Title: Development of predictive models to control the anaerobic digestion process

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Abstract:
The conversion of biogenic residues to biogas as sustainable energy source is one major challenge in the context of the energy transition from fossil fuels to renewable resources. In that context, this research project aims in general at the understanding, prediction and control of biomass conversion dynamics to biogas by a combination of process engineering, microbiological analyses and mathematical modelling. To reach this goal, an in-depth knowledge of the influence of feedstock composition and quality on product quantity and quality based on physical, chemical and microbiological process parameters, and the formulation of respective process models is required. Resulting models should allow to control demand-driven product formation and to avoid instabilities/disturbances of the transformation processes. Process modeling is in this project thought to be based on combining model equations for material transformations (based on chemical process parameters) and microbial diversity dynamics using differential equations. The microbial diversity is intended to be considered for dynamic simulations/analyses by using concepts from (microbial) ecology such as e.g. traits-based approaches. Examples for relevant modelling approaches are the Anaerobic Digestion Model No. 1 (Batstone et al. 2002) or the Anaerobic Microbial Degradation Model (Dalby et al. (2021). The combination of this project with other KIDS methods is possible, e.g. for process optimization/control or for data-driven model approaches. This project is related to overarching themes digital twins/process control.

Desired skills of the applicant:
Required: Mathematical modelling (e.g. differential equations, model calibration), interest in biological and chemical data and methods to generate those

Optional: AI/data-driven modelling, multivariate statistics, concrete knowledge /experience on chemical /biological process engineering

References:
Anaerobic Digestion Model No. 1: currently the most complex and most widely used model, based on optimal reaction kinetics, assumes perfectly balanced mixture of all reactions, neglects the microbial diversity in its real taxonomic, functional and ecological complexity

Batstone, D.J., Keller, J., Angelidaki, I., Kalyuzhnyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders, W.T., Siegrist, H., Vavilin, V.A., 2002. The IWA Anaerobic Digestion Model No 1 (ADM1). Water Sci. Technol. 45(10), 65-73. PMID: 12188579.

Cinar, S., Cinar, S.O., Wieczorek, N., Sohoo, I., Kuchta, K., 2021. Integration of artificial intelligence into biogas plant operation. Processes 9(1), 85. link

Moretta, F., Rizzo, E., Manenti, F., Bozzanoet, G., 2021. Enhancement of anaerobic digestion digital twin through aerobic simulation and kinetic optimization for co-digestion scenarios. Biores. Technol. 341, 125845. link

Anaerobic Microbial Degradation Model: considers various methanogenic groups whose relative abundances shift in response for example to changes in the process temperature, but requires the existence of pure cultures as well as substrate utilization and growth kinetics

Dalby, F.R., Hafner, S.D., Petersen, S.O., Vanderzaag, A., Habtewold, J., Dunfield, K., Chantigny, M.H., Sommer, S.G., 2021. A mechanistic model of methane emission from animal slurry with a focus on microbial groups. PLoS ONE 16(6): e0252881. link

Leite and Kuramae 2020 provide an overview of model-based approaches for microbial community analyses.

Leite, M.F.A., Kuramae E.E., 2020. You must choose, but choose wisely: Model-based approaches for microbial community analysis, Soil Biol. Biochem. 151, 108042. link

An overview about the current state of biogas production and future development for agricultural biogas plants in Germany is given in Theuerl et al. 2019

Theuerl, S.; Herrmann, C.; Heiermann, M.; Grundmann, P.; Landwehr, N.; Kreidenweis, U.; Prochnow, A. The Future Agricultural Biogas Plant in Germany: A Vision. Energies 2019, 12, 396. link