Paper 288

Quantitative Evaluation Methods for Sustainability Performance of Complex Engineering Systems

With the increasing emphasis on sustainable development, the comprehensive performance of engineering systems in terms of energy utilization, resource consumption, and environmental impact has attracted growing attention. Complex engineering systems consist of multiple subsystems and diverse technical units, characterized by structural complexity, variable operating conditions, and strong system coupling. Their sustainability performance cannot be accurately captured through single indicators or qualitative assessments, highlighting the need for quantitative evaluation methods tailored to complex systems.

The sustainability performance of complex engineering systems typically involves multiple dimensions, including energy efficiency, resource utilization, environmental emissions, and operational reliability. These dimensions interact and constrain each other; for example, improving energy efficiency may alter resource consumption patterns, while emission control measures can introduce additional energy demand. Conventional evaluation approaches often focus on isolated aspects, failing to reflect overall system sustainability. Moreover, under dynamic and multi-operational conditions, system performance fluctuates significantly, making static evaluation insufficient for engineering applications. Consequently, there is a need for quantitative evaluation methods that integrate multi-dimensional indicators and account for dynamic behavior.

This study proposes a quantitative evaluation methodology for the sustainability performance of complex engineering systems. A comprehensive indicator framework encompassing energy, resource, and environmental metrics is developed, integrating system operational data and model-based analysis. Weighting and normalization techniques are applied to aggregate multiple indicators into a unified sustainability performance index. Case studies of representative engineering systems are conducted to validate the proposed method and assess the impact of different operational strategies on sustainability performance.

The results demonstrate that the proposed quantitative evaluation method effectively captures variations in sustainability performance under diverse operating conditions, providing scientific support for system optimization and operational management. This research offers a systematic and engineering-oriented approach to sustainability assessment, facilitating the transition of complex engineering systems toward efficient, low-carbon, and sustainable development.