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Sustainable Energy Planning: Flexibility, Governance and Resource Constraints

Pedro Cabrera [a], Rasmus Magni Johannsen [b] and Poul Alberg Østergaard [b*]

[a] *Group for the Research on Renewable Energy Systems (GRRES), Department of Mechanical Engineering, Universidad de Las Palmas de Gran Canaria, Campus Universitario de Tafira, 35017 Las Palmas de Gran Canaria, Spain*
[b] *Department of Sustainability and Planning, Aalborg University, Rendsburggade 14, 9000 Aalborg Denmark*

ABSTRACT

Volume 51 of the International Journal of Sustainable Energy Planning and Management. brings together six contributions addressing technical, economic, institutional and environmental challenges in sustainable energy transitions. The studies examine the provision of ancillary services through district heating technologies in Sweden, governance barriers to district heating decarbonisation in the Danube Region, and the role of household waste segregation in biogas-based energy systems in Indonesia. Two contributions focus on solar energy development in India, exploring the impacts of long-term climate variability on photovoltaic performance and the physical feasibility of solar-dominant net-zero pathways under land and critical mineral constraints. A further study evaluates the techno-economic and environmental performance of solar water heating in Fiji's hospitality sector. Collectively, these contributions highlight the importance of integrating operational flexibility, institutional capacity, resource availability, climate resilience and context-specific economic conditions into sustainable energy planning.

Keywords

District heating
Ancillary services
Sustainable energy planning
Energy flexibility
Energy governance
Solar energy
Bioenergy
Resource constraints

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1. Contents

Sustainable energy transitions require planning approaches that extend beyond technological feasibility and renewable capacity expansion. The contributions in this volume examine complementary dimensions of this challenge, ranging from operational flexibility and institutional coordination to resource availability, climate-related risks and investment feasibility. Together, they illustrate how the successful integration of renewable energy technologies depends on both system-level considerations and the specific conditions under which energy transitions are implemented.

District heating and energy system flexibility are recurring topics within the IJSEPM journal them due to

* Corresponding author e-mail: poul@plan.aau.dk

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the significance of the sector as a means to renewable energy integration through sector coupling. Less frequently, the short-term energy and electricity markets, such as markets for ancillary services, are featured in research in the IJSEPM. In this volume, Vilén et al.[1] analyse the role of district heating technologies in ancillary services for the electricity system, based on a case study of the Swedish energy system. The authors find that technologies such as heat pumps and combined heat and power plants can contribute with flexibility and ancillary services in a cost-efficient manner, although additional capacity expansions for the purpose of ancillary service provision are not cost efficient. This extends on prior work within the IJSEPM journal on economic incentives for flexibility district heating in the Nordics [2], where the existing markets conditions including tax and tariff design impact the investment decisions in district heating technologies. Further, a previous study explored how future Nordic electricity price levels influence district heating investment decisions, thereby affecting the deployment of electric boilers and thermal storage systems and the flexibility they can provide [3].

Beyond technological developments and system flexibility, the transition of district heating systems also depends on effective governance and stakeholder coordination. In this volume, Merza [4] examines the institutional barriers to district heating decarbonisation across eight countries in the Danube Region, combining evidence from 127 stakeholder survey responses, utility-level data and comparative assessments of national governance frameworks. The study identifies a recurring system-stakeholder mismatch, whereby the complexity of district heating systems exceeds the institutional capacity required to coordinate and implement their transformation. Despite the availability of decarbonisation technologies and funding opportunities, fragmented regulatory frameworks, limited planning capacity and insufficient stakeholder coordination continue to hinder implementation. These findings extend previous IJSEPM research by Kaiser et al. [5] , who demonstrate the value of participatory multi-criteria decision-making in municipal heat planning, while Vassallo and Kontu [6] highlight the operational and economic challenges associated with declining heat demand in Finnish district heating systems. Together, these contributions emphasise that successful district heating transitions require integrated planning that addresses technological, economic and institutional challenges.

Biogas is a good supplement to the energy system, providing a storable fuel to complement variable renewable energy sources. In this issue, H and colleagues address the availability of biogas substrate in Indonesia, investigation scenarios for household separation of organic waste streams. They find that separation is critical and that policy should address this [7]. Lybæk and Kjær previously demonstrated the important role of municipalities in the rollout of biogas [8] while Kurbatova assessed the economics of biogas production from animal waste in Ukraine [9].

Long-term renewable energy planning also requires consideration of how changing climatic and environmental conditions affect energy resource availability and technological performance. In this volume, Ojha et al. [10] investigate the impacts of solar irradiance, atmospheric aerosols, temperature and cloud cover on photovoltaic performance across six Indian states over the period 1990–2023. Combining satellite observations, meteorological reanalysis, photovoltaic performance modelling and statistical analysis, the authors estimate cumulative climate-related performance losses ranging from 10% to 21%, primarily associated with aerosol loading, irradiance changes and rising temperatures. Climate projections for 2040–2060 further suggest increasing risks to photovoltaic generation under high-emission scenarios. These findings complement previous IJSEPM research by Nassif et al. [11], who integrate spatial and projected climatic conditions into photovoltaic site selection in Iraq, and Ghosh et al. [12] , who examine the combined effects of climate change and air pollution mitigation on future photovoltaic potential in India. From a broader energy systems perspective, Cabrera et al. [13] further demonstrate how interannual renewable generation variability influences hydrogen production costs and storage requirements. Together, these studies highlight the importance of incorporating resource variability, environmental risks and flexibility requirements into long-term renewable energy planning.

Beyond climate-related performance risks, large-scale photovoltaic deployment also faces physical constraints associated with land availability and critical material requirements. In this volume, Akilesh and Damodaran [14] assess the feasibility of a solar-dominant pathway towards India's 2070 net-zero target by combining long-term electricity demand projections with estimates of photovoltaic capacity, land requirements and silver demand. Their analysis reveals substantial land and

mineral pressures under high-demand scenarios, identifying a land-mineral paradox in which more efficient photovoltaic technologies may reduce land requirements while increasing dependence on silver. These findings extend their previous IJSEPM research on the economic and geographical drivers of solar deployment in India [15] and complement the work of Putra et al. [16] , who explore agrivoltaic development as a means of reconciling renewable energy expansion with competing land uses. From a broader energy systems perspective, Déniz-Díaz et al. [17] demonstrate the importance of considering generation, storage and interconnection constraints when planning high-renewable transitions in emerging economies. Together, these studies underline the need to evaluate renewable energy targets against both physical resource limitations and wider system requirements.

Renewable thermal energy technologies can also contribute to reducing fossil fuel dependence in tourism-dependent island economies. In this volume, Kumar et al. [18] investigate the techno-economic and environmental feasibility of solar water heating in a representative 46-room hotel in Fiji, using RETScreen and the System Advisor Model to compare system performance and financial outcomes. The proposed system achieves a modelled solar fraction of 45.5%, annual energy savings of approximately 10 MWh and avoided operational emissions of around 3.5 tonnes of CO_2 per year. The estimated simple payback period increases from 7.7 to approximately 8.3 years when more conservative lifecycle assumptions are considered. Previous IJSEPM research by Bose et al. [19] examined the techno-economic potential of thermal energy storage for heat supply in tourist facilities, highlighting the relevance of occupancy and operational conditions, while Ferreira and Silva [20] developed a costing methodology for solar thermal systems considering collector sizing and storage requirements. These contributions emphasise the importance of site-specific demand, investment conditions and robust techno-economic assessment when planning renewable heating solutions for the hospitality sector.

Taken together, the contributions to this volume reinforce the multidimensional nature of sustainable energy planning. The studies on district heating demonstrate that technological flexibility and institutional coordination are both important for effective energy system transformation. Similarly, the analysis of biogas production highlights the relevance of resource management and local implementation conditions, while the contributions on solar energy reveal how climatic variability, land availability and critical material requirements can constrain long-term deployment strategies. The assessment of solar water heating in Fiji further illustrates the potential of context-specific renewable solutions to reduce fossil fuel dependence in energy-intensive economic activities.

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