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A Bi-Level Sector Coupling Framework for Multi-Actor Energy Systems: Integrating Techno-Economic Optimisation and Cooperative Game Theory

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Extended Abstract

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Abstract Summary

Despite numerous studies, a significant gap remains in corporate-oriented techno-economic frameworks that integrate multiple actors within sector coupled energy systems. This study introduces a bi-level sector-coupling optimisation framework that bridges techno-economic system modelling and stakeholder-oriented value allocation. The approach is based on a novel definition of sector coupling, structured around three complementary pillars: techno-economic, commercial, and organisational.

The techno-economic layer is formulated as a mixed-integer linear programming (MILP) model, implemented in Python and solved using Gurobi, to simulate hourly system operation. The model integrates electricity, district heating (DH), district cooling (DC), and power-to-X (PtX), capturing sector interactions through temperature-dependent heat integration and mass-flow modelling. Nonlinear relationships are linearised using McCormick envelope relaxations, enabling tractable optimisation. A scenario-based framework is applied, including a reference system, a fully coupled system, and a decoupled configuration.

The case study focuses on a sector-coupling hub comprising a multi-energy utility and a 1 GW electrolyser. Results show that sector coupling enables significant system-level benefits by utilising excess heat from PtX in both DH and DC. A two-fold benefit emerges from combining excess heat utilisation with avoided cooling costs, increasing system flexibility and expanding the feasible operating range of PtX. The total benefit amounts to 271.45 million DKK/year (~35 million EUR), including 80.05 million DKK/year from heat utilisation and avoided cooling, and 191.40 million DKK/year from increased hydrogen production.

However, the results reveal an uneven distribution of benefits across actors, leading to misalignment between system-level gains and individual incentives. To address this, a

cooperative game-theoretic framework is proposed that applies bargaining and Shapley value allocation to enable a fair distribution of jointly generated value.

Presenting Author Biography

Buster Bukart Hansen is a PhD candidate at the University of Southern Denmark (SDU), specialising in integrated multi-energy systems and sector coupling. His research focuses on techno-economic optimisation, power-to-X integration, and the development of novel frameworks for value creation and allocation in multi-actor energy systems. By combining advanced optimisation modelling with cooperative game theory and business case analysis, his work bridges engineering-based system design with stakeholder-driven decision-making in the energy transition.