Mapping the challenge of renewable electricity market integration – Multi-scenario analysis with an agent-based electricity market model

Themenbereich 6 - Modellierung

Martin KLEIN[1(1)], Marc DEISSENROTH[(1)], Christoph SCHIMECZEK[(1)]
[(1)] Deutsches Zentrum für Luft- und Raumfahrt, Institut für Technische Thermodynamik, Abteilung Energiesystemanalyse

Motivation

Part of the difficulty in successfully conducting a model-based thought experiment is that the electricity system as the subject under investigation can be regarded as a complex system - many dependencies work in many directions, and many individual elements influence each other [1]. The art of modeling is to select which effects are viewed independently of each other and which effects are calculated endogenously in the model, i.e. are emergent from the model script. It is often unclear how the individual exogenous parameters *in combination* influence the results. One important task of energy systems analysis is to investigate this area of tension.

Methodological approach

Analysts employ various energy system models that study how to reduce emissions, secure supply and minimize costs. Agent-based modeling and simulation (ABMS) has been applied to a variety of research areas [2], including energy systems analysis [3]. The basic principle is to use software agents to encapsulate and combine the attributes and behaviors of real actors [4]. Here, we want to explore the analytical possibilities of an agent-based market model of the German electricity system [5] to study the aforementioned combination of influences in a structured way. The fast execution speed of our ABMS makes it possible to run the model with many parameter sets, to equate the result for each combination, and then to map them in one plot. As an example, we systematically vary solar photovoltaics (PV) and wind capacity for a possible future German electricity system and evaluate the overall system cost and CO_2 emissions for each run in a so-called *system cost map*.

Results and Conclusion

Figure 1 shows a system cost map. The visual representation is explained in the caption. The shape of the cost landscape allows us to make concrete statements about how emission reductions can be achieved in the energy system. Two measures stand out.
Firstly, an economic intervention would be to increase the CO_2 price. This would raise system cost in the bottom left of the graph, whereas the upper right part would be almost untouched, since in this region almost no electricity production is covered by conventional means that would be subject to CO_2 pricing. The rise of the CO_2 price would shift the cost minimum further to the right towards systems with higher shares of renewables as those would have comparatively lower system costs. Since CO_2 pricing nevertheless affects the entire remaining power plant fleet, the total system costs of such a system would rise. It would then be the task of the legislator to redistribute the revenue from such a CO_2 levy (be it a tax, a trading system or another measure) fairly.
Secondly, a technical way to move the system optimum further in the direction of lower emissions (upper right corner) is to make the system as such more flexible so that it can “absorb” higher renewable shares without them having to be curtailed, by means of storage, sector coupling or transmission. As such, more renewables could be integrated and the cost increase per additional GW of renewables would not be as steep. This would mean that the cost optimum would position itself further to the top-right in the graph.
To conclude, such fairly simple system cost maps can show at one glance both the potentials and the challenges of an energy system with high shares of renewable energy sources.

[1] Pfaffenwaldring 38-40, D-70568 Stuttgart, +49 711 6862-8239, m.klein@dlr.de, dlr.de/tt/system

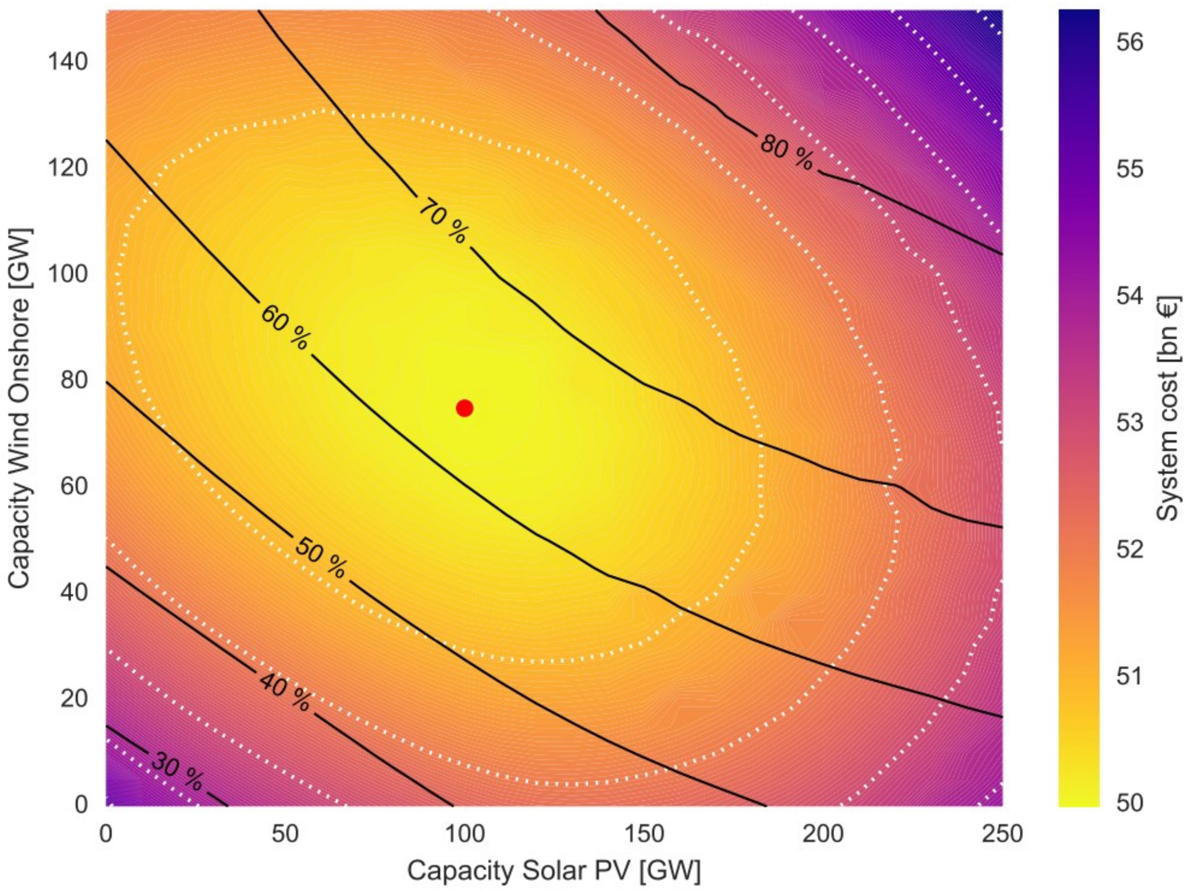

Figure 1: The x- and y-axis shows the installed capacity of PV and wind energy in GW, respectively. The colored area describes the system costs in billions of euros per year from yellow to violet. The red dot indicates the point in the landscape that has the lowest system costs. States that are 1 billion Euro away from this cost minimum are marked with the first concentric, dashed white line. These iso-cost lines mark system configurations that have exactly the same system costs. System states that are one billion euros more expensive follow with the next line, and so on. The black lines show emission reductions compared to the year 1990. All system states on a black line exhibit the same annual CO_2 emissions.

Literature

[1] C. S. E. Bale, L. Varga, and T. J. Foxon, “Energy and complexity: New ways forward,” *Applied Energy*, vol. 138, pp. 150–159, Jan. 2015.

[2] D. Helbing, “Agent-Based Modeling,” in *Social Self-Organization*, D. Helbing, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 25–70.

[3] A. Weidlich and D. Veit, “A critical survey of agent-based wholesale electricity market models,” *Energy Economics*, vol. 30, no. 4, pp. 1728–1759, Jul. 2008.

[4] C. M. Macal and M. J. North, “Tutorial on agent-based modelling and simulation,” *Journal of Simulation*, vol. 4, no. 3, pp. 151–162, Sep. 2010.

[5] M. Deissenroth, M. Klein, K. Nienhaus, and M. Reeg, “Assessing the Plurality of Actors and Policy Interactions - Agent-based Modelling of Renewable Energy Market Integration,” *Complexity*, vol. 2017, pp. 1–24, Dec. 2017.