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Optimized siting of hybrid renewable energy infrastructure in Kenya using geospatial techniques

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Abstract
Amid the intensifying greenhouse gas emissions globally and the mounting pressure to decarbonize energy systems, renewable energy sources are becoming essential to achieving carbon neutrality while supporting system reliability, environmental sustainability, and efficiency in resource use. This has escalated the need for spatial planning tools capable of identifying optimal locations for energy infrastructure under multiple and competing constraints particularly in developing countries. Identifying optimal locations for renewable energy development is particularly challenging in developing countries. This is because often the rapid increase in electricity demand, environmental sensitivities, competing land uses, infrastructural limitations, and capital inadequacies must all be carefully balanced. In this context, optimizing siting of hybrid solar, wind, and biomass energy infrastructure presents a promising approach to enhance energy security while supporting global decarbonization goals.

This study presents a GIS-based Multi-Criteria Decision-Making framework for spatially siting hybrid solar, wind, and biomass energy systems in Kenya. The framework integrates multiple spatial datasets based on fifteen criteria grouped into 1. Technical, 2. Environmental, 3. Socioeconomic categories, derived from scientific literature. These criteria are then weighted using a structured Best-worst Method (BWM) in a two-step Delphi to ensure consistency and robustness in stakeholder preference modeling. The results from the Delphi-BWM highlight the dominant influence of technical criteria, particularly solar irradiation, and wind speed. Environmental and socioeconomic factors play a secondary but complementary roles in the siting process. The derived weights are standardized and processed within a GIS environment using the weighted overlay analysis to generate composite spatial suitability maps showing areas with highest potential for hybrid renewable energy deployment.

The analysis depends on the quality and spatial resolution of the spatial datasets as well as expert judgement, which may introduce inherent subjectivity. Nonetheless, the findings will prove how geospatial analysis can significantly improve the strategic planning of low-carbon energy systems. The proposed method will provide policymakers, energy planners, and other stakeholders with a scalable decision-support tool to accelerate renewable energy expansion while ensuring grid integration and sustainable land use. This research is important for Kenya's energy transition goals and global decarbonization efforts by showing how spatially optimized hybrid renewable energy systems can promote clean energy development pathways and thus supporting long-term carbon neutrality strategies.