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Beyond costs: How hydrogen infrastructure reshapes the structure of a net-zero energy system

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Extended Abstract

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Abstract Summary

Hydrogen infrastructure is widely regarded as a key enabler of climate-neutral energy systems. Existing studies typically assess its value in terms of total system cost reductions, potentially overlooking its broader impact on system structure and operation. This paper analyzes how hydrogen transport infrastructure influences the spatial organization of production and the provision of flexibility in a net-zero energy system. We use a long-term energy system optimization model for Germany that co-optimizes investments and operations under a net-zero constraint. Two configurations are compared, one including a hydrogen backbone network based on planned infrastructure, and one without hydrogen transport, where hydrogen must be produced locally. Results show that hydrogen infrastructure leads to only modest reductions in total system costs (around 1%), but significantly reshapes the system structure. Without hydrogen transport, production is decentralized, and flexibility relies on local solar generation and battery storage, requiring substantially higher battery deployment. In contrast, a hydrogen backbone enables spatial specialization in renewable-rich regions, particularly those with high wind potential, and shifts flexibility provision toward hydrogen-based technologies. Hydrogen transport also reduces the need for electricity transmission expansion by enabling greater spatial coordination of energy resources. These findings indicate that the value of hydrogen infrastructure goes beyond direct cost reductions and is largely related to its ability to reshape the structure of the energy system, the provision of flexibility, and the integration of renewable resources.

Presenting Author Biography

Philip Guerra is a PhD candidate and researcher at the Institute of Sustainable Energy Systems (INES), Hochschule Offenburg, Germany, working within the Hydrogen Valley Südbaden project. His research focuses on energy system modeling, hydrogen integration, and power system planning under net-zero targets. Prior to his current position, he worked for two years at the Chilean Independent System Operator in power system planning.