A TOY MODEL FOR DECENTRALIZED ENERGY SYSTEMS EVOLUTION

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Overview

Toward the development of sustainable energy systems, the majority of studies consider optimization models with a single objective function such as cost for design and policy making [1]. These models are flexible and allow to efficiently integrate solutions such as interregional energy trading and sector coupling [2], yet they do not capture the complexity of energy systems. As complex systems, energy systems are highly nonlinear and optimized through a process of evolution with the self-organization of actors from the bottom-up adapting to the system based on their own objective [3,4], which is in contradiction with the assumption of a centralized optimization process. This is further true considering the paradigm shift toward even more decentralized systems for the integration of intermittent renewable resources including peer-to-peer energy trading [5].

Considering the lack of a central mechanism for organizing the realization of sustainable energy systems designed by optimization, another approach is to study them through simulations that better capture their complexity, such as the recently emerging agents models [6], in order to identify the roots of issues, bifurcation or tipping points, and control strategies.

The objective of this study is to suggest a simple differential model for studying the evolution of such decentralized energy systems. Differential equations have long been used in other fields to model highly complex systems such as the evolution of biological and market systems [7,8], or the stability of power grids [9], exhibiting complex dynamics such as chaos from apparently simple models. They also benefit from a mature mathematical background regarding the stability analysis of their linear approximation unlike other metaheuristic models based on iterative procedures.

Methods

Considering the basic components of energy systems being energy supply, demand, price and cost, the problem is reduced to a simple differential supply model where the supplier of given energy resource adapts its supply capacity to fluctuations in the selling price, itself varying with the energy balance. The model is modified to have multiple suppliers or prosumers with bounded supply capacity, projections on their profit based on the price trend, and delay in the update of their capacity. The simulations are runned on Matlab using the ode45 solver for cases without delay, and the ddensd solver for cases with delay.

Results

The developed model captures the competition between suppliers and the evolution of their capacity, with suppliers having the lowest costs being selected. Depending on their supply capacity limit, the selected suppliers could evolve to occupy most of the market to the detriment of others, resulting in centralized systems.

Instabilities in the supply capacity can also be observed causing periods of over and under supply. It appears that these instabilities are amplified by the capacity update delay as observed in other supply-demand models such as the famous Cobweb model [10], but also that they are mitigated by the suppliers projections on their profit over longer periods, although the forecasting method considered is basic. This indicates that the supply capacity from non-professional suppliers who lack projection abilities in highly decentralized systems, such as household prosumers, could be unreliable for energy balancing.

Conclusions

The presented toy model captures the basic mechanisms of energy supply capacity evolution in a decentralized system of suppliers or prosumers trying to maximise their profit. If uncontrolled, suppliers with the lowest production cost may grow toward centralized systems. Furthermore, the capacity update delay and the projection ability of suppliers appear as important parameters for preventing supply instabilities which may cause a waste of capital and materials.

Although being extremely reduced, this model is general and flexible so that it can be adapted to more specific problems. Because of its simplicity, it may also be used for educational purposes. Future research directions include the consideration of storage technologies and a complete analysis of the model.

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