

# **A generalized kinetic model for anaerobic co-digestion of agro-industrial biomass mixtures improved through pretreatments or additives**

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## **Abstract-**

**Anaerobic co-digestion is increasingly recognised as a strategy to enhance biogas production from agro-industrial biomass by exploiting synergistic interactions among multiple organic substrates. However, most existing kinetic models remain case-specific and fail to provide reliable predictions when substrate ratios, pretreatments, or additives are modified, limiting their practical applicability. This study proposes a generalised combinatorial kinetic framework for n-substrate anaerobic co-digestion. The model integrates established formulations, including the Modified Gompertz and first-order models, into a structured interaction-based approach capable of explicitly representing multi-order substrate interactions without repetition. Interaction coefficients are weighted according to substrate contributions, ensuring consistency between mono-digestion and higher-order co-digestion systems. The framework further incorporates pretreatments and nanoparticle additives through multiplicative interaction terms, allowing performance enhancements to be modelled explicitly rather than indirectly absorbed into kinetic parameters. Although the combinatorial structure can manage up to 108 interaction parameters in a three-substrate Gompertz-based system, the methodology reduces the minimum experimental requirement to only 8 BMP tests by sequentially constructing higher-order interactions from lower-order combinations. This significantly decreases experimental effort while preserving scalability. While the model currently simplifies additive concentration effects and potential inhibitory phenomena, it provides a flexible and extensible structure capable of evolving with emerging research trends. Overall, the proposed framework addresses a critical gap in anaerobic co-digestion modelling and supports a more systematic design of agro-industrial biomass co-digestion systems for bioenergy production within circular bioeconomy strategies.**

**Index Terms-** Anaerobic co-digestion; Agro-industrial biomass; Kinetic modelling; Biogas production; Pretreatment; Substrate interactions; Predicting performance indexes; Nanoparticle-assisted anaerobic digestion; Synergistic effects in anaerobic co-digestion; Kinetic parameter estimation; Substrate interaction modelling

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