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Benchmarking Renewable Energy Systems using DEA Methodology

Brooklyn Tremblay*

Department of Renewable Energy Economics, University of British Columbia, Vancouver, Canada

Introduction

As the global urgency for sustainable energy solutions accelerates, benchmarking renewable energy systems has become an essential tool for policymakers, utility providers and researchers. The growing reliance on renewable sources such as solar, wind, hydro and biomass necessitates precise evaluation methods to determine their efficiency, sustainability and adaptability across different regions and operational contexts. Among various analytical techniques, Data Envelopment Analysis (DEA) has emerged as a powerful non-parametric method used to assess the relative efficiency of Decision-Making Units (DMUs) like energy plants, national renewable portfolios, or regional energy initiatives. DEA is particularly advantageous for handling multiple inputs and outputs without requiring a pre-defined functional form, making it suitable for evaluating the performance of complex renewable energy systems. By offering insights into best practices, DEA helps identify underperforming units and guides strategic improvements, thereby optimizing energy resource utilization, reducing environmental impact and supporting evidence-based energy policy formation [1].

Description

The DEA methodology operates by constructing an efficient frontier composed of the best-performing DMUs based on input-output analysis. Inputs typically include capital investment, land use, labor and operational costs, while outputs might measure generated electricity, emission reductions, or overall energy conversion efficiency. A DEA model input-oriented or output-oriented then determines how efficiently each unit converts its resources into desired results. In the context of renewable energy systems, DEA has been employed to benchmark various technologies across countries or regions, revealing which energy systems are maximizing performance under similar resource conditions. For instance, a solar farm in Germany and a similar facility in India may be compared not only in terms of kilowatt-hours generated but also their land efficiency, cost-effectiveness and carbon footprint. These evaluations help stakeholders pinpoint inefficiencies and adopt innovations from top performers, whether through better technology integration, improved management, or optimized policy support.

In practice, DEA enables comparative analysis across time periods (static or dynamic models), accommodating environmental and operational variables. For example, dynamic DEA models are used to assess how renewable systems evolve over time with technological progress and policy shifts. Researchers and government agencies often use DEA to inform investment decisions, prioritize R&D funding and design performance-based incentive mechanisms. Moreover, hybrid approaches that combine DEA with other tools like Life Cycle Assessment (LCA), Analytic Hierarchy Process (AHP), or machine learning enhance its predictive power and practical relevance. The growing availability of high-resolution energy data has further expanded DEA's utility, allowing for more accurate and localized benchmarking of microgrids, rural energy systems and off-grid renewable solutions. Thus, DEA is not only a benchmarking tool but also a strategic framework to support the global transition toward sustainable energy futures [2].

Conclusion

Benchmarking renewable energy systems using DEA methodology provides a robust, data-driven approach to assess and enhance the efficiency of sustainable energy production and distribution. By identifying best-performing systems and uncovering areas of inefficiency, DEA supports evidence-based improvements and policy interventions tailored to regional needs. Its flexibility in handling diverse energy scenarios and integration with advanced analytical tools makes DEA a valuable asset in driving forward the global renewable energy agenda. As the world continues to navigate the complexities of energy transition, DEA stands out as a vital instrument in ensuring that renewable energy systems are not only sustainable in theory but also optimized in practice.

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Conflict of Interest

None.

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***Address for Correspondence:** Brooklyn Tremblay, Department of Renewable Energy Economics, University of British Columbia, Vancouver, Canada; E-mail: brooklyntremblay@ubc.ca*

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