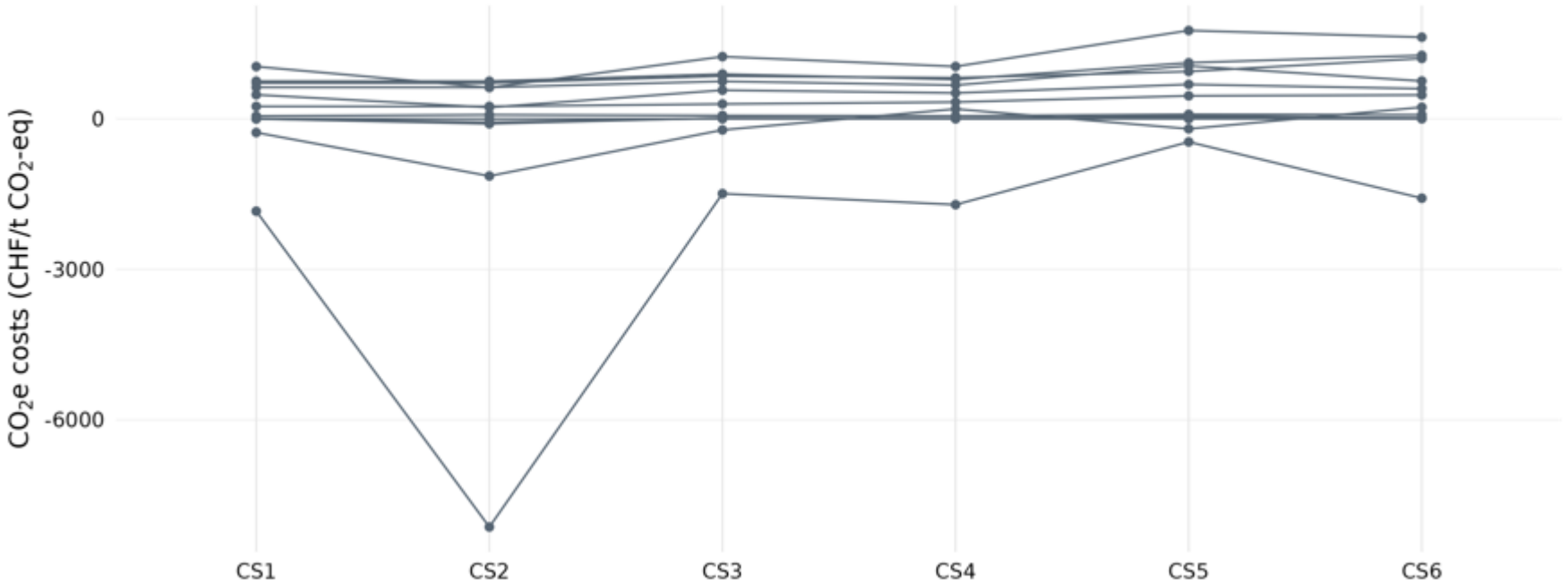
# Follow-up study: Cost variability

**Overall measure cost changes across scenarios**

Each line represents one measure

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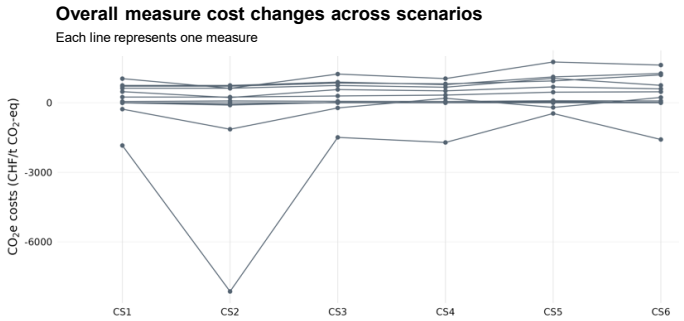
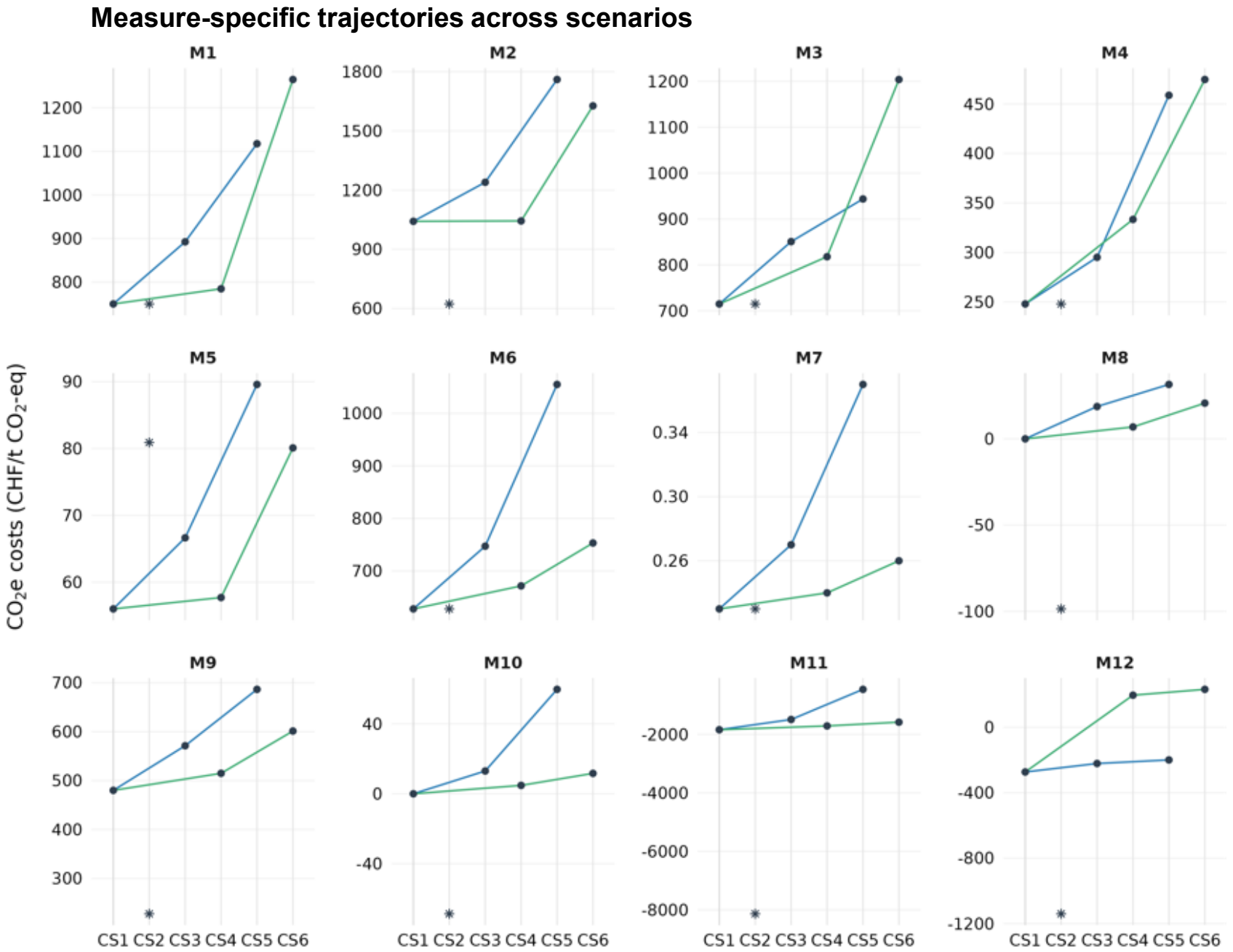
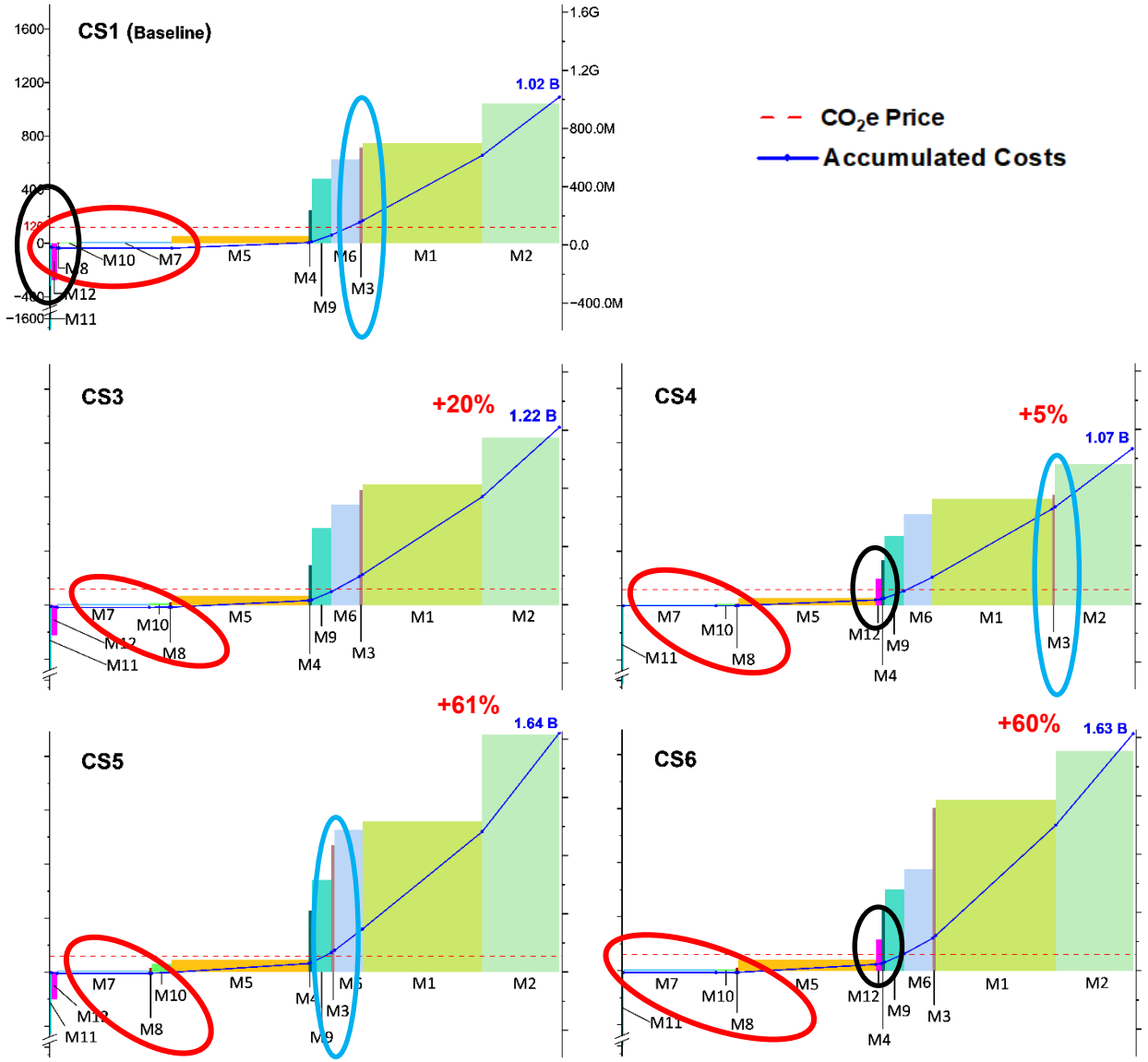
# Follow-up study: Cost variability




- Costs vary widely, with no consistent pattern
- Subsidies strongly distort cost estimates
- Subsidies reflect transfers, not true costs



# Follow-up study: MACC variability




## Results

- Minor ranking shifts across scenarios
- Cost-effective measures remain largely stable
- One measure (M12) shows pronounced sensitivity to cost assumptions
- Total costs increase non-linearly by 5%–61%

## Conclusion

- Cost assumptions have **limited impact** on measure selection
- Sensitivity is concentrated in **specific measures**
- Variations are greater in **cost levels** than in measure ranking
- **Transparent cost communication** is critical for informed policy design

# Future Avenues

## ❖ Structural measure: Site-adapted production

- Site-adapted production: Adjust livestock numbers to local grassland and feed availability
- An extremely important measure (the only true structural measure, which means that the farm needs to go major changes (e.g. change in livestock numbers))

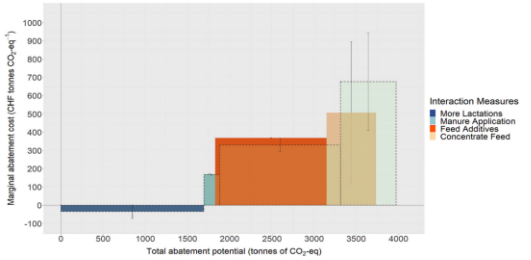
- Structural measures have a high potential (Bretscher et al., 2018)
- This study focused mainly on technical measures

- Currently not feasible to assess this measure
- Very complicated to simulate the measure
- SWISSland model required

Bretscher, D., Ammann, C., Wüst, C., Nyfeler, A., & Felder, D. (2018). Reduktionspotenziale von Treibhausgasemissionen aus der Schweizer Nutztierhaltung. Agrarforschung Schweiz, 9(11-12), 376-383.

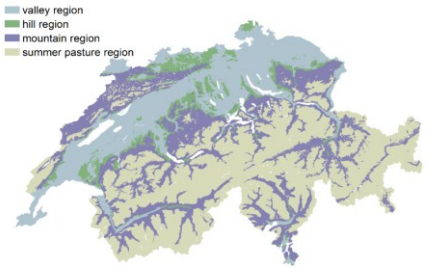
# Future Avenues

- **Interactions** between multiple measure: Cost implications and potential synergies



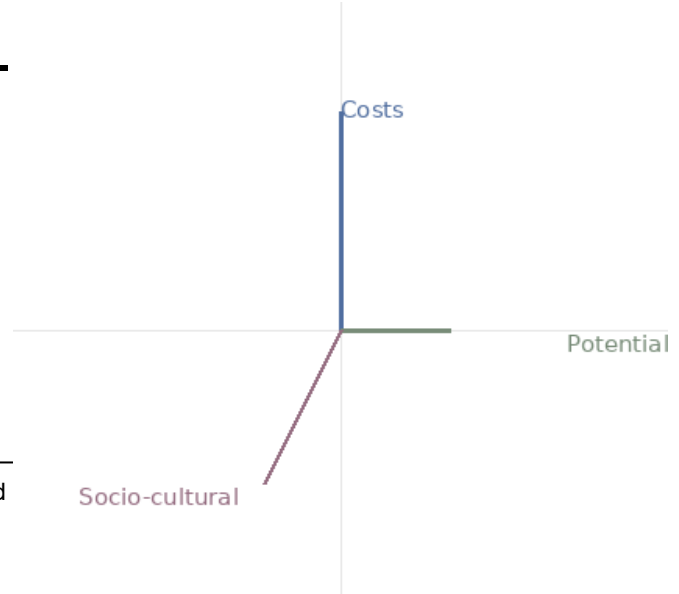

Source: Huber et al., 2019

- Spatial **heterogeneity**: Towards more cost-effective targeting




Source: Wüst-Galley et al., 2019

- **3-dimensional MACC** development: Incorporating socio-cultural constraints
- …




Huber, R., Tarruella, M., Schäfer, D., & Finger, R. (2023). Marginal climate change abatement costs in Swiss dairy production considering farm heterogeneity and interaction effects. Agricultural Systems, 207, 103639.
Wüst-Galley, C., Keel, S. G., & Leifeld, J. (2019). A model-based carbon inventory for National greenhouse gas reporting of mineral agricul-tural soils.

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# Thank you for your attention

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