# *EFFICIENT PATHWAYS FOR THE ENERGY TRANSITION BY SOFT COUPLING OF OPTIMIZATION AND SIMULATION MODEL*

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## Overview

We present the soft coupling of an optimization and an agent-based simulation model (ABM) in the field of energy sytems. The models' foci are on the electricity system and investment as well as operation of power plants and flexibility options like storage. The optimization model result yields a cost optimal system considering techno-economic parameters of the available technologies and assuming certainty of the whole system demand and supply at all times. Reality shows, that the state of the energy system is uncertain at any time as many different actors as well as environmental and technical factors are changing the state permanently. This gap between model results and reality should be narrowed to assure model based pathways as efficient as possible for the energy transition. Therefore we couple the optimization model with the ABM that allows to study behaviour of actors on the markets within a regulatory regime. An iteratively adjustment of both models' results leads to a cost optimized energy system that should be economically feasible for all actors. We present the soft coupling method and the model harmonization as mandatory basis for all following comparative analysis. Model inherent discrepancies and their impact on the results are demonstrated.

## Methods

The soft coupling of the optimization model E2M2 (Sun et al. 2008) with the agent-based simulation model AMIRIS (Nienhaus et al. 2014) is realized by an iterative approach, see figure 1. E2M2 is a fundamental linear and mixed integer electricity market model for Europe. During a model run, investment in power plants, flexibility options and the grid are calculated for one year on an hourly basis. The agent-based model AMIRIS maps actors as agents into the model and simulates their profits given the wholesale electricity market and the control power market as well as the German regulatory framework for the deployment of renewable energy sources (EEG). Both models use same scenario parameters that are independent of the model approach. These include variable costs, fossil fuel costs and technology parameters as well as the overall demand profile and renewable energy sources electricity generation. A first run of E2M2 determines the minimum cost function for the scenario, i.e. the ouput includes installed capacities, dispatch and hourly costs and the $CO_2$ certificate price. These data constitute the input of an AMIRIS run, that yields dispatch and wholesale market prices, the operation of plants and profit of actors. During model harmonization, the goal is to achieve same prices and dispatch to ensure a basis for comparative studies. For this purpose, flexibility options are switched off and a homo oeconomicus is assumed. Further, techno-economic parameters in both models like load, efficiency of power plants, variable O&M costs, specific $CO_2$ emissions, ETS price, fossil fuel cost and electricity generation from wind and solar radiation are aligned.

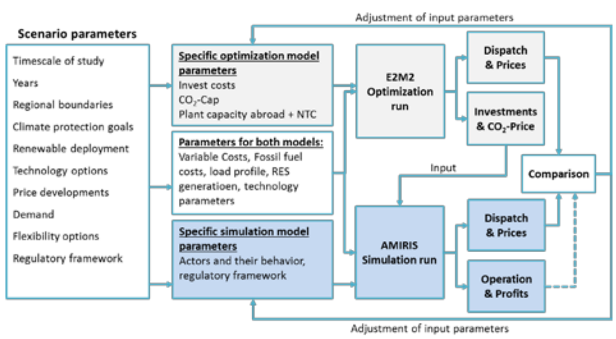


**Figure 1 Soft coupling of the optimization with the agent-based simulation model.**

Following the harmonization, storages are used for the optimization and for arbitrage opportunities on the wholesale market in the simulation. Whereas the optimization model assumes perfect foresight, the agent-based model assigns storage operation to actors with bounded rationality, i.e. the actors do not know the behaviour of the competitors and have to estimate prices for arbitrage.

## Results

The harmonization of both models is done by an alignment of techno-economic parameters, load and supply data and the assumption of a homo oeconomicus. We find very close results for residual load and dispatch of the power plants and the hourly electricity prices for both models are within a range of ±0.01 €/MWh, figure 2.

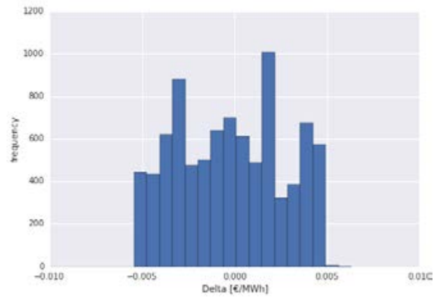


**Figure 2 Difference of output prices from optimization and simulation model for the harmonization run.**

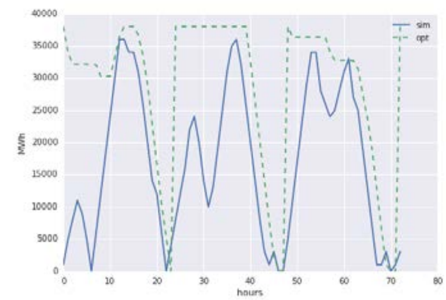


**Figure 3 Storage Dispatch of three days. Solid line shows result from simulation, dashed from optimization.**

For the study of flexibility options, storages are used in both models, losses during dis-/charge are neglected. The optimization assumes a foresight of 24 hours in which storage is used to reduce system costs. The resulting installed storage capacities are about 38 GWh with a power of 6 GW, which are equally distributed to six actors as input for the simulation model. In figure 3, three days of storage operation are compared, the solid line shows the sum of all six storages of the agent-based model. The simulation results reveal a more volatile operation of the storage, as the actors have bounded rationality and decide on their market price forecasts. Though they act under uncertainty and have to compete with other storage operators, each of the storage actors gains a yearly profit from arbitrage of about 3.5 M€.

## Conclusions

We showed a soft coupling approach of an optimization with a simulation model. The coupling requires a harmonized base data input, that is achieved by alignment of techno-economic data as well as RES electricity generation and load time series. The successful harmonization is gained under the assumption of the homo oeconomicus and the perfect foresight in the simulation model and is proven by nearly identical price output of the models. The calibration of two fundamental different models is an astonishing milestone for further comparative analysis. A first study of storage usage for minimizing overall system costs in the optimization and for arbitrage in the ABM model reveals discrepancies of the model concepts, as expected. Storages will be operated more volatile by actors than optimization results suggest. The actors gain money from arbitrage. Whether this is enough to balance cost from investment and operation has to be studied. Arbitrage is only one business case a storage can be used for. Others might be portfolio optimization or participation on the control power market. Next steps will be to apply these business cases to the actors and to estimate the effect of the regulatory framework on their profits. Decisions of power plant and storage operators are guided by regulations, e.g. legal requirements for curtailment, or by legal possibilities to participate on different markets. The regulatory framework therefore might determine success or failure of business models for flexibility options. In case no profitable business case can be found within a scenario, either regulations have to be adapted or an alternative scenario has to be optimized and analysed by the ABM iteratively. This way, efficient pathways for the energy transition can be identified.

## References


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