Chemical Engineering Dissertation Defense

Integrating Nature's Capacity into Engineering Decision-Making and Sustainability Assessment

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Abstract

Human activities associated with energy production, industrial manufacturing, and resource consumption have contributed to increasing environmental degradation, climate change, ecosystem disruption, and growing concerns regarding the long-term sustainability of human development. Although sustainable engineering and environmental assessment methodologies have advanced significantly, ecosystem services and ecological carrying capacity are often insufficiently incorporated into engineering system design and decision-making processes. Industrial systems are frequently optimized primarily based on economic and technical objectives, while the dynamic interactions between technological systems and ecosystems remain underrepresented. In addition, conventional sustainability assessments often emphasize relative environmental improvements, such as reductions in emissions or resource use compared with baseline systems, without explicitly evaluating whether human activities operate within environmental limits defined by planetary boundaries and ecosystem capacity.

To address these challenges, this dissertation develops integrated decision-support and sustainability assessment frameworks through the combination of process systems engineering, life cycle assessment (LCA), and absolute environmental sustainability assessment (AESA). The research advances methodologies for incorporating ecosystem services and societal impacts into engineering analysis and sustainability evaluation across multiple spatial and sectoral scales. In particular, the dissertation demonstrates how ecosystem restoration and natural pollutant-removal capacity can be integrated with engineering system optimization to simultaneously improve environmental performance, generate societal benefits, and support more equitable sustainability outcomes. The work further investigates how different environmental allocation approaches influence sustainability assessment results and develops new analytical metrics to evaluate the distribution of environmental capacity and ecological restoration benefits under sustainability frameworks. In addition, the dissertation translates these methodologies into practical applications through the development of an interactive computational tool that enables users to assess environmental sustainability. Overall, this work advances the integration of engineering systems, ecosystem services, and sustainability concepts within analytical and decision-support frameworks, providing methodological foundations and practical tools to support nature-positive and sustainable decision-making.

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