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Editorial

Energy and Complexity

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Sustainable energy systems are complex sociotechnical systems with a social network of many players that "together" develop, operate, and maintain the technical infrastructure. No single player controls the system, but their actions are coordinated through a range of institutions—informal and formal rules—and regulations. As the control is distributed among actors, the overall system behaviour (at different time scales) emerges from operating practices and characteristics, from (dis)investment decisions, and from other aspects of the players' strategies.

A successful realization of sustainable energy systems depends on their societal acceptability, market dynamics, regulations, and the support of different stakeholder groups. To facilitate the introduction of flexibility sources like storage, demand-side response, flexible clean generation, and interconnections between different power systems, different sociotechnical designs have to be considered.

Sustainable energy systems require a complex, irreducible approach for design and operation and for robust what-if analyses. Essential aspects of the overall system behaviour or structure might be misunderstood or even overlooked if traditional methods continue to be applied; that is, methods which examine the connections between the heterogeneous parts and the whole system of systems are needed. Multidisciplinary research including engineering science, economics, political science, and behavioural science is needed to meet ambitions.

This special issue addresses recent advances regarding complexity in energy systems. From 10 submissions, 7 papers are published in this special issue. Each paper was reviewed by at least two reviewers and revised according to review comments. The accepted papers show that insights into the possible consequences of design choices and operational modes can be provided by engineering science, advanced modelling, and optimization techniques, but at the same time new market structures, organizational interactions, and institutional designs should be taken into consideration.

In the paper "Structural Evaluation for Distribution Networks with Distributed Generation Based on Complex Network," F. Xue et al. addressed challenges of the operation of distribution grid with a high participation of distributed generators (DG) and energy storage systems. They stressed that in the field of complex networks the performance and vulnerabilities of networked infrastructures are tightly related to the original topology and structural factors as positions of generation and load buses and capacities. However, when integrating distributed generating systems with distribution networks two perspectives should be taken into account: local perspective from individual viewpoint of DGs and global perspective from overall viewpoint of the original network. Case studies were used to illustrate the proposed Power-Supply-Ability metrics to identify potential structural vulnerabilities of distribution networks in general and the impact of DGs on security in particular. Also site selection for DGs can benefit from these metrics by providing evaluation of different location possibilities.

In the paper "A Stability Analysis of Thermostatically Controlled Loads for Power System Frequency Control," E. Webborn and R. S. Mackay investigated thermostatically controlled loads (TCLs) functioning as a flexible demand

resource with the potential to play a significant role in supporting electricity grid operation. The mathematical modelling and simulation study showed the short-term benefits of using identical TCLs for frequency response and discussed long-term issues indicating that a population of refrigerators might perform a valuable service to the grid without requiring centralised or stochastic control.

In the paper "Enabling the Analysis of Emergent Behavior in Future Electrical Distribution Systems Using Agent-Based Modeling and Simulation," S. Kolen et al. investigated emergent system behaviour of future electrical distribution grids and in particular cyber-physical interactions and communication through electrical lines as well as control systems. They developed an agent-based modelling and simulation tool DistAIX to be used for large-scale system analysis addressing the need for scalable capability to observe emergent behaviour that is vital for the development of decentralized control strategies.

In the paper "Sociotechnical Network Analysis for Power Grid Resilience in South Korea," D. A. Eisenberg et al. showed that to improve power grid resilience technological solutions to reduce the probability of losses are not sufficient. Policies and protocols for social processes should be taken into consideration, too. Case study of the Korean power grid illustrated that both technological and social analyses are needed to provide important information regarding power grid resilience, and both are necessary to avoid unintended consequences for future blackouts.

In the paper "Assessing the Plurality of Actors and Policy Interactions: Agent-Based Modelling of Renewable Energy Market Integration," M. Deissenroth et al. discussed to what extent and how growing participation of renewable energy sources (RES) should be integrated into energy markets with new regulations. They proposed an agent-based model to study the impact of changing energy policy instruments on the economic performance of RES operators and marketers. They concluded that changes in the political framework cannot be mapped directly to RES operators without considering intermediary market actors, the characteristics and strategies of these being an important factor for successful RES marketing and further deployment.

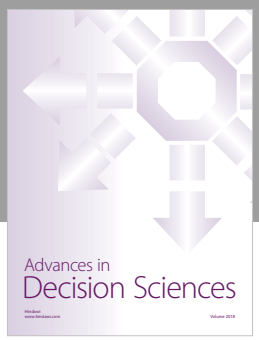
In the paper "Conceptualization of Vehicle-to-Grid Contract Types and Their Formalization in Agent-Based Models," E. H. Park Lee et al. looked at a specific application of fuel cell electric vehicles (FCEVs) which can be used as flexible power plants in future energy systems. Technical and economic feasibility of such an innovative concept should be accompanied by an institutional analysis. They investigate by agent-based simulation how different types of contracts, that is, price-based, volume-based, and control-based contracts, can be used not only for the benefits of car owners but also for balancing local energy supply in microgrids.

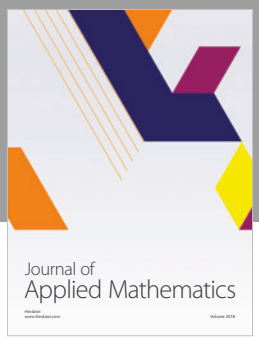
The paper "Creating Agent-Based Energy Transition Management Models That Can Uncover Profitable Pathways to Climate Change Mitigation" by A. Hoekstra et al. closes this special issue. The authors of the last paper presented a literature review comparing equilibrium models, system dynamics, and discrete event simulation with agent-based models to address general energy transition and climate change problems. Exploring these problems using agent-based modeling is often the most promising strategy as interactions between the global, national, local, and individual level can be taken into account.

The papers in this special issue represent exciting and insightful observations into energy problems from the complexity perspective. We hope that this special issue will attract attention to the many important opportunities for further research into complexity and energy and will function as a valuable resource to further develop the knowledge needed for energy transition.

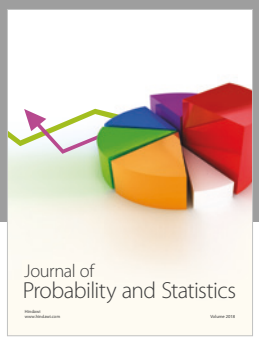
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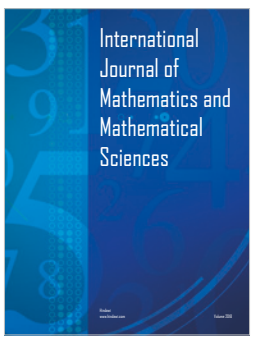








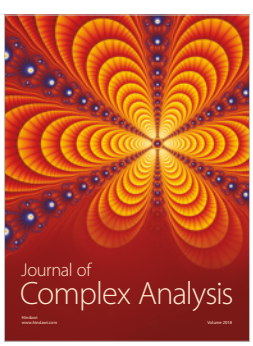


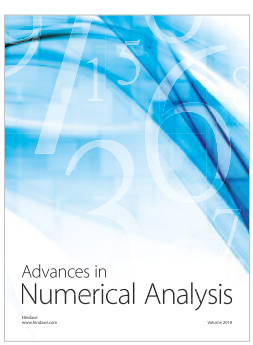


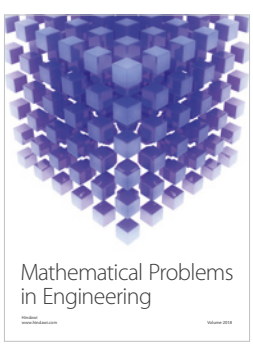




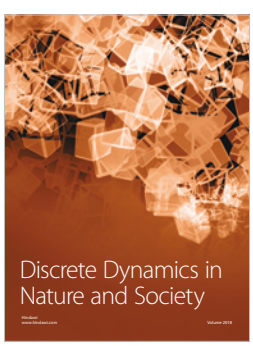




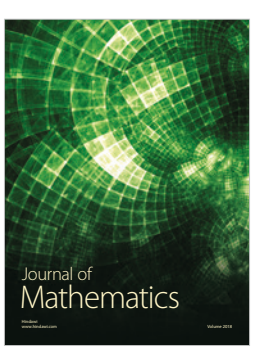




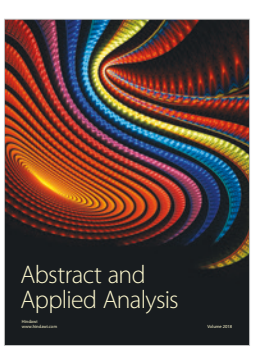


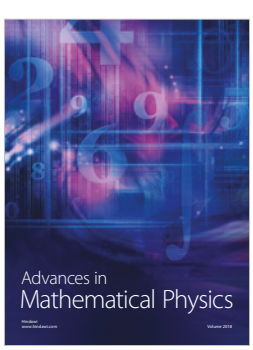












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