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Editorial: Life cycle analysis of alternative fuels for the maritime sector and similar industry

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Editorial on the Research Topic
Life cycle analysis of alternative fuels for the maritime sector and similar industry

1 Introduction

The maritime industry, along with other transport sectors, is under increasing pressure to transition toward sustainable energy sources to mitigate environmental impacts. Alternative fuels such as biofuels, hydrogen, and hybrid-electric solutions offer promising pathways to decarbonisation. However, a comprehensive assessment of these alternatives requires rigorous Life Cycle Analysis (LCA) to account for environmental, social, and economic factors.

This Research Topic brings together interdisciplinary research addressing key challenges in LCA methodologies, regulatory inconsistencies, socio-economic implications, and technical advancements in alternative fuel adoption. The contributions herein highlight the complexities of assessing alternative fuels holistically, demonstrating the need for harmonisation in regulatory frameworks, robust computational tools, and a deeper understanding of the social trade-offs involved in transitioning to low-carbon energy solutions.

2 Key themes and contributions

2.1 Regulatory and methodological challenges in LCA of alternative fuels

One of the central challenges in alternative fuel adoption is the variation in carbon intensity (CI) assessment due to differences in regulatory frameworks. Fuel standards such as the European Renewable Energy Directive (RED), United Kingdom Renewable Transport Fuel Obligation (RTFO), California Low Carbon Fuel Standard (LCFS), US Renewable Fuel Standard (RFS), and Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) employ different LCA approaches, land use change (LUC) considerations, and electricity input calculations. These discrepancies can lead to inconsistent sustainability assessments, complicating global efforts to transition toward alternative fuels.

Roux et al. explore how these regulatory inconsistencies obscure the potential climate benefits of transportation fuels, arguing for greater harmonisation in fuel standards to improve comparability and decision-making in fuel adoption policies.

2.2 Socio-economic impacts of biofuel adoption in maritime and aviation

While environmental considerations are often prioritised in LCA, social impacts are equally crucial in determining the feasibility of alternative fuels. Biofuel production, for instance, has significant implications for job creation, rural economies, resource allocation, and social equity.

Kostidi and Lyridis contribute to this discussion by conducting a Social Life Cycle Assessment (S-LCA) and Social Cost-Benefit Analysis (S-CBA) of a pilot biorefinery project supplying the maritime and aviation industries. Their findings highlight the trade-offs between economic growth, sustainability goals, and potential socio-economic disruptions, underscoring the importance of integrating social dimensions into fuel sustainability assessments.

2.3 Technological challenges in fuel cell-based maritime power systems

Fuel cell technologies, particularly solid oxide fuel cells (SOFCs) combined with lithium battery systems, offer a low-emission energy source for shipboard power generation. However, their stability under dynamic maritime operating conditions remains a critical challenge.

Fang et al. investigate large-signal stability in SOFC–lithium battery ship DC microgrids, proposing a hybrid potential function-based stability criterion to improve voltage control and power distribution resilience. Their research provides valuable insights into the operational limitations of SOFC-based microgrids and how stability analysis can enhance their reliability for maritime applications.

2.4 Computational advances for hybrid AC/DC microgrids supporting alternative fuels

Efficient power flow algorithms are essential for managing hybrid AC/DC microgrids, which could increasingly incorporate alternative fuels such as hydrogen and biofuels. Traditional unified iteration methods (UIMs) for power flow analysis are computationally intensive, requiring large-scale matrix inversions that can increase memory usage and slow down convergence.

Dong et al. introduce an improved unified iteration method (IUIM) that significantly reduces computational complexity by simplifying the Jacobian matrix. Their study demonstrates an 80% improvement in computational speed compared to standard UIMs, potentially making the approach suitable for shipboard microgrids with low-voltage variations. This advancement could support real-time energy management in maritime hybrid power systems.

3 Conclusion and future directions

The studies presented in this Research Topic underscore the multidimensional challenges in alternative fuel adoption, spanning regulatory frameworks, social acceptance, technological feasibility, and computational efficiency. Several key insights emerge:

- Harmonisation of LCA methodologies is essential to ensure consistent carbon intensity assessments across different fuel types and regulatory jurisdictions.
- Incorporating social dimensions into LCA is critical to balance economic benefits with potential socio-environmental trade-offs.
- Advancing stability analysis and control methods for fuel cell-based ship power systems can enhance alternative fuel reliability in maritime operations.
- Optimised computational models for hybrid AC/DC microgrids can facilitate energy transitions in maritime transport.

Future research should focus on integrating interdisciplinary methodologies that combine engineering, policy analysis, social sciences, and economics to create holistic sustainability assessments. A collaborative approach between academia, industry, and policymakers will be crucial in accelerating the adoption of viable alternative fuel solutions for the maritime and related industries.

This Research Topic provides a valuable foundation for ongoing discussions and innovations, paving the way for more effective and equitable energy transitions in global transportation sectors.

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