Ph.D. in Information Technology
Thesis Defense

September 18th, 2026
At 10:30 a.m.
Meeting Room 2B - Building 20A

Davide Carecci – 38th Cycle

MODELING, OPTIMIZATION AND CONTROL OF THE ANAEROBIC CO-DIGESTION PROCESS IN THE AGRO-INDUSTRIAL SECTOR

Supervisor: Prof. Gianni Ferretti

Abstract:

The transition toward a circular and low-carbon energy system requires efficient, reliable, and environmentally sustainable technologies for renewable energy production. Anaerobic digestion (AD) converts organic residues into biomethane, enabling waste valorization and sustainable energy generation. In particular, the co-digestion (AcoD) of agro-industrial feedstocks is widely implemented at full scale and represents a mature and promising process to improve Europe's energy independence. Future challenges for these facilities concern the enhancement of their techno-economic performance to sustain production without subsidies. This requires maximizing biomethane production per unit of input organic matter, which is far from trivial due to the high complexity and nonlinearity of the bioprocess and the need for strict operational control to avoid process instability. As a result, plants often operate conservatively and sub-optimally. Moreover, limited techno-economic margins restrict the adoption of advanced \emph{online} instrumentation and control tools, thereby constraining opportunities for performance improvements. The main goal of this dissertation is the development of digital tools to enable more efficient operation under safety and realistic industrial constraints. To address key limitations in the literature—such as insufficient application of rigorous parameter estimation guidelines for mechanistic models, the limited development of control-oriented models, and the scarcity of model predictive control (MPC) applications and experimental validations in AcoD systems—the research proposes a coherent framework combining modeling, system identification, advanced monitoring and robust predictive control. A high-fidelity model is first developed extending the state of the art. From it, a reduced-order mechanistic models is derived and both are trained and validated using data from bench-scale experiments, enabling their use for \emph{offline} diet optimization and real-time control. To improve model reliability, only practically-identifiable parameters are estimated, and identifiability is improved combining data from continuous operation with batch activity tests. Building on these models, unmeasurable state estimation through Extended Kalman Filtering (EKF) and robust (tube-based) nonlinear model predictive control (NMPC) strategies—particular emphasis in addressing parametric uncertainty—are developed to maximize biomethane production while ensuring safe operation under uncertainty and limited instrumentation. The results highlight both strengths and limitations of the developed models, particularly in predicting key process variables in the gaseous stream and digestate bulk (e.g., volatile fatty acids concentration) during time-varying AcoD operation. Both conventional and

NMPC control schemes are first evaluated through numerical studies and subsequently validated experimentally on a real bench-scale reactor. The experiments demonstrate stable closed-loop operation with biomethane production gains of approximately 17\% compared with baseline conditions representative of typical full-scale plants. Overall, this research bridges the gap between advanced control theory and practical implementation in agro-industrial AcoD systems.

PhD Committee

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