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Gas sensors Array Applied to the monitoring of Biogas Process

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What is biomethanation process?

Biological process which results in the production of biogas

Archea methanogens are strict anaerobic

→ do not survive in presence of oxygen

Biomethanation:

Organic substrate ➡ biogas + biomass

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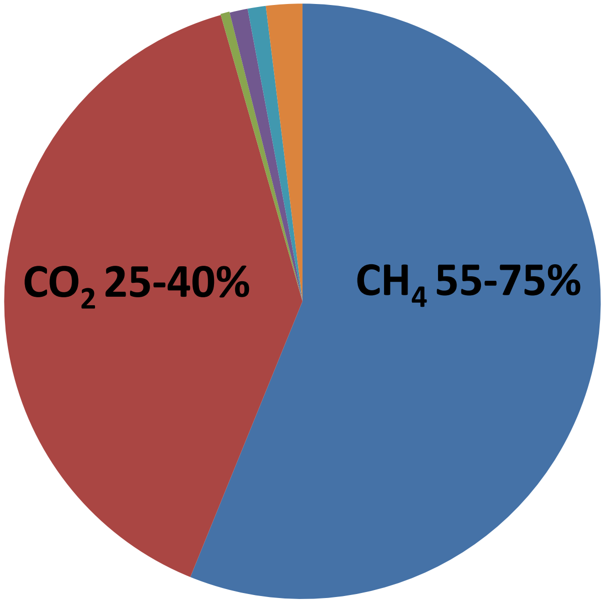
Anaerobic microorganisms

BIOGAS

Water vapour, NH_3, H_2S 3%
+ Trace compounds



No oxygen

Highly toxic and corrosive

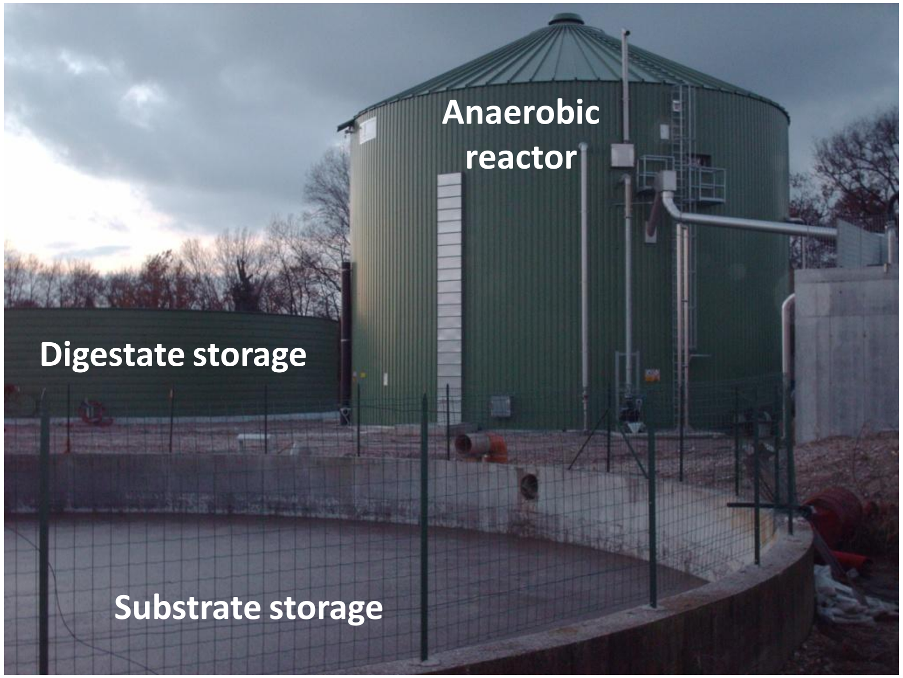
On-farm methanation produces biogas as a renewable energy

Cow and pig manure/slurry, energy crops
Organic waste

Anaerobic reactor, 38°C or 55°C

Biogas | Digestate = fertilizer

Heat and/or Electricity



Problem: Biogas reactors are sensitive to high organic loadings that lead to the accumulation of acids and process disturbances/collapse

High reactor loading versus Process stability

Why to focus on e-nose technology?

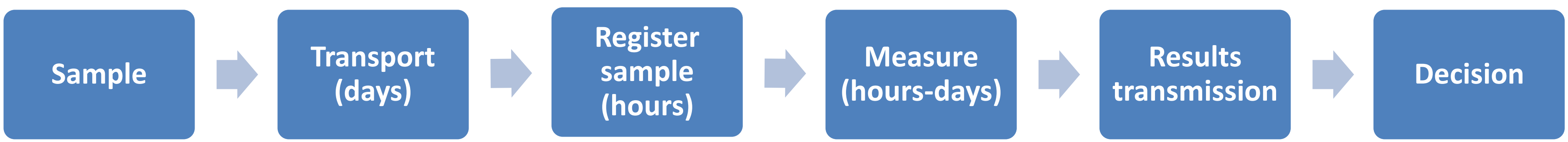
Anaerobic digestion process monitoring:

- Online monitoring: [CH4], [CO2], biogas production, pH
- Offline analysis: alkalinity, Volatile Fatty Acids (individuals/total), etc.
- No online tool for early warning of anaerobic digestion process disorders

E-nose advantages:

- Online monitoring
- Gas phase sampling (easier than liquid-phase sampling in anaerobic reactors)
- Rapid turn-over of gas phase of the reactor (hours)

Actual situation



Ideal situation

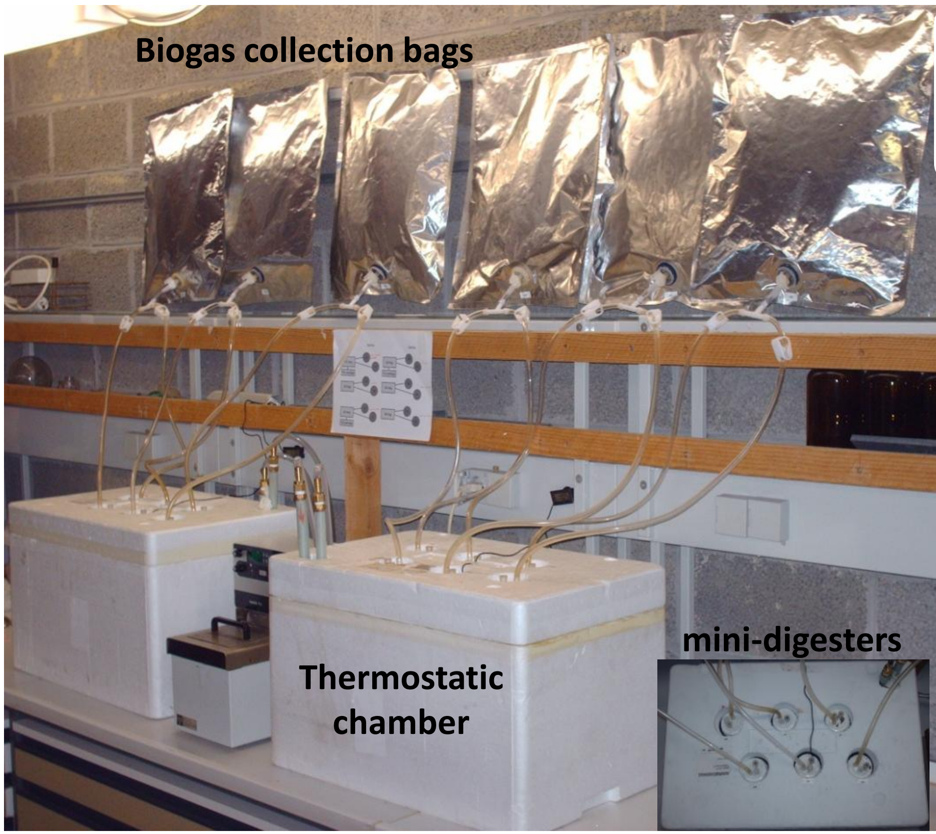
Adapted from Holm-Nielsen, 2008


To feed or not to feed my bioreactor? That’s the question!
Photo: James Arthur

Small-scale test on 12 semi-continuous anaerobic digesters

1.5 kg anaerobic sludge per mini-digester, 38±2°C

60 days of monitoring



- Cautious Feeding: 1.3 gVS.L^{-1}.day $^{-1}$
  - Sucrose 1kg.L^{-1}
  - Maize oil
  - Mix sucrose and oil (1:1)
- Overfed digesters: 1.3 to 5.3 gVS.L^{-1}.day $^{-1}$
  - Sucrose 1kg.L^{-1}
  - Maize oil
  - Mix sucrose and oil (1:1)

Mini-digesters - Variables

Feeding system

Daily feeding

Biogas collected every day in gas bags

Daily measurements:

- **Home-made e-nose**
  - → 6 MOX gas sensors array
- **pH of the sludge**
- **CH_4 and CO_2 concentration (IR cells)**
- **H_2S and CO concentration (EC cells)**

Home-made e-nose

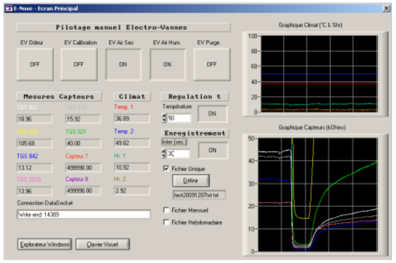
CH_4 & CO_2 measurements

E-nose instrumentation

6 commercial metal oxide gas sensors
Home-made array of sensors

Dilution (25x) is needed
- **to avoid sensors saturation (60% CH_4)**
- **to supply oxygen for optimum functioning of the sensors**

Biogas sample → Dilution 25x → Sensors array → Data acquisition



Sensors conductance after 10 min

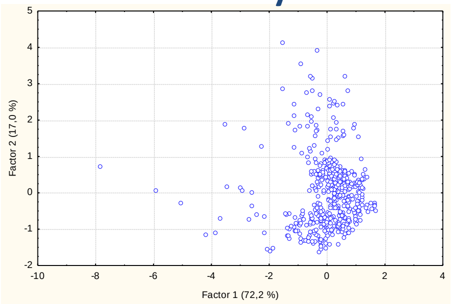
Data normalization

$$Y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{j} x_{ij}^{2}}}$$

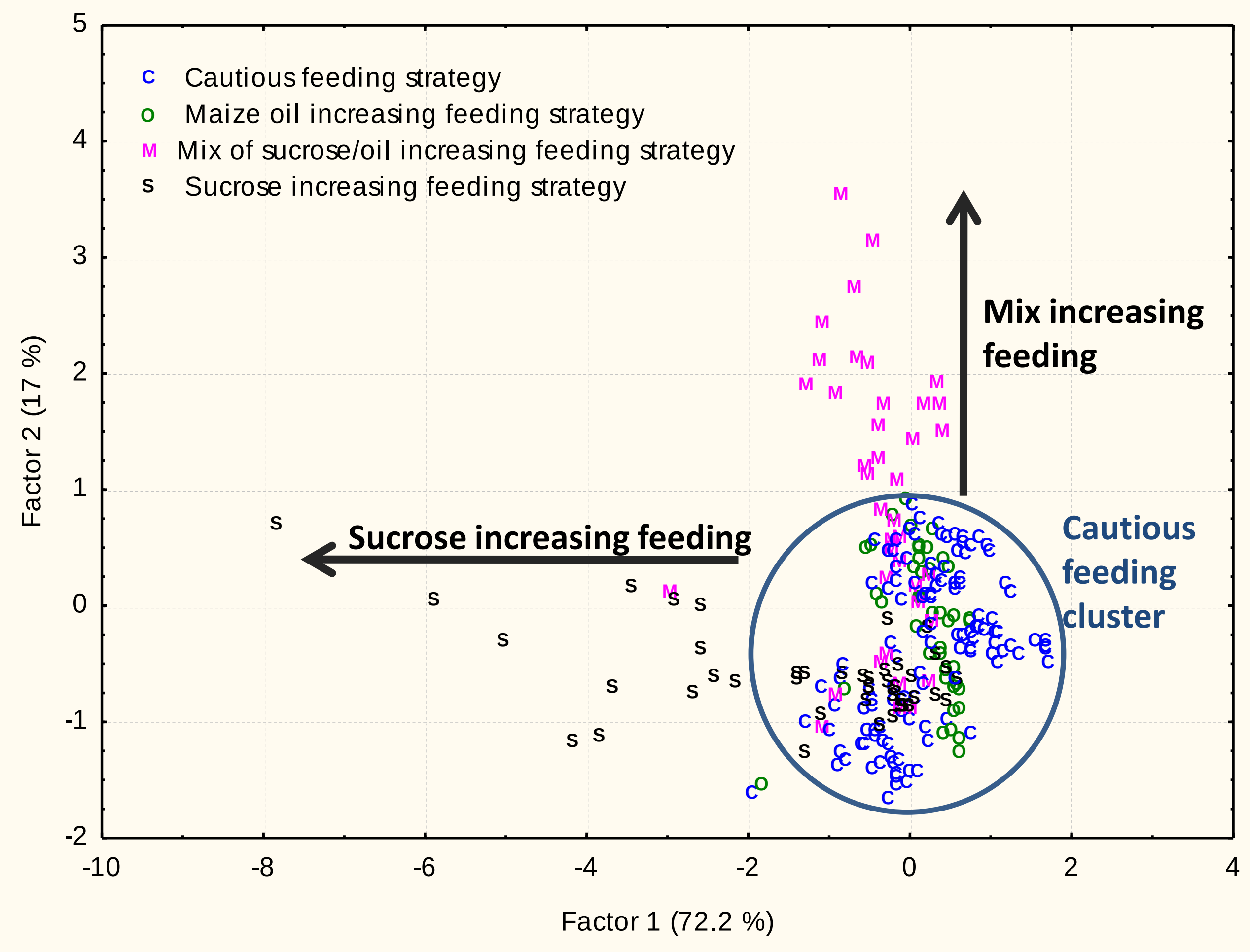
Data

Euclidean and Mahalanobis distance from the cautious feeding group

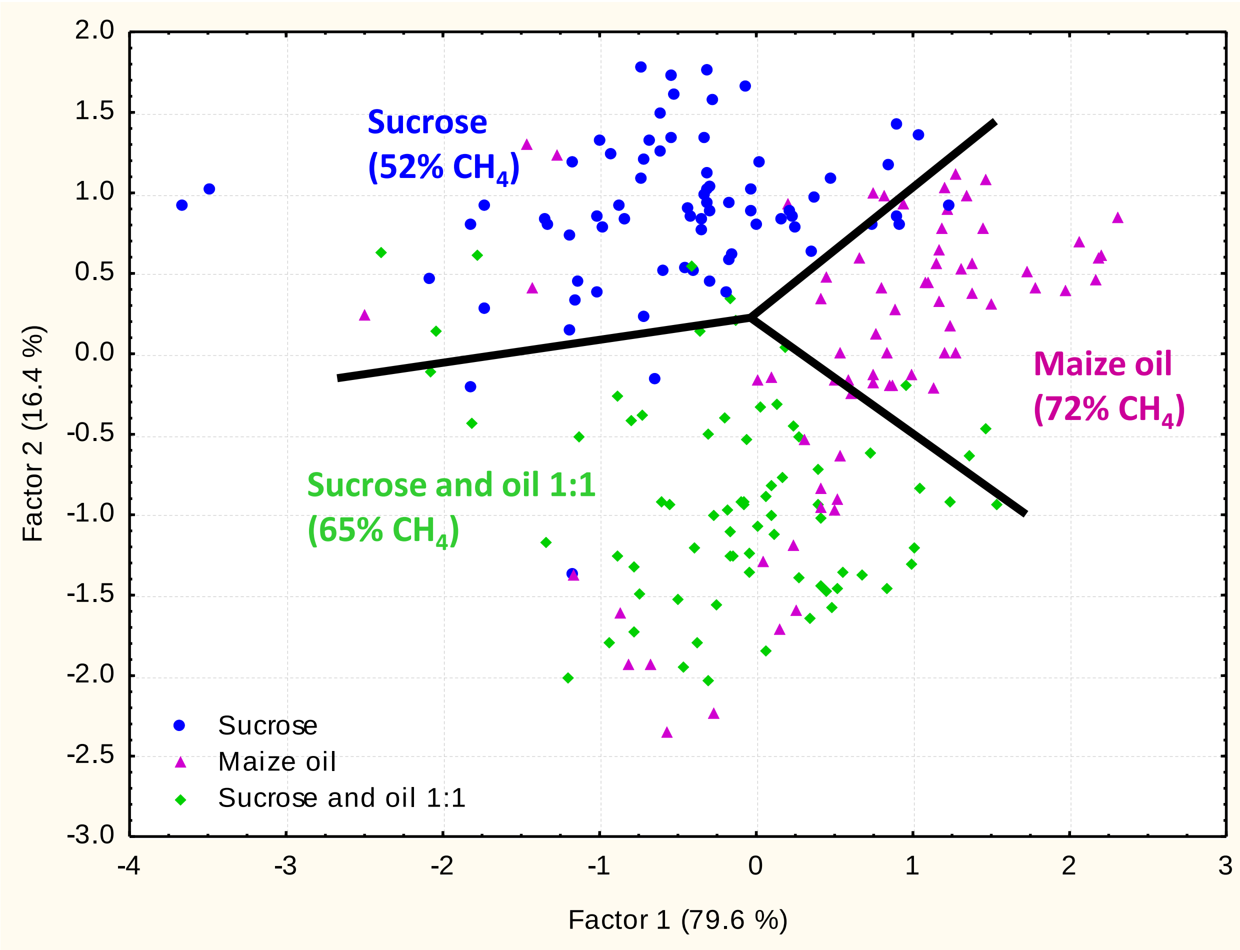
PCA analysis



Increasing feeding strategy scores are moved away from the scores of the cautious feeding strategy

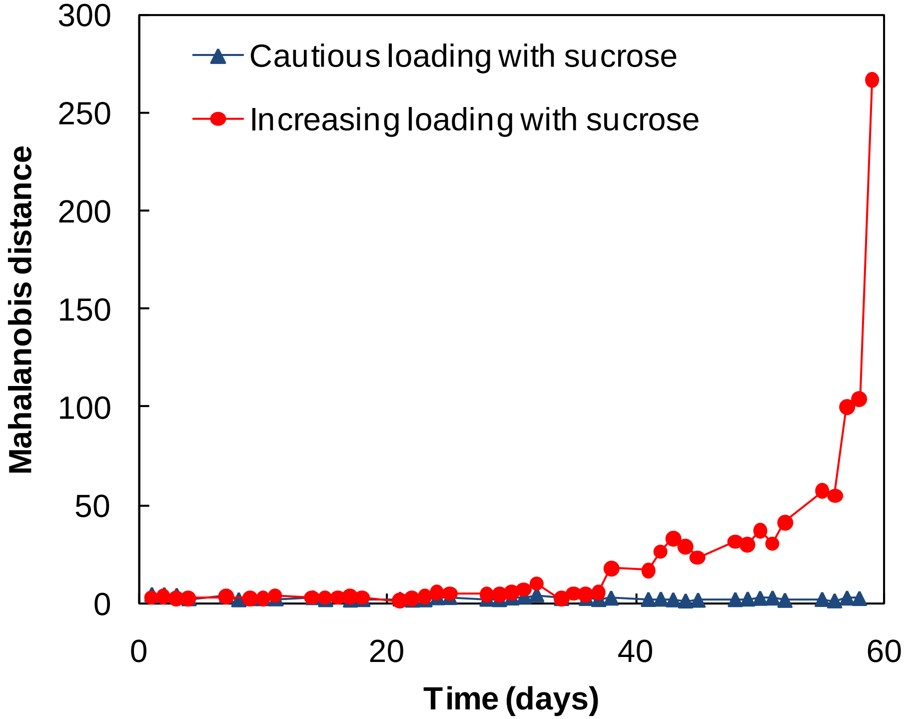


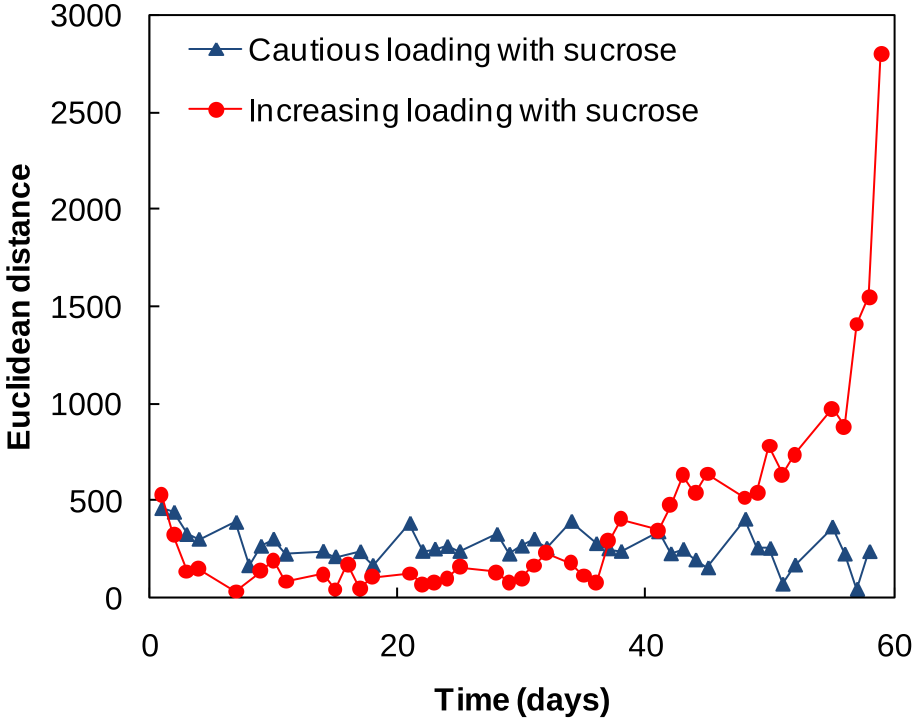
Substrate composition slightly influences e-nose response



Cautious loading observations form a general pattern in which 3 overlapped clusters are highlighted : the feeding regimes. Although, it does not interfere with disturbances detection.

Euclidean versus Mahalanobis distances





Mahalanobis distance could be used as an indirect early warning indicator of anaerobic digestion process overload

1. **Disturbances due to high loading rates of the reactors are detected by the e-nose apparatus.**
2. **E-nose response is slightly influenced by substrate composition but it does not interfere with disturbances detection.**
3. **CH_4 content is largely influenced by substrate composition and does not interfere on e-nose response**
4. **PCA analysis: 2 main factors are related to the feeding rate of the reactors**
5. **Mahalanobis distance from a "cautious feeding group" should be confirmed as an early warning indicator for organic overload in anaerobic reactors**

Online monitoring of 4 anaerobic reactors of 100 L

- **Development of a biogas sampling and dilution device**
- **Comparison with state variables of the anaerobic reactors**
- **Analysis of signal evolution in time (H_2S poisoning, drift)**

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Online test on real biogas plants

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