Ph.D. Thesis Defense

The William G. Lowrie Department of Chemical and Biomolecular Engineering

"Science-based Method for Integrating Absolute Environmental Sustainability in Assessment and Design of Chemical Process System"

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<u>Abstract</u>

Currently, global objectives such as 'Nature-Positive by 2030' and 'Net-Zero Emission by 2050' have been proposed and widely embraced as guiding principles for future development. To achieve these ambitious global goals, the role of nature should be incorporated into sustainability assessment and system design. This work focuses on developing science-based methods and frameworks for assessing absolute environmental sustainability and designing absolutely sustainable chemical systems. Nature's carrying capacity, quantified by biophysical models and geographical data, is used as an absolute reference value in this science-based method, which is more robust, has high geographical resolution and encourages sustainability actions towards global goals. This method has been applied to four major chemical products in their primary supplying countries. Results illustrate their regional and global sustainability issues. Additionally, promising nature-based solutions have been explored to achieve 'Net-Zero' emissions. A user-friendly open-source software and its ecological inventory database have been developed. It assists stakeholders with diverse backgrounds in decision making on absolute environmental sustainability purpose. For absolutely sustainable system design, a multiobjective mixedinteger linear programming model is developed for designing a supply chain within the ecological safe and socially just space. This model encompasses the entire life cycle of the product system and optimizes three key aspects: ecological overshoot, social shortfall, and biodiversity loss. By applying this framework to the Li-ion battery supply chain, the result shows the optimal network structure, and also underscores the imperative of integrating ecological ceiling and social foundation in facilitating the transition toward a more sustainable future.