RÉPUBLIQUE FRANÇAISE
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LBE Laboratoire Biotechnologie de l'Environnement

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Environnement
Terre
Eau

Coupling genome based and energy based approaches of syntrophic microbial interactions for the modelling of high rate anaerobic digestion
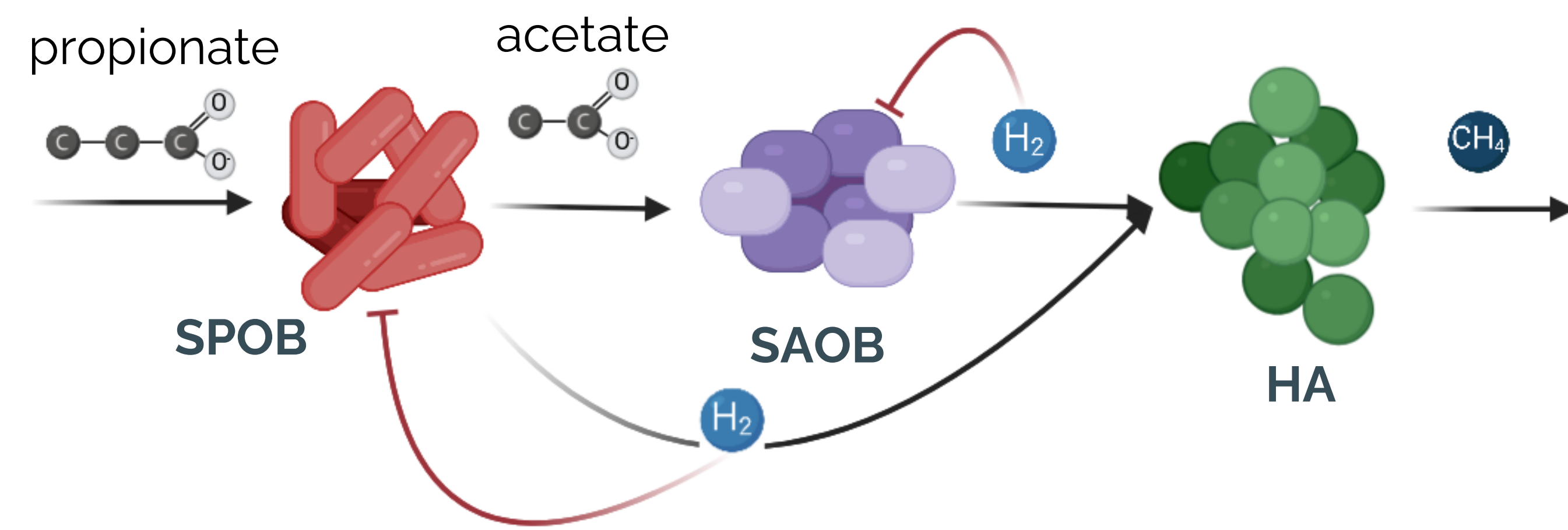
Sahak YEGHIAZARYAN

Introduction/ Context – Anaerobic digestion (AD) of nitrogen-rich waste involves converting organic matter into methane. The final step, essential for digester efficiency, is handled by syntrophic bacteria (SPOB and SAOB) and hydrogenotrophic archaea (HA). Hydrogen plays a critical role, as its accumulation inhibits the bacteria while serving as the substrate for the archaea. Understanding these microbial interactions and optimizing conditions for their activity is crucial for efficient AD.

propionate → SPOB → acetate → SAOB (H_2) → HA → CH_4

Objectives

Dynamic modeling

$$q_s = q_{s_{max}} \cdot \frac{S}{S + K_s} \cdot I$$

$$X(t + \Delta t) = X(t) + q_s \cdot \Delta t \cdot \underbrace{I \cdot Y_{s/x}}$$

Calculated as in ADM1
or
Estimated from thermodynamics
Kleerebezem et al. 2010

⚙ Compare the predictive power of 2 versions of model

⚙ Asses the variance of growth yield of same cultures
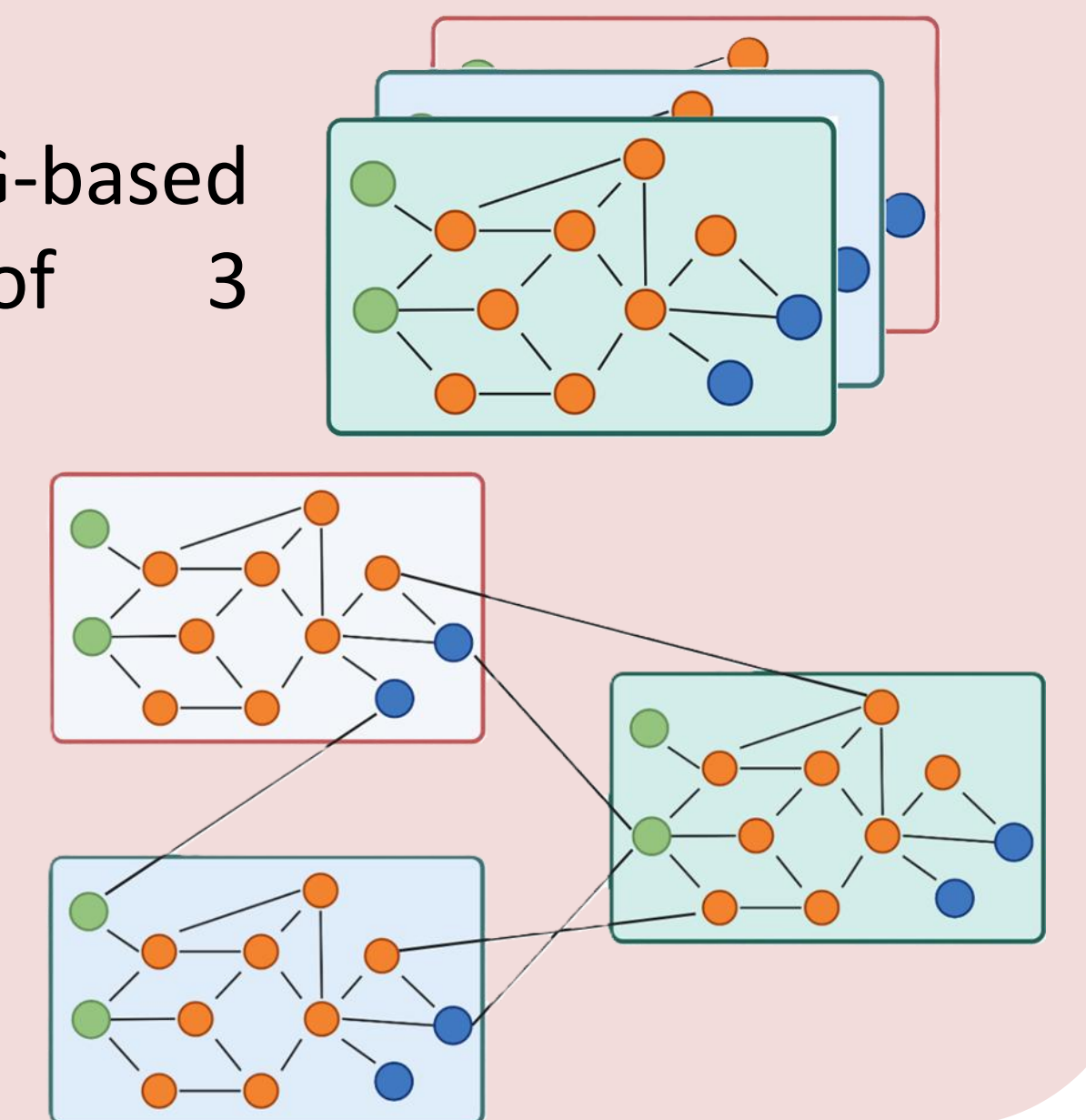• During time
• Between different reactors
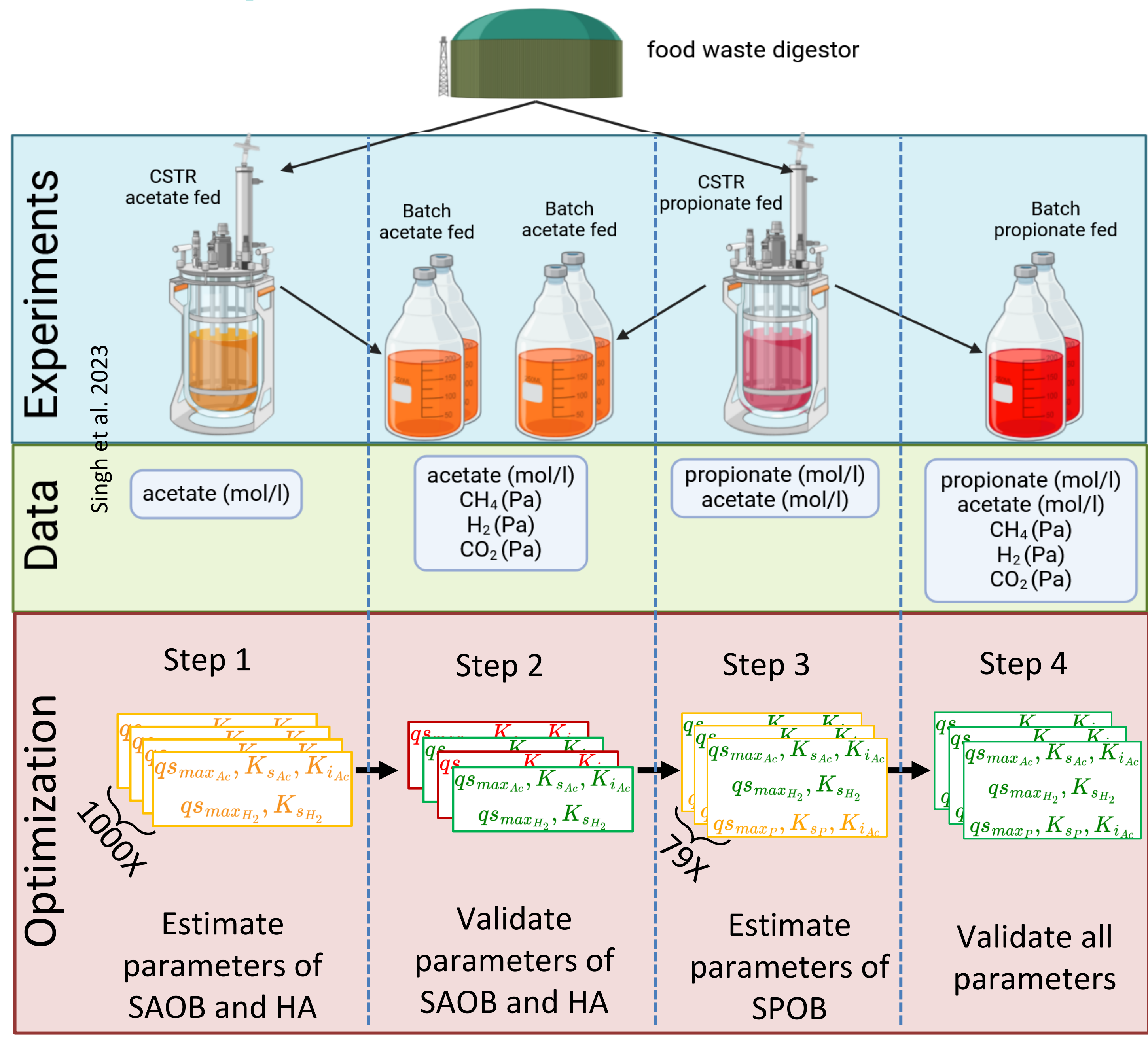Use predictions from kinetic and metabolic models.

Metabolic modeling

⚙ Construct MAG-based metabolic models of 3 microorganisms
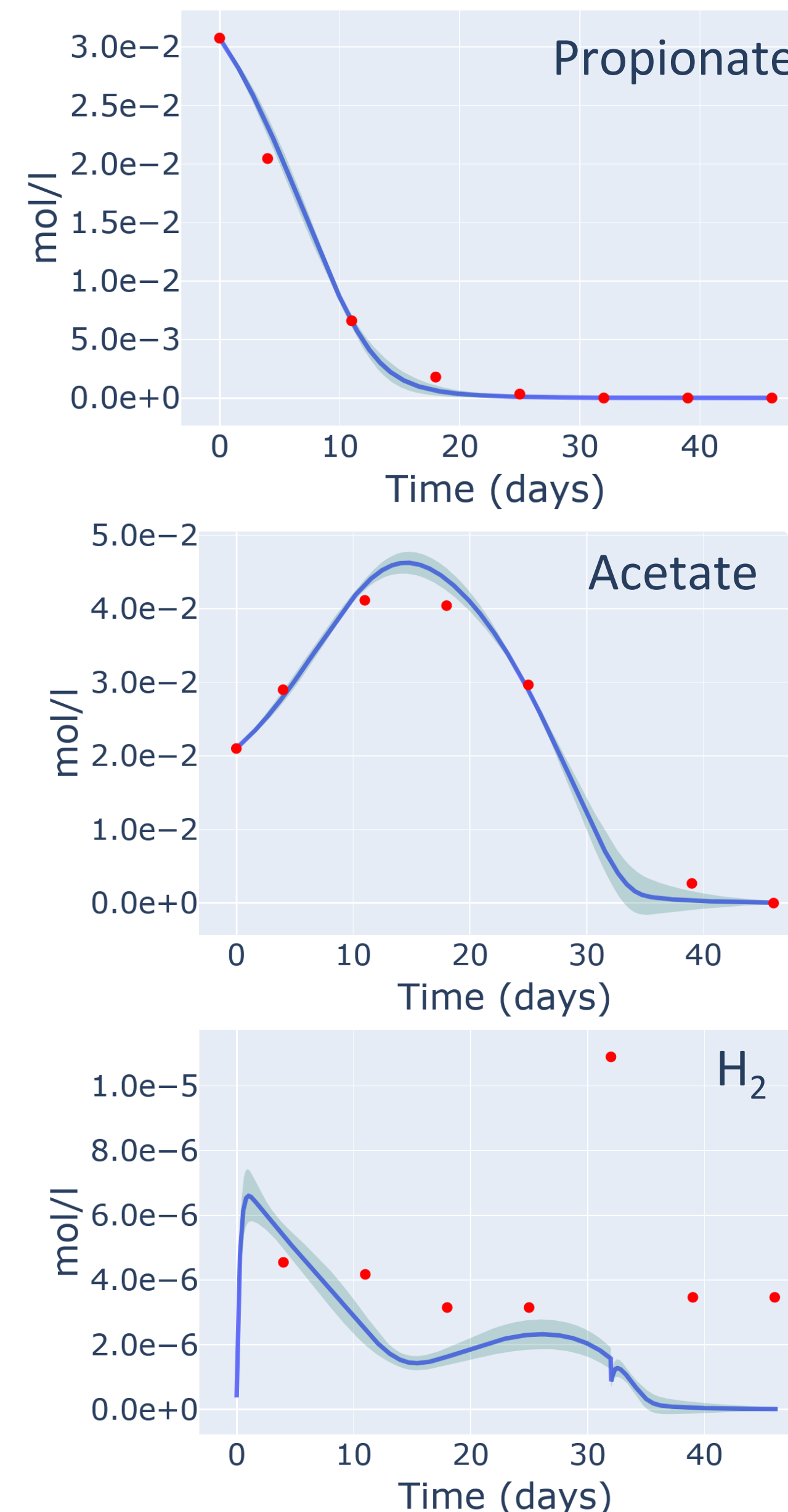
⚙ Obtain a model of 3 microorganisms in the form of a community, and get predictions from the community form.
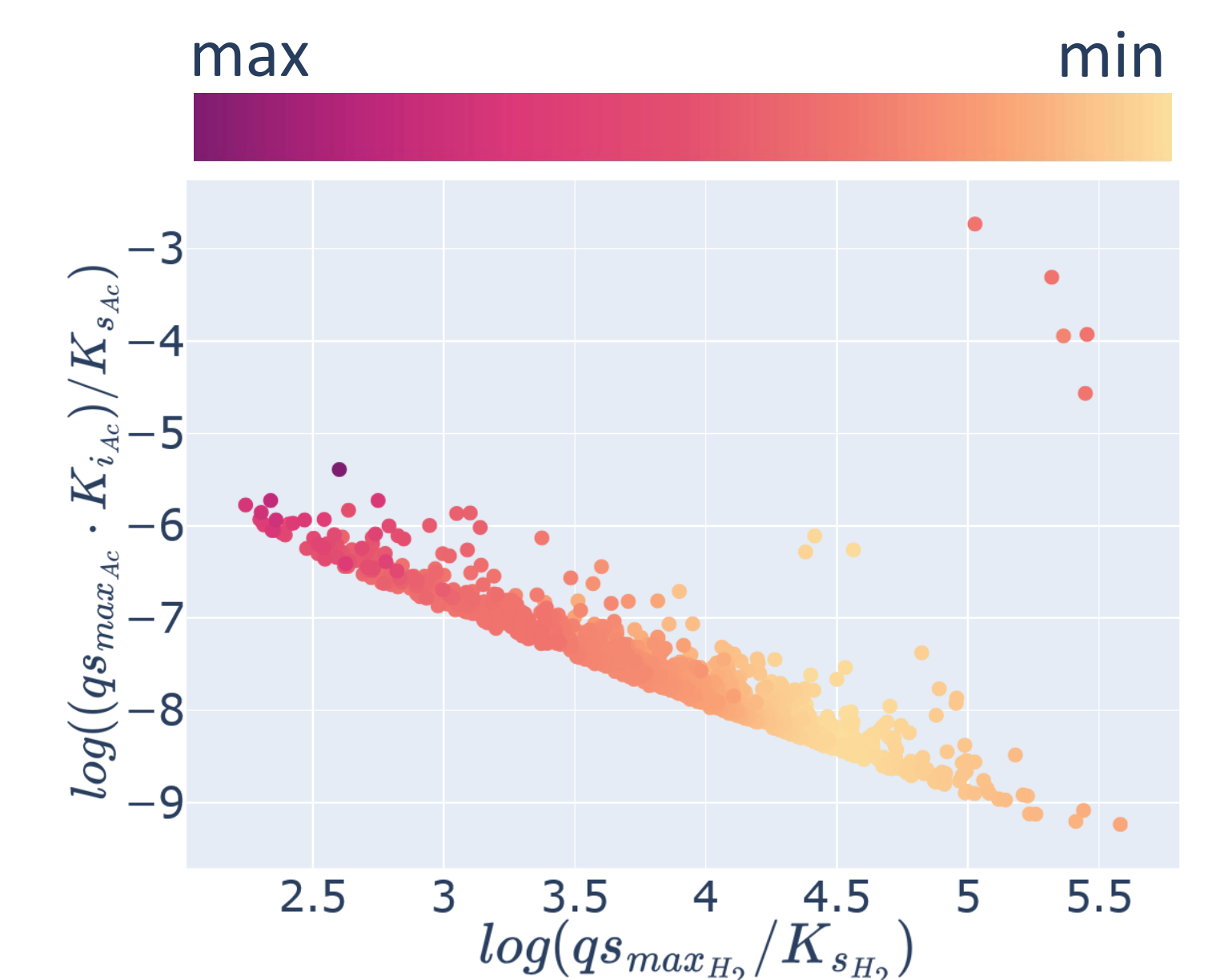

Data and optimization

food waste digestor

Experiments — Singh et al. 2023
CSTR acetate fed | Batch acetate fed | Batch acetate fed | CSTR propionate fed | Batch propionate fed

Data
acetate (mol/l) | acetate (mol/l) CH_4 (Pa) H_2 (Pa) CO_2 (Pa) | propionate (mol/l) acetate (mol/l) | propionate (mol/l) acetate (mol/l) CH_4 (Pa) H_2 (Pa) CO_2 (Pa)

Optimization

Step 1 — q_s, $qs_{max_{Ac}}$, $K_{s_{Ac}}$, $K_{i_{Ac}}$, $qs_{max_{H_2}}$, $K_{s_{H_2}}$ — 1000x
Estimate parameters of SAOB and HA

Step 2 — $qs_{max_{Ac}}$, $K_{s_{Ac}}$, $K_{i_{Ac}}$, $qs_{max_{H_2}}$, $K_{s_{H_2}}$ — 79x
Validate parameters of SAOB and HA

Step 3 — $qs_{max_{Ac}}$, $K_{s_{Ac}}$, $K_{i_{Ac}}$, $qs_{max_{H_2}}$, $K_{s_{H_2}}$, qs_{max_P}, K_{s_P}, K_{i}
Estimate parameters of SPOB

Step 4 — $qs_{max_{Ac}}$, $K_{s_{Ac}}$, $K_{i_{Ac}}$, $qs_{max_{H_2}}$, $K_{s_{H_2}}$, qs_{max_P}, K_{s_P}, $K_{i_{Ac}}$
Validate all parameters

Results

Legend
— Prediction
— Confidence Interval
• Experimental data

Propionate — mol/l vs Time (days)
Acetate — mol/l vs Time (days)
H_2 — mol/l vs Time (days)

Simulation of the AMD1-like model with validated parameters from Step 4.

max — min

$log(qs_{max_{Ac}} \cdot K_{i_{Ac}}) / K_{s_{Ac}}$ vs $log(qs_{max_{H_2}} / K_{s_{H_2}})$

Correlation of ratio of optimized parameters of SAOB and HA from Step1. Color indicates error of these parameters obtained in Step 2.

Perspectives

• Model the same process with thermodynamics and compare it with an ADM1-like model
• Use metabolic networks to predict process yields
• Couple of thermodynamic and metabolic-based models

References

Singh, A., Schnürer, A., Dolfing, J., Westerholm, M., 2023. Syntrophic entanglements for propionate and acetate oxidation under thermophilic and high-ammonia conditions. ISME J. 17, 1966–1978. https://doi.org/10.1038/s41396-023-01504-y

Kleerebezem, R., Van Loosdrecht, M.C.M., 2010. A Generalized Method for Thermodynamic State Analysis of Environmental Systems. Crit. Rev. Environ. Sci. Technol. 40, 1–54. https://doi.org/10.1080/10643380802000974