The CH4rLiE Project: A Novel Approach to Methane Recovery based on CERN gas recuperation systems

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CH4RLIE

Sustainable HEP 2026

UNIVERSITÀ DI PAVIA

INFN Istituto Nazionale di Fisica Nucleare

DISAFA Università degli studi di Torino

CERN EP-DT Detector Technologies

Funded by the European Union NextGenerationEU

CH4rLiE

PRIN PNRR 2022 - P2022FTF7L

Funded by the European Union
NextGenerationEU

CH4 Livestock Emission

Goal of the project: *The CH4rLiE project aims at developing a prototype for methane emissions capture in a barn environment. ... CH4rLiE ... proposes to act on the methane already produced and diffused in the air, using a specially developed recovery system. The idea arose from the expertise acquired in the Large Hadron Collider experiments at CERN, where "gas recuperation systems" are being developed to extract CF4 and other components from gaseous detectors exhausted gas mixture. ... (project abstract)*

The team

Università degli Studi di Pavia, Dipartimenti di Fisica e Chimica
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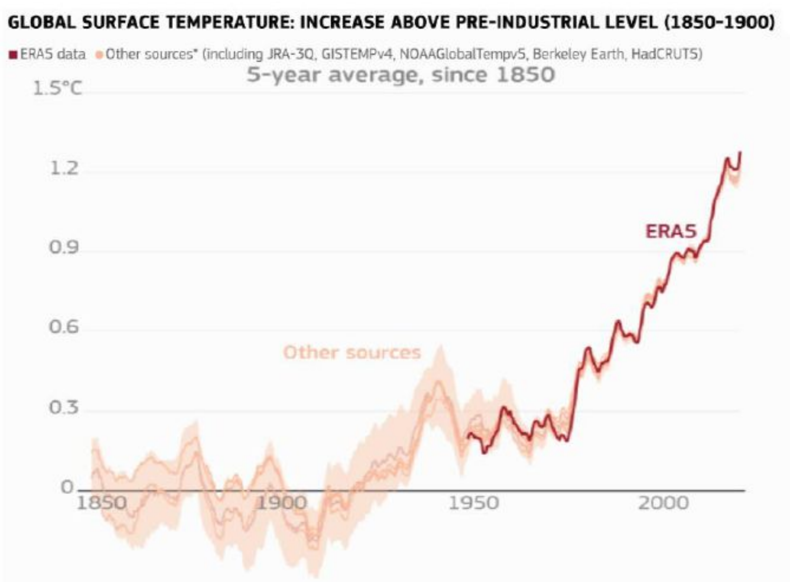
CERN EP-DT group
M. C. Arena, A. Bouzaiene, R. Guida, B. Mandelli

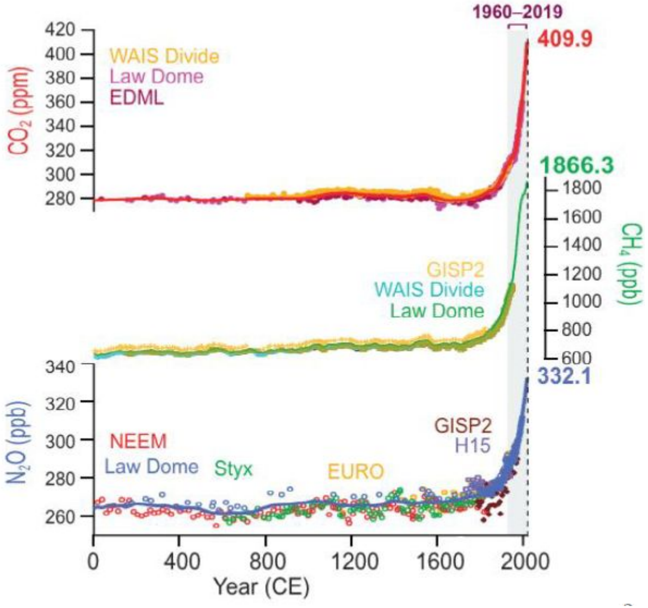
Global warming

Observed surface temperature
increase > 1 °C after industrialization



EU Copernicus – Climate Change Service

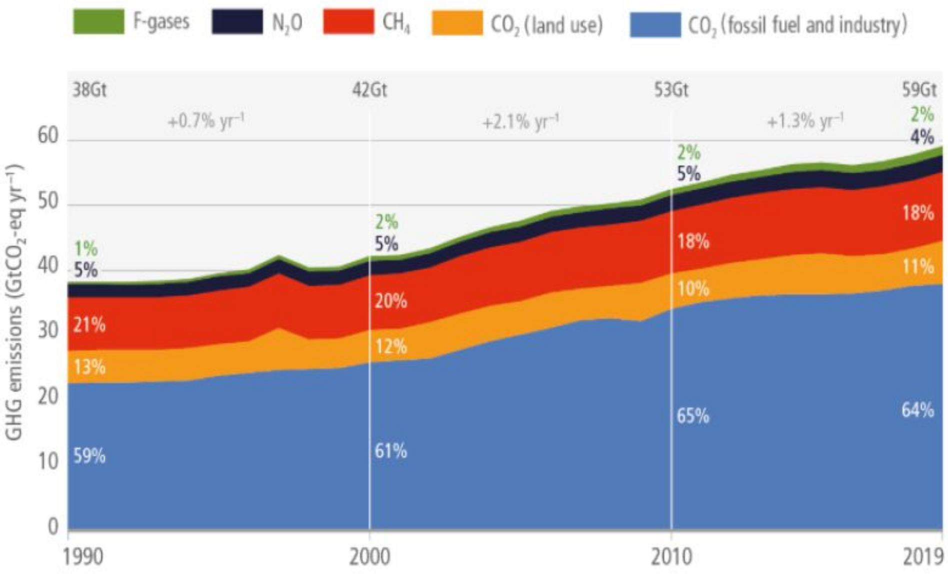
Main anthropogenic cause:
Greenhouse gas emission (CO2, CH4, N2O, ...)



IPCC: 2013

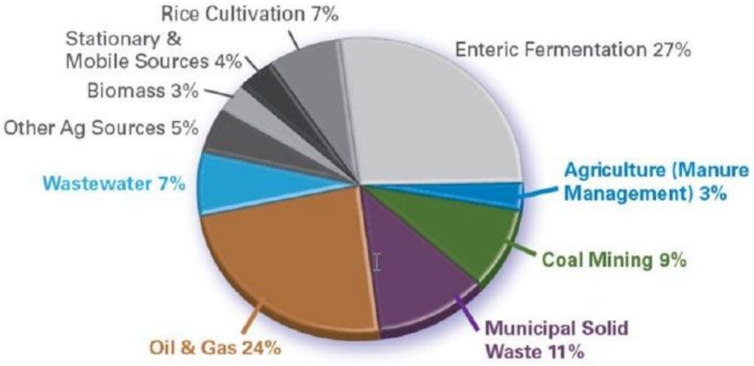
CH4 in Global Warming

GWP_{100} of CH4 = 28 (AR6, IPCC)



IPCC, Sixth Assessment Report (AR6)

W. Wang et al. (2020)



In Italy ~ 32% of CH4 from agriculture

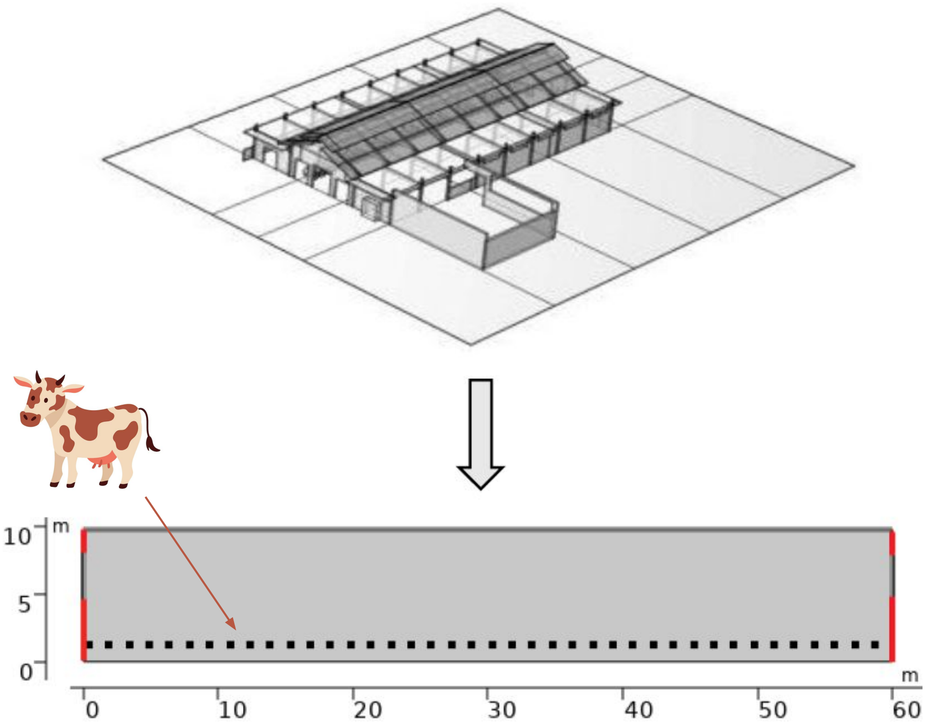
Project organization

1. **Characterization of barn environment**
   COMSOL simulations and in situ measurements are used to identify the CH4 accumulation points in a selected barn

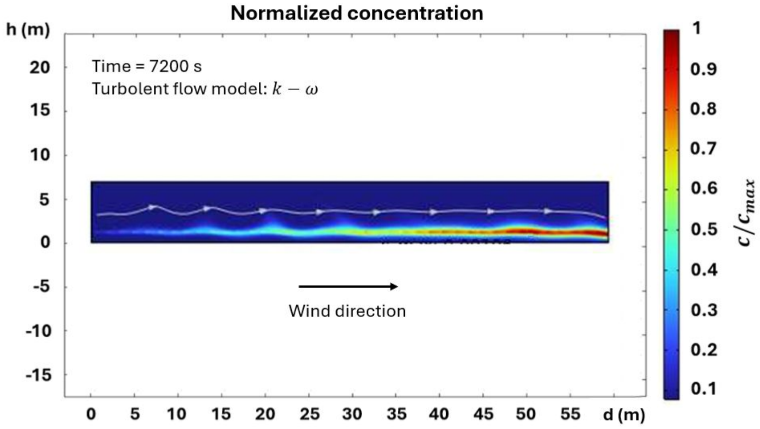
2. **Optimization of CH4 adsorbent**
   Adsorption tests are carried out with commercial zeolites and new materials to identify best adsorbent

3. **CH4 capture prototype development**
   A capture prototype is designed and tested in laboratory

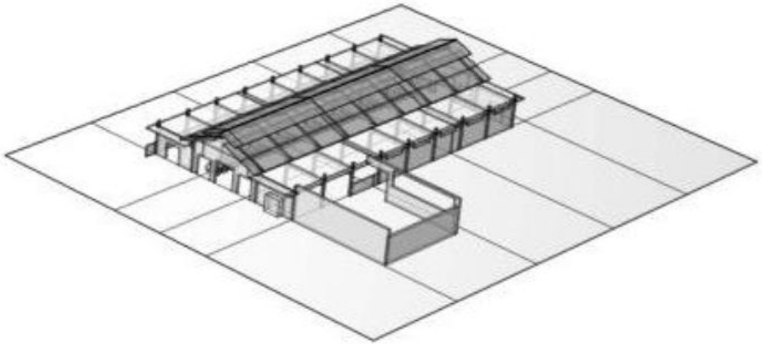
COMSOL simulations

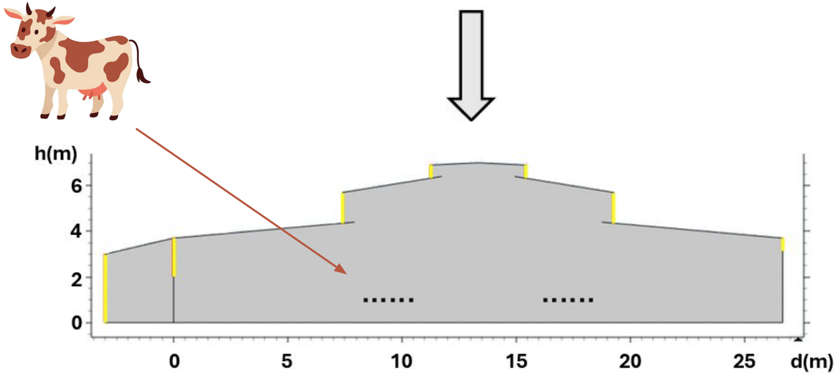


Computational Fluid Dynamics simulations to predict CH_4 transport in the barn and identify possible accumulation points where to install the capture prototype



COMSOL simulations





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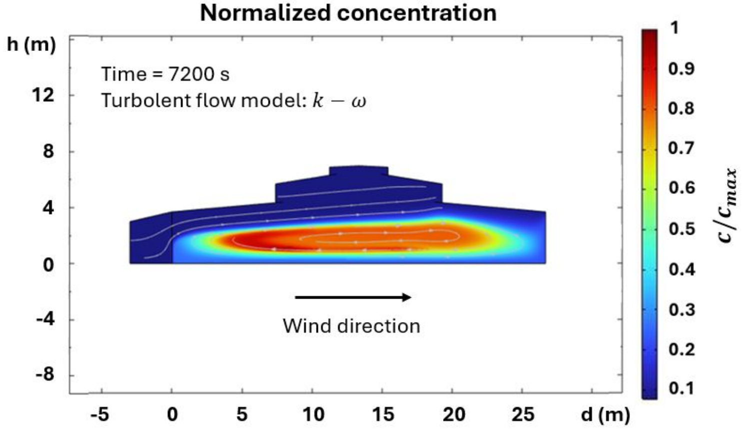
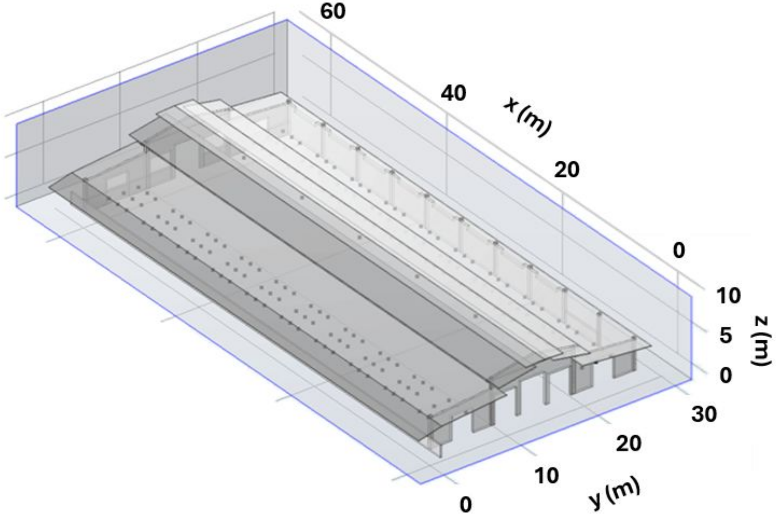
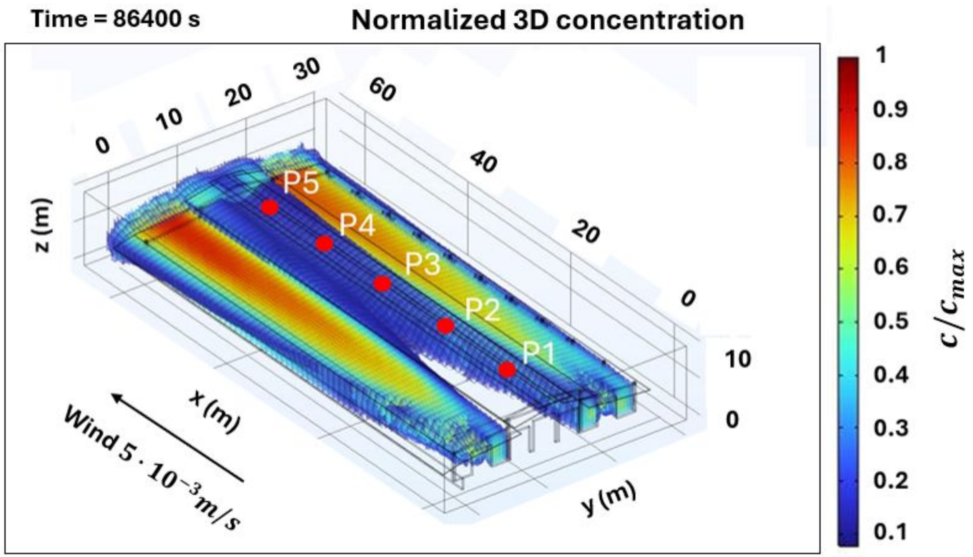
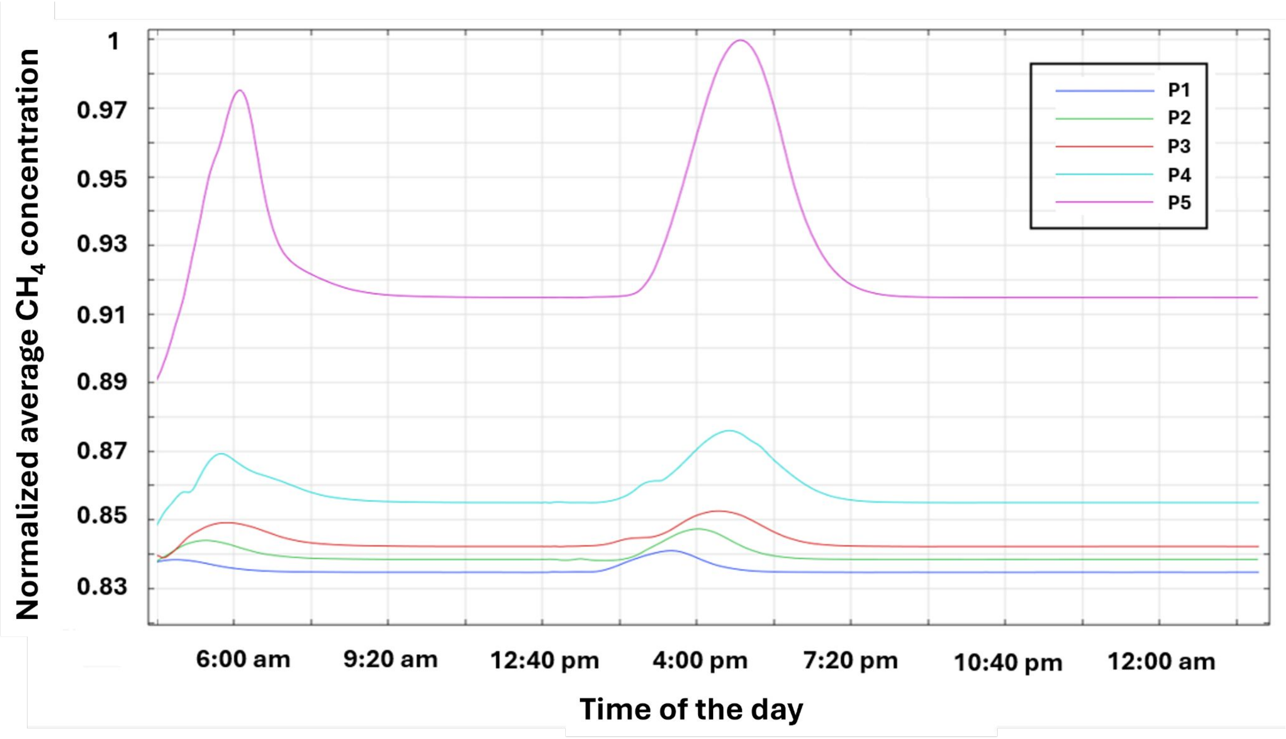


COMSOL simulations



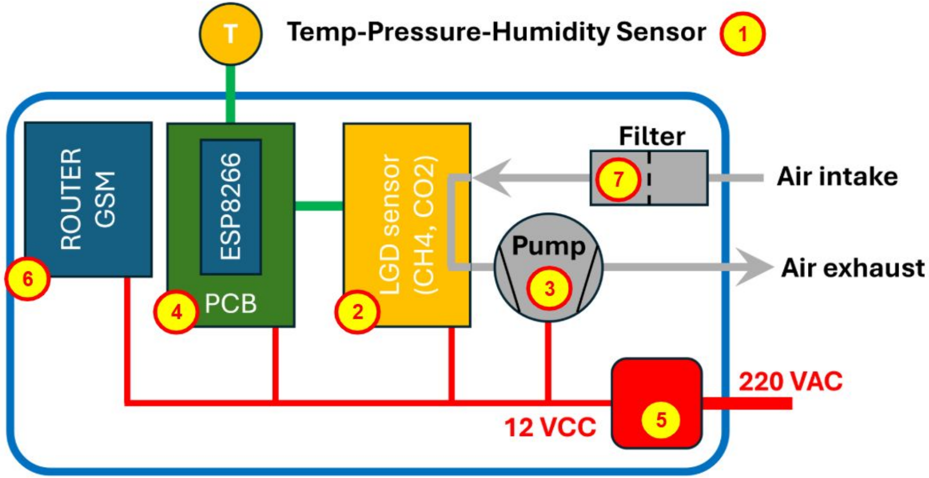


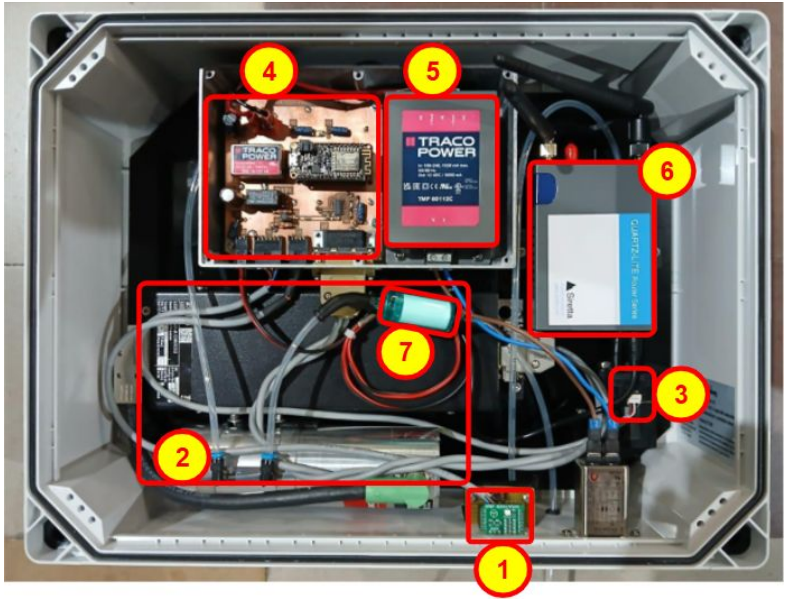
COMSOL simulations



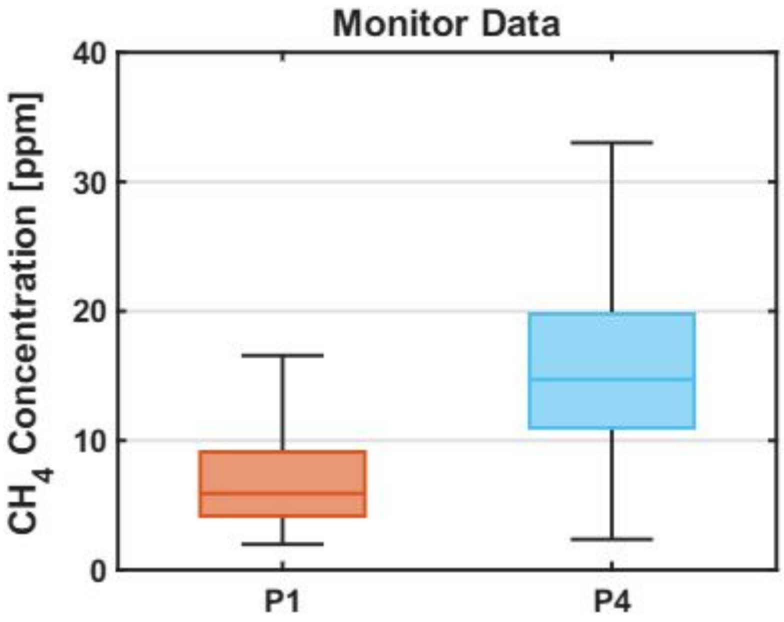
Barn monitoring

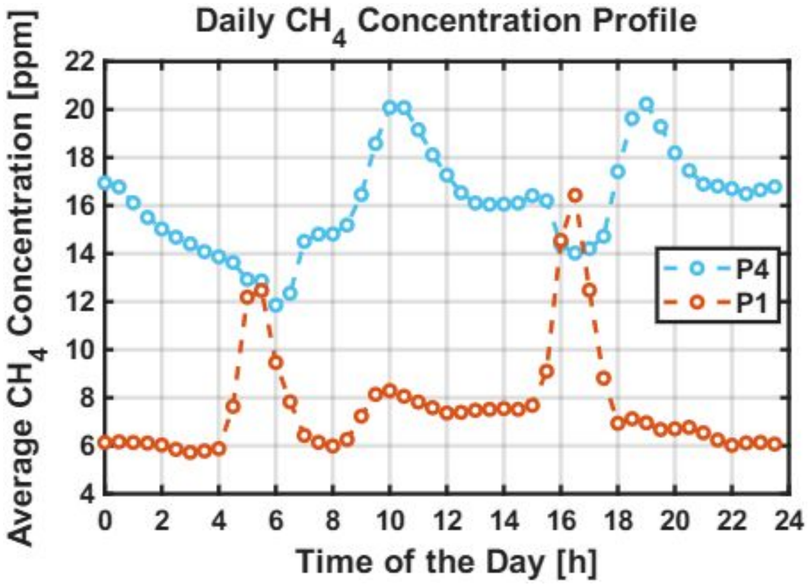
Two monitoring stations installed in the barn in July 2025 to acquire information on the environmental conditions, CH4 and CO2 concentrations.





CH4 concentration analysis





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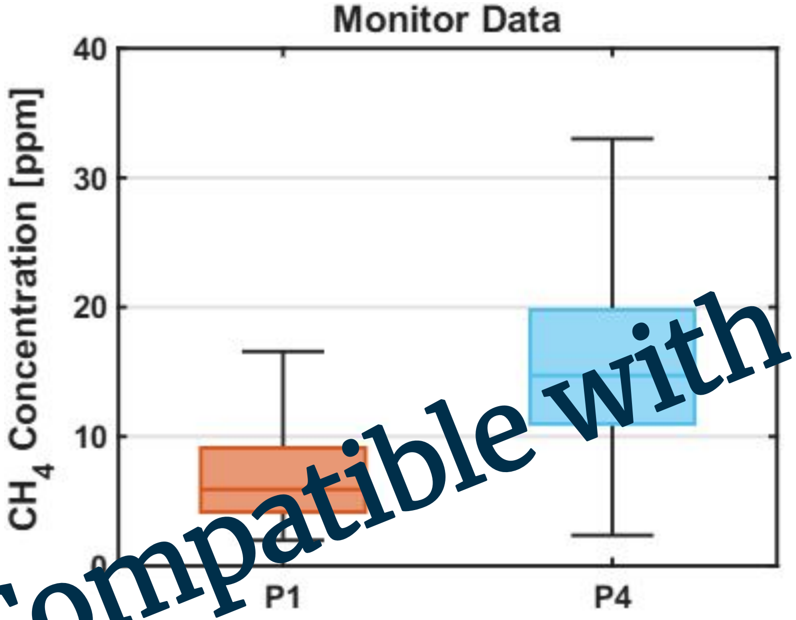
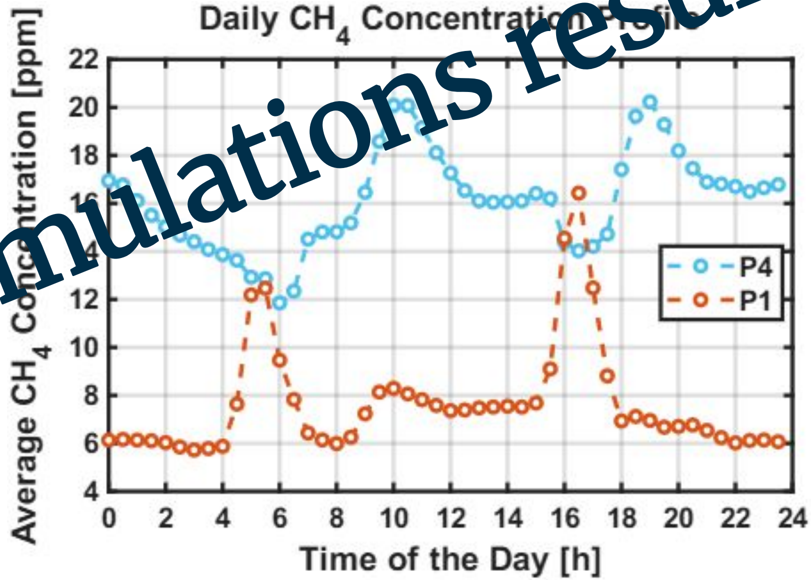
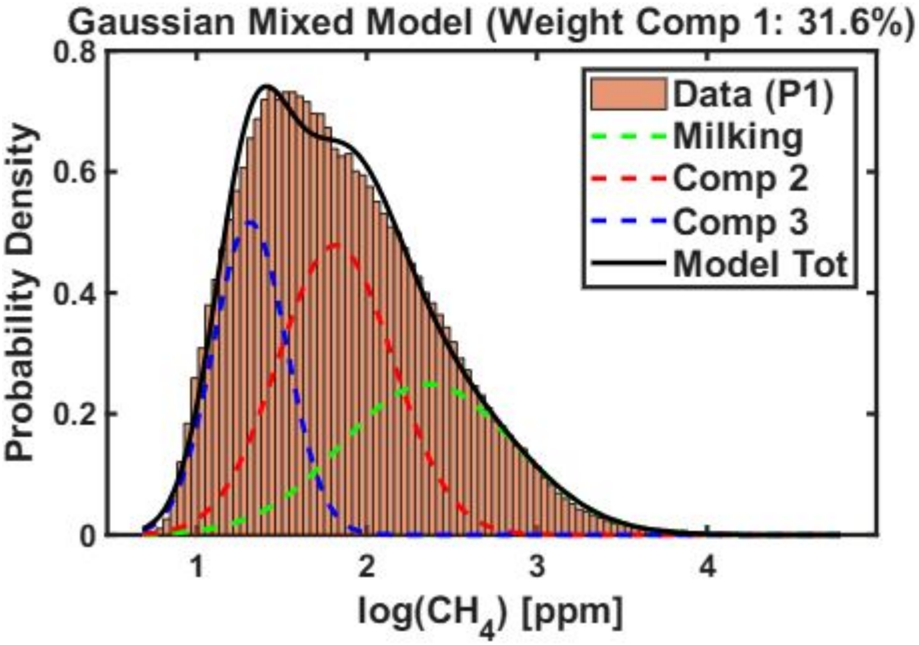




Compatible with simulations results!

CH4 concentration analysis



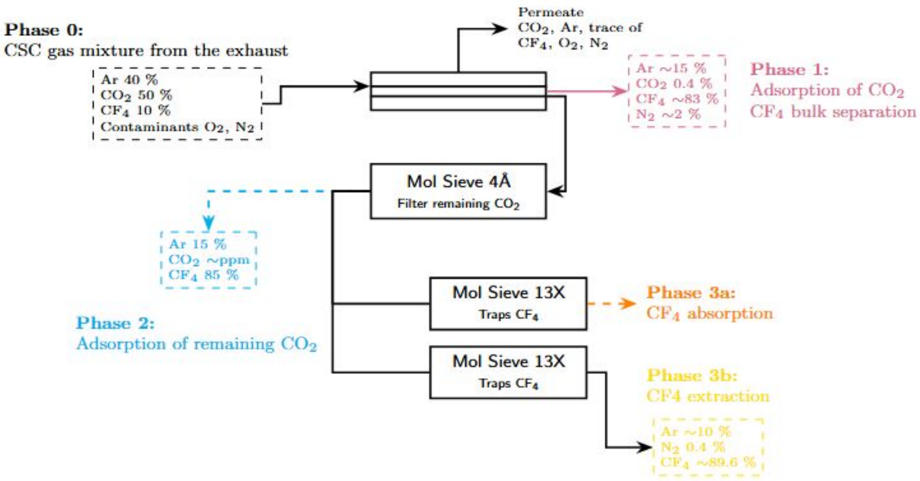
In P1 the CH4 concentration presents three components:

- enteric emissions during milking operations
- barn background
- episodic events

In P4 the distribution is purely log-normal, indicating that P4 captures the emissions from the entire barn environment.

Ideas for the recovery system

CF4 recovery system for CMS Cathode Strip Chambers



Pre-filtering module to separate CO2, Ar

Z10 to capture CF4

High purity:
- 96.5 % of CF4 in the recuperated mixture

Recovery system:
- 70 % efficiency → Annual saving 800 kg of CF4 (10 000 tCO2eq)

Which adsorbent?

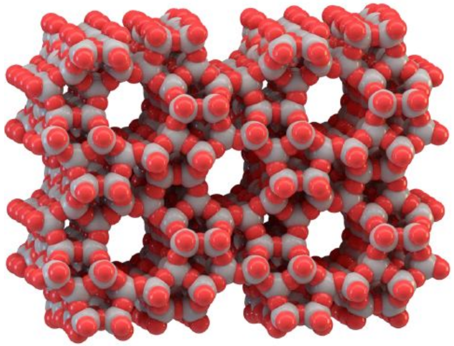
Commercial zeolites used for first tests

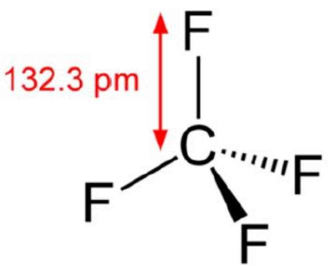
In parallel, new materials prepared for CH_4 adsorption

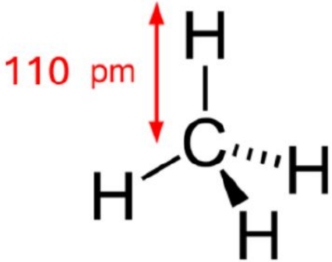
Preparation of pyrolytic carbon having a high surface area from lignin

Supported on inert material (high surface silica)

Supported on zeolites



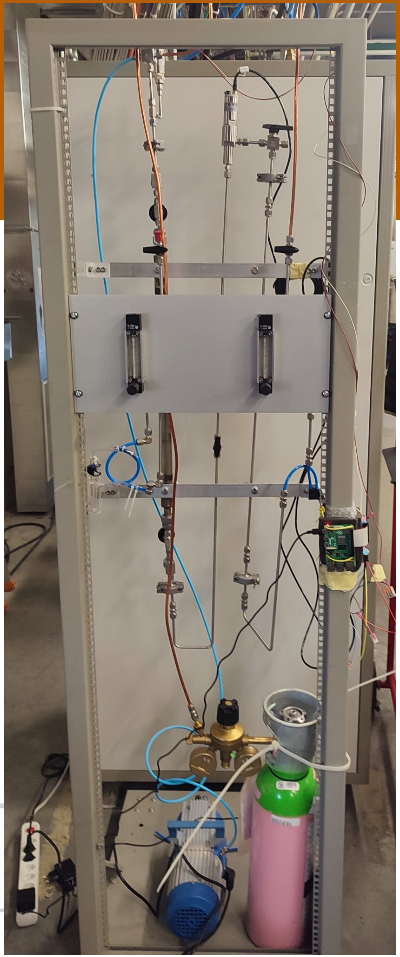




How to select the zeolite?

$N_2 + O_2 + CH_4$
78.65 / 20.9 / 0.45%

How to select the zeolite?



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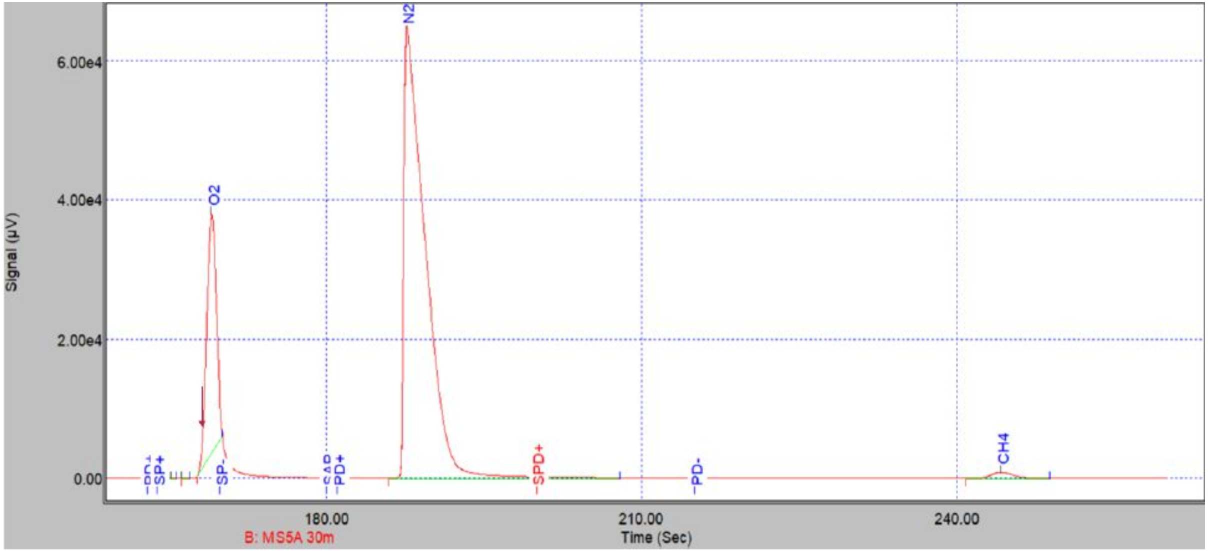

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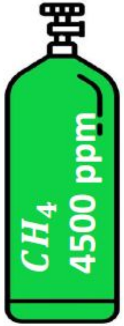
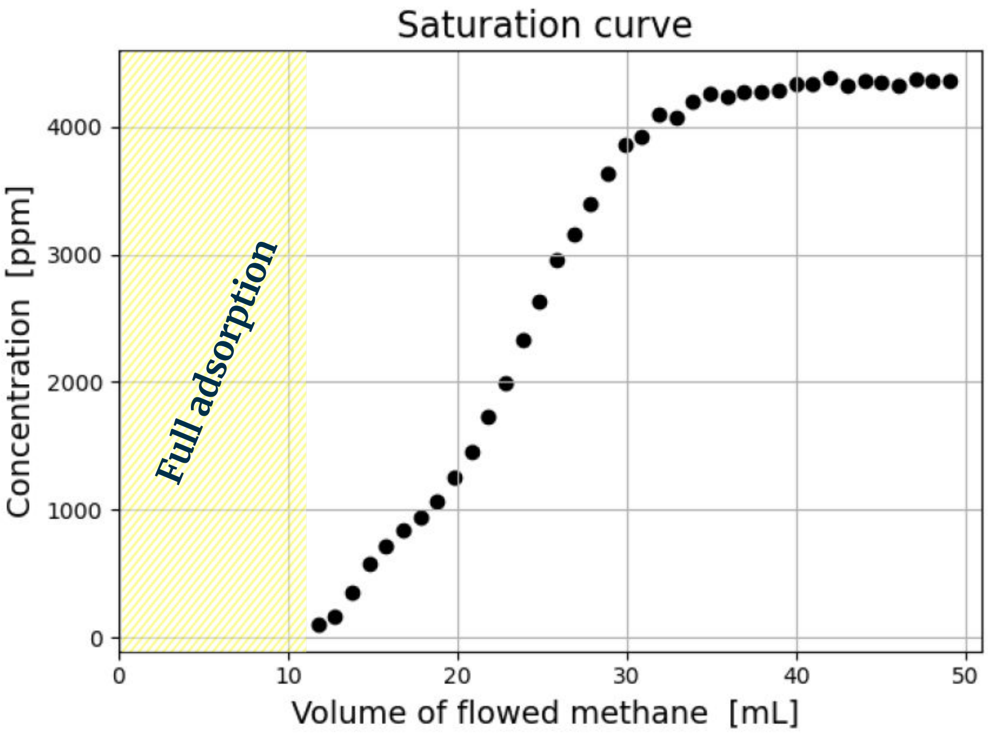


Zeolites

Gas Chromatograph (GC)

How to select the zeolite?



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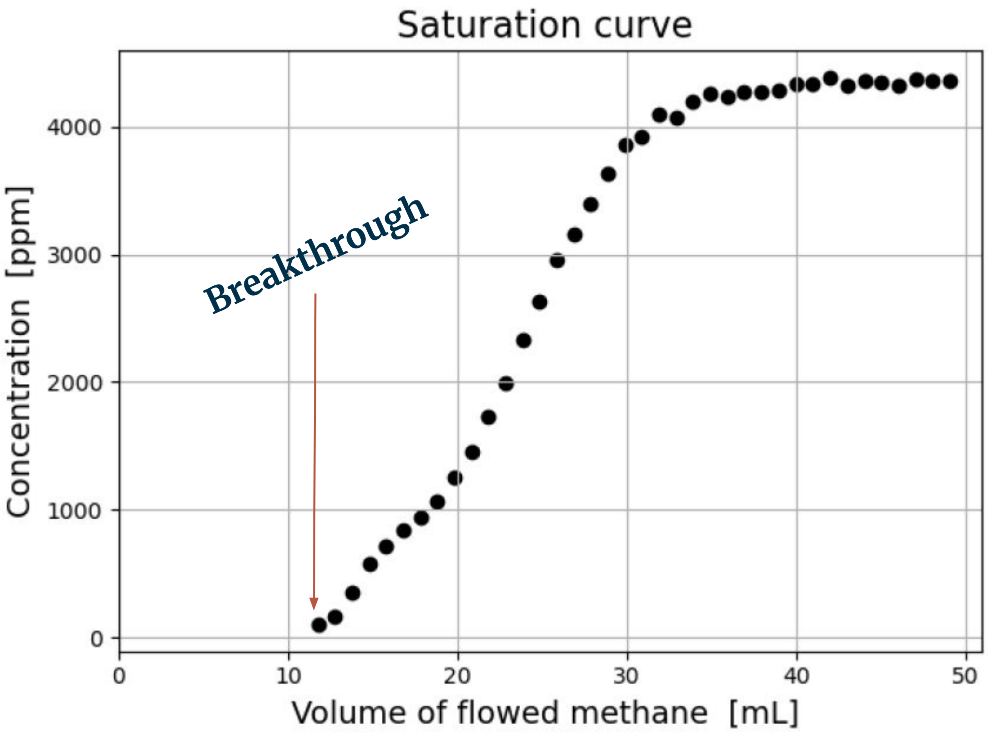
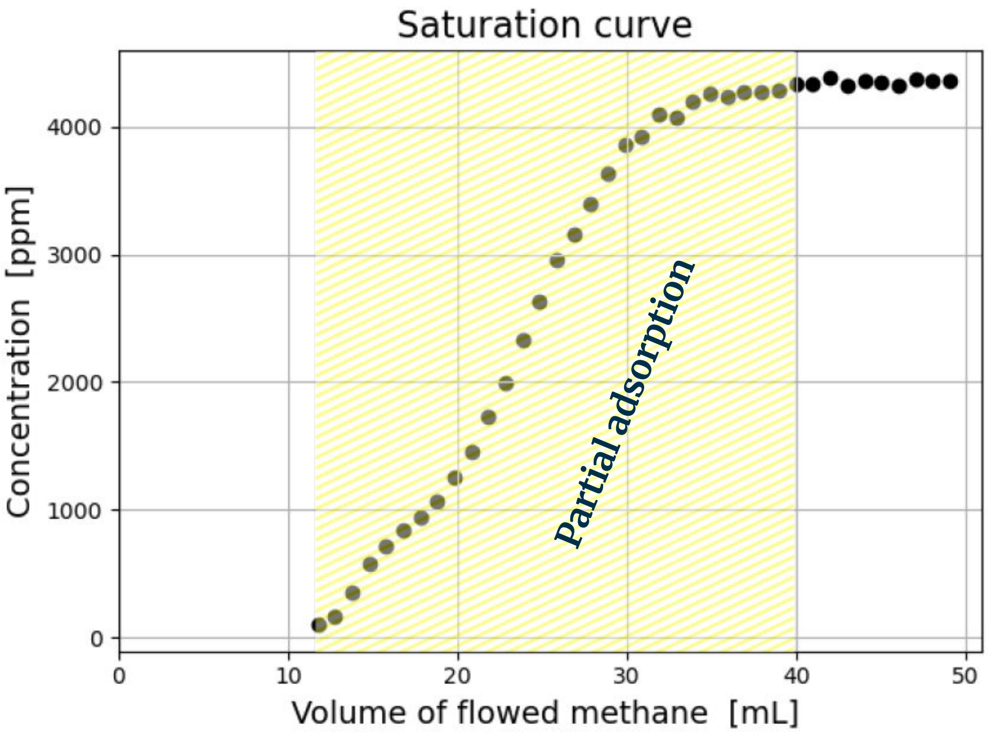


Volume of CH4 adsorbed before first peak appearance:

$$V_{CH_4}^{BK} = \sum_{i=0}^{BK} \phi_i \Delta t_i p_i C_{CH_4}^{SAT}$$

How to select the zeolite?



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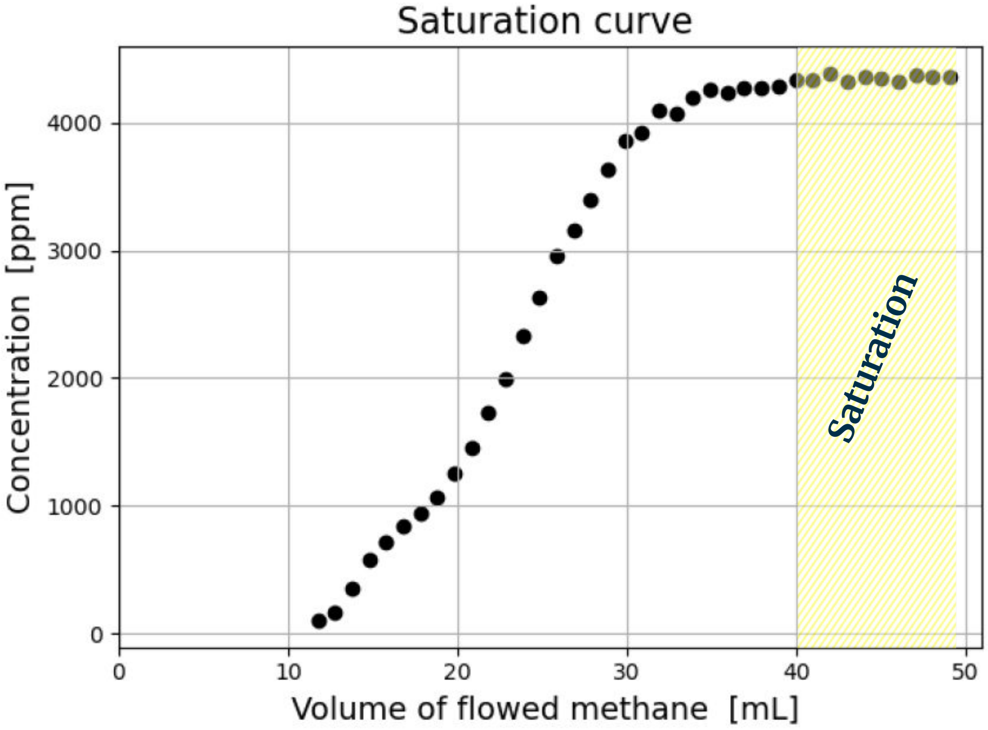
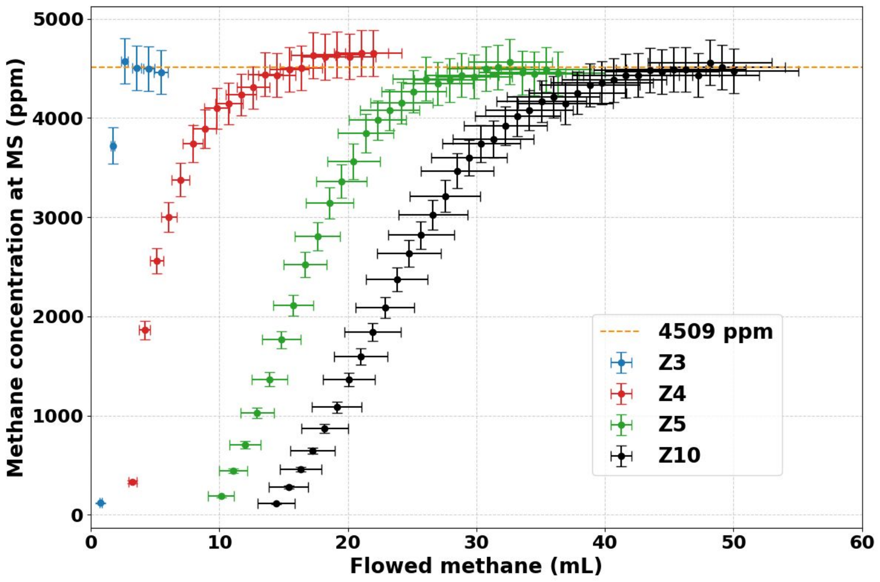


Total volume of CH4 adsorbed:

$$V_{\mathrm{CH_4}}^{Tot} = V_{\mathrm{CH_4}}^{Flushed} - \int \text{GC saturation curve}$$

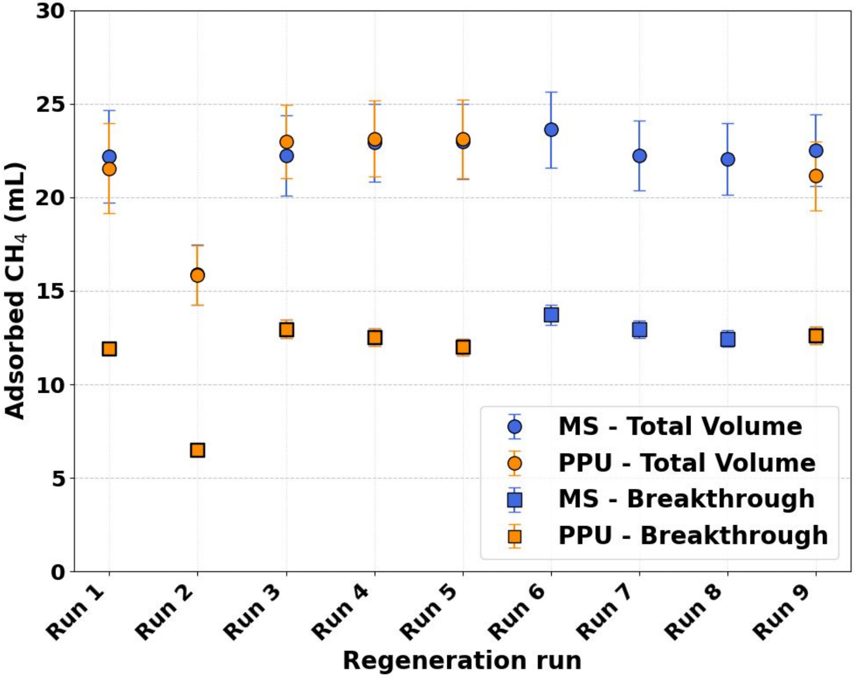
$$= \sum_{i=0}^{n} \phi_i \Delta t_i p_i C_{\mathrm{CH_4}}^{SAT} - \sum_{i=0}^{n} \phi_i \Delta t_i p_i \mathrm{GC}_i$$

First results



Z5 and Z10 are the most promising candidates for CH4 adsorption

First results

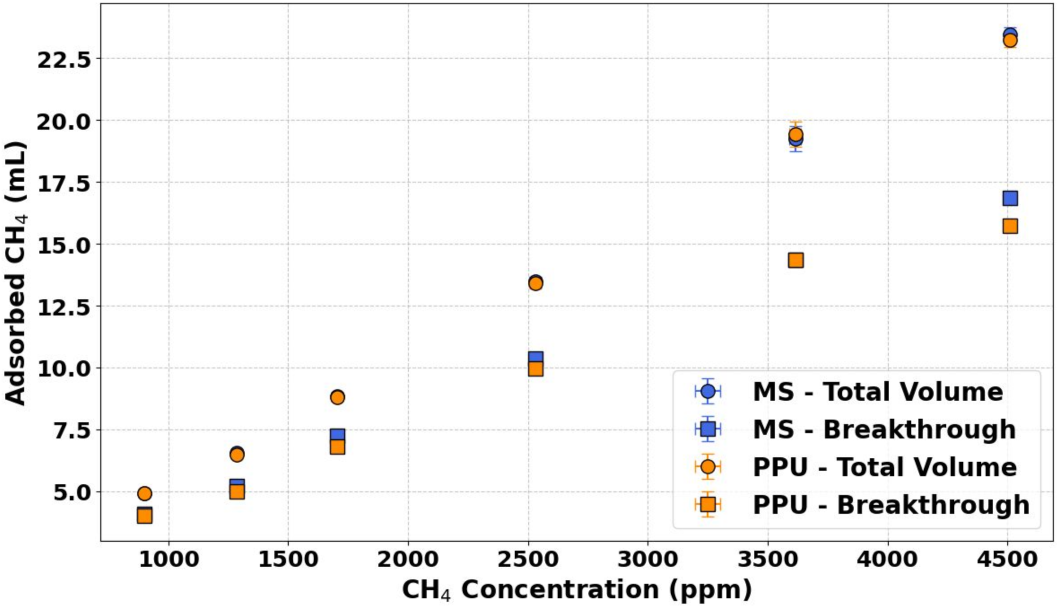


Two regeneration methods:

- TSA: Temperature Swing Adsorption
- VSA: Vacuum Swing Adsorption

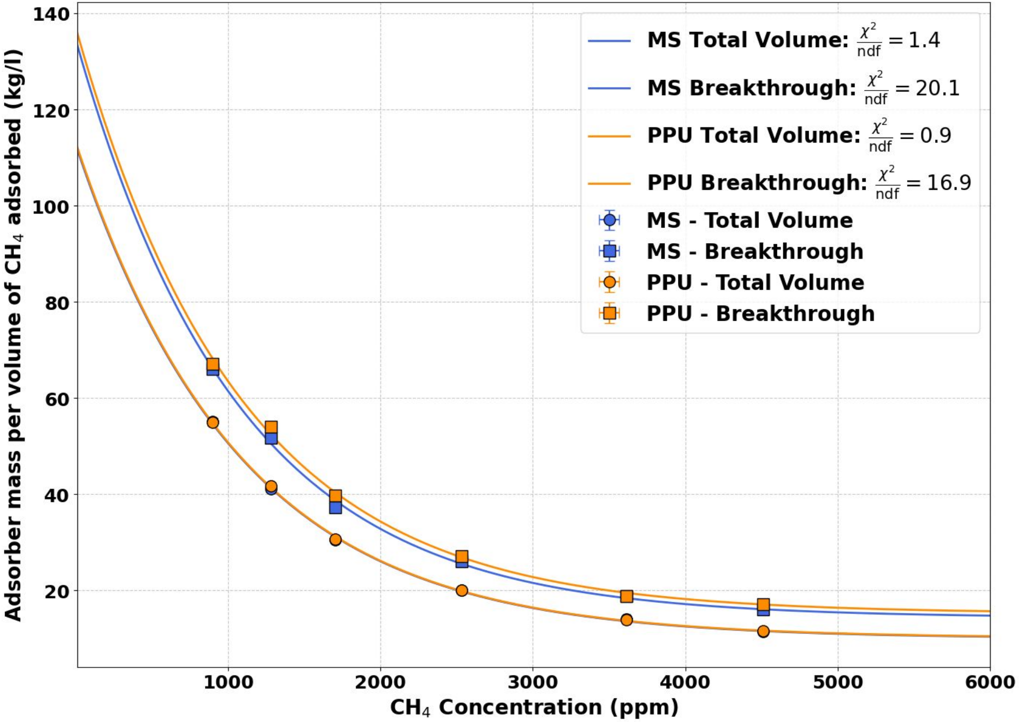
Z5 maintains a more constant adsorption capacity after TSA regeneration w.r.t. Z10 → Z5 selected!

First results



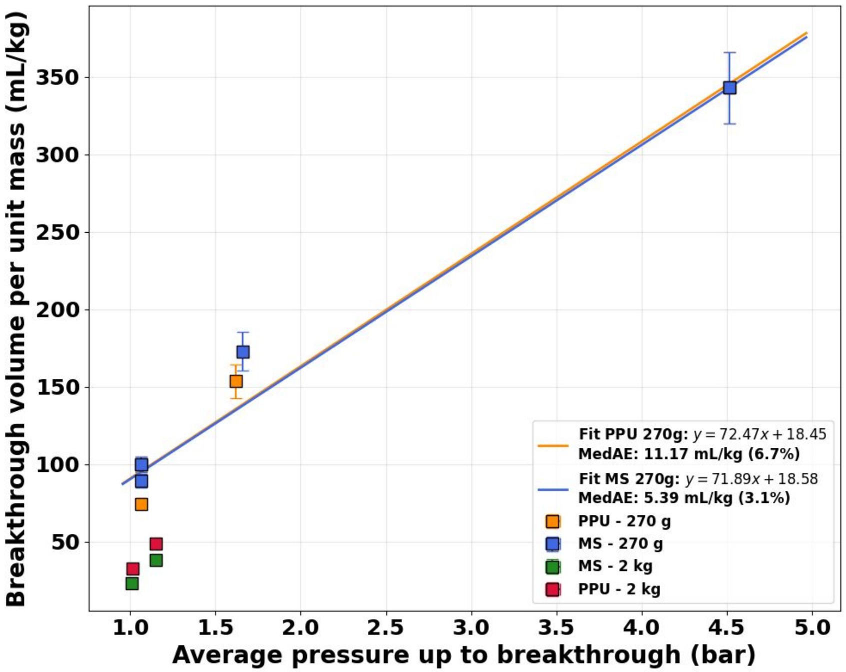
Z5 adsorption capabilities were tested with different CH4 concentrations in the mixture

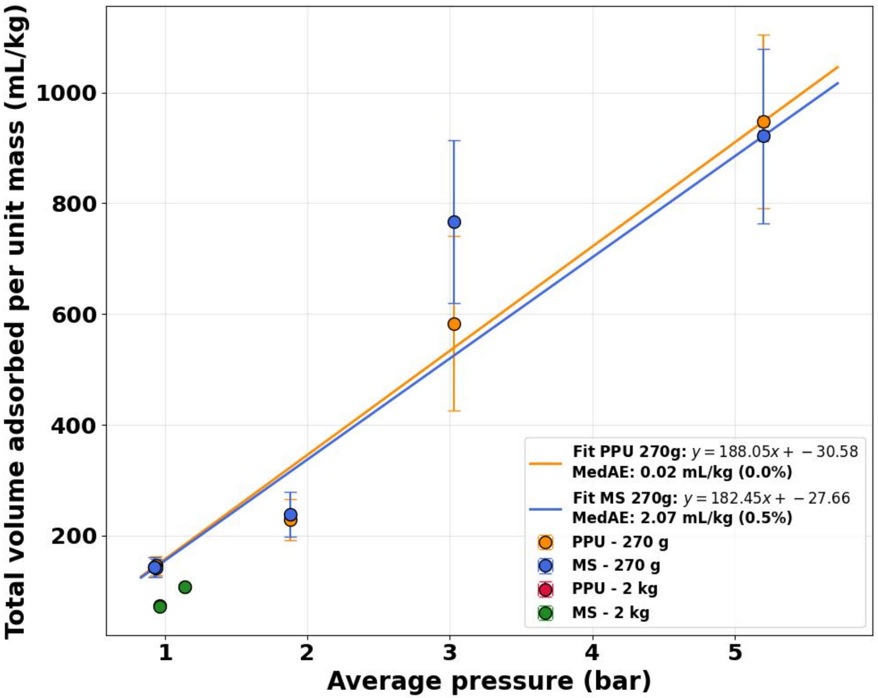
Extrapolation to the real condition



Assuming a baseline concentration of CH4 of approximately 100 ppm within the livestock facility environment, roughly 100 kg of commercial Z5 zeolite adsorbent is required to capture 1 L of CH4.

The role of gas pressure





Summary and future perspectives

- It is possible to adsorb CH_4 using commercial zeolites. Zeolites Z5 (5A) and Z10 (13X) are the most effective commercially available zeolites for capturing CH_4.
- Both regeneration processes, TSA and VSA are effective for regenerating zeolites saturated with CH_4.
- Scalability: the adsorption process is effective both on small volumes and on larger volumes
- Pressure effect: the adsorption capacity increases linearly with pressure

Thank you!

CH4rLiE project ended in Feb.2026. The second phase project, CLIMATE, has been submitted to the recent italian PRIN 2026 call.