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Simulation-Based Quantification of CO_2 Savings in Cellular Energy Systems

Despite significant progress in Germany's energy transition, substantial potential remains for reducing CO_2 emissions within the energy sector. In 2023, the energy industry accounted for 30.5% of total emissions, making it the largest emitter, even though renewable energy sources contributed 52% to electricity generation. This duality highlights the scope for further renewable energy expansion while emphasizing that decarbonization must extend beyond electricity production to encompass sectors such as buildings, mobility, and industry. Electrification emerges as a pivotal strategy to lower residual emissions across these domains and meet climate protection targets. However, the shift from centralized fossil-fuel power plants to numerous decentralized renewable sources, coupled with the supply of newly electrified loads, poses complex challenges to the energy system, including the integration of renewables, grid stress, and system stability maintenance. These issues necessitate innovative approaches to advance the energy transition comprehensively. Cellular energy systems offer a promising solution by restructuring the energy system into decentralized units grounded in energetic subsidiarity. This framework leverages technical and informational advantages to address the demands of a future energy system comprising thousands of small-scale units, ensuring compliance with technical and ecological constraints—such as reliable energy provision and greenhouse gas emission reductions—in a cost-effective manner while promoting operational continuity and investment incentives. This study introduces the concept of cellular energy systems and details a simulation environment designed to model multimodal energy cells. It investigates energy demands for electricity, heat, and mobility, evaluating the effects of optimally harnessing renewable generation potentials and local flexibility options on CO_2 emissions. By quantifying greenhouse gas emissions, the research elucidates the contribution of cellular energy systems to emission reductions.

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