Back-testing the agent-based model AMIRIS for the Austrian day-ahead electricity market

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Abstract

The energy transition requires significant changes to current energy systems. Especially electricity markets are in the spotlight of policy-makers, investors, and researchers. This is due to the emergence of new market participants and innovative technologies disrupting the dominance of conventional power supply. Thus, we present the open agent-based electricity market model AMIRIS, which allows investigating current and future electricity systems. In this work, we apply AMIRIS to simulate the Austrian day-ahead electricity market prices. We use but freely available data in hourly resolution for the year 2019 and perform a back-test of the model with historical prices. The results show a high level of agreement of simulated results and historical data with regard to statistical characteristics (e.g. average price and price duration curve). However, AMIRIS tends to overestimate lower prices and underestimate higher prices. Also, AMIRIS does currently not include strategical bidding components and looking at the price time series, differences between the simulated and historical values are apparent. We conclude that the flexibility and the convenient parameterization of AMIRIS make it a powerful tool to assess today's and tomorrow's research questions in the field of energy economics. However, for deeper insights on the electricity market, further research is required to integrate bidding strategies of, e.g. energy storage system operators.

Keywords:

energy system modelling, agent-based modelling, day-ahead market, back-testing, Austria

1 Introduction

Electricity markets are an essential domain of energy systems. They play a crucial role in the allocation of resources and in financing the energy system actors. It is of high interest to modelers to understand the growing complexity of markets during the last decades [1]. Renewable energy technologies have entered the market. Market price dynamics changed along due to the high fixed but low variable cost and a fluctuating electricity generation of variable renewable power plants. The rising share of these technologies induces further changes to compensate for their variable electricity production potential, i.e. an increasing importance of flexibility options like energy storage systems or grid extensions. Therefore, powerful tools are necessary to understand current and future interactions of energy actors on the electricity markets. This understanding is essential for designing effective and efficient policy instruments and for investors to make profitable decisions.

The method of agent-based modelling (ABM) promises to account for these challenges by spotlighting agents' behaviour and their interactions with the environment [2]. However, comprehensive calibration and empirical validation of the model used is essential to account for robust simulations [3]. Detailed back-testing of models for the German day-ahead electricity market is carried out in [4], [5] concluding that ABM is in principle capable of simulating electricity prices. However, the Austrian electricity market is substantially different from the German one due to its already high share of renewables in the energy mix and its large capacities of hydro-storages [6]. This makes the Austrian electricity market an interesting and challenging case study to accurately simulate prices and market effects. Accordingly, we deploy the state-of-the art ABM AMIRIS to simulate day-ahead electricity prices for the Austrian market in 2019. We elaborate on AMIRIS' key features and use cases in Section 2. Subsequently, we describe the data used to run our calculations in Section 3. Section 4 presents the scenario results comparing simulated and historical price time series for the Austrian market, while Section 5 concludes this study.

2 AMIRIS

We rely on the **A**gent-based **M**arket model for the **I**nvestigation of **R**enewable and **I**ntegrated energy **S**ystems AMIRIS to simulate electricity markets. The model, which is extensively and consistently developed for more than a decade at the German Aerospace Center in Stuttgart, is based on the open framework FAME[1] and published under an open-source license[2]. FAME gives scientists great flexibility to design their models and removes tedious overhead tasks (e.g. connecting to inputs and outputs or parallel simulation execution) from the modelers' to-do lists. In AMIRIS, agents are represented in various types accounting for different actors of the electricity systems. Figure 1 represents a schematic overview of the current agent types and their interconnections, i.e. energy, money, and information flows.

At the model's core lies a representation of the day-ahead electricity market, where an hourly market clearing with uniform pricing is carried out [7]. Traders send their bids to the market after collecting relevant information such as fuel prices, CO_2 prices, and marginal costs from power plant operators. Markups and markdowns can be added by traders to account for non-convex costs [8], [9]. Neighbouring markets are implemented through time series of imports and exports, although a dedicated market coupling agent [10] will soon be available.

AMIRIS input data include power plants capacities, renewable energy generation, load time series, fuel prices, CO_2 prices, policy instruments and remuneration schemes, etc. A detailed description of these data used can be found in Section 3. Running AMIRIS on a standard laptop computer takes less than one minute and delivers day-ahead prices, power plant dispatch, market values, emissions, and system costs for an entire year in hourly resolution.

[1] https://gitlab.com/fame-framework

[2] https://gitlab.com/dlr-ve/esy/amiris

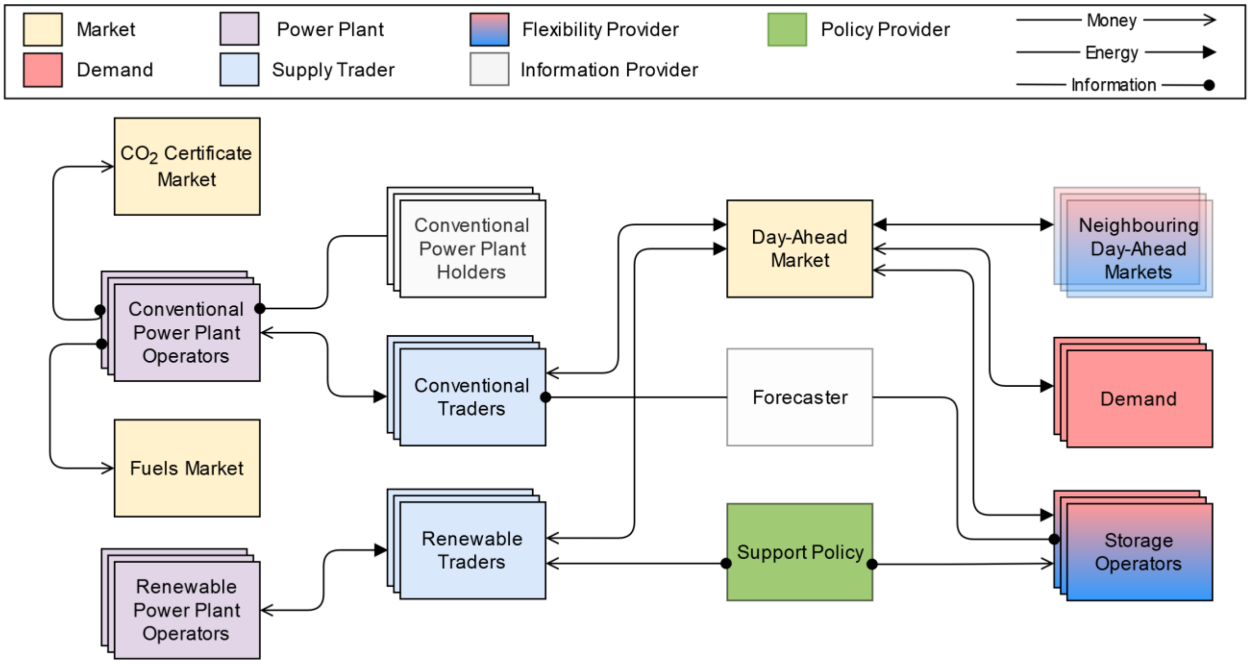

Figure 1: Schematic representation of the AMIRIS model structure

The model's versatility and its short runtime allow various analyses regarding refinancing potentials of renewable power plants [11], market effects caused by different remuneration schemes [12], economic assessments of individual actors such as battery storage operators [5], effects of cross-border electricity trading during extreme weather events [13], and economic potentials of demand response [14].

3 Data

Input data is essential for all modelling efforts. In order to guarantee reproducibility and transparency of our model results, we use the openly available data listed in Table 1. Information on power plant capacities in Austria for 2019 is derived from [6]. Several time series, such as renewable energy generation, demand, imports and exports were derived from that source. Prices and volumes of emission allowances were downloaded from [15]. Gas prices are taken from [16], while all other fuel prices are assumed to be constant, taken from [17].

Table 1: Input parameters to the ABM AMIRIS

	Parameter	Value	Unit	Source
Demand	Electric load	time series	MWh/h	[6]
Imports/Exports	Electric load	time series	MWh/h	[6]
Emission allowances	CO_2	time series	EUR/t	[15]
Fuel prices	Gas	time series	EUR/MWh_{th}	[16]
	Coal	5	EUR/MWh_{th}	[17]
	Oil	40	EUR/MWh_{th}	[17], own estimate
Capacities	Coal	264	MW	[6]
	Gas Turbine	1,208	MW	[6]
	Gas CC	3,260	MW	[6]
	Biomass	500	MW	[6]
	Oil	178	MW	[6]
	Pumped Hydro Storage	3,400	MW	[6]
Feed-in	Hydro Reservoir	time series	MWh/h	[6], own estimate
	Run-of-river	time series	MWh/h	[6]
	Waste	time series	MWh/h	[6]
	PV	time series	MWh/h	[6]
	Wind	time series	MWh/h	[6]
Specific emissions	Gas	0.201	tCO_2/MWh_{th}	[18]
	Coal	0.354	tCO_2/MWh_{th}	[18]
	Oil	0.264	tCO_2/MWh_{th}	[18]
Availabilities	Gas	97	%	[19]
	Coal	98	%	[19]
	Oil	93	%	[19]
Minimum and maximum efficiencies	Gas	30 – 60	%	own estimate
	Coal	40	%	[20]
	Oil	35	%	own estimate

Support instruments for renewable energies are parameterized by applying simplified feed-in tariffs from [21]. Power plant availabilities and their efficiencies come from [19] and [20], respectively. We test simulated prices against historical Austrian day-ahead prices, taken from [20].

4 Results

We back-tested simulated day-ahead electricity prices from AMIRIS against historical prices from the Austrian electricity market in 2019. Figure 2 shows price duration curves which are a good indicator of overall price levels. When looking at lower prices, AMIRIS does not exactly reproduce the data. Especially, no negative prices are modelled. This is a common problem in energy system models since negative prices do not stem from negative marginal cost but originate in strategic bidding and must-run conditions [22], [23].

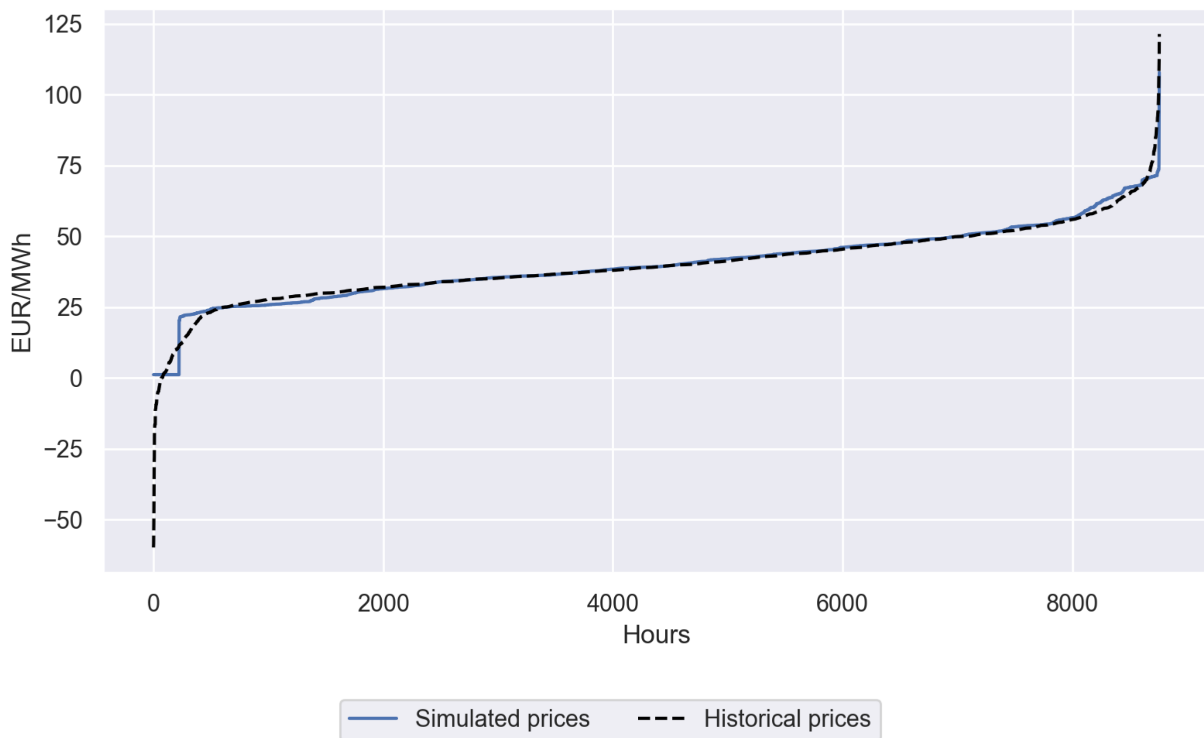

Figure 2: Comparison of simulated and historical day-ahead price-duration curves

A statistical summary of simulated and historical prices is provided in Table 2. Sample means, at $40.20\ \mathrm{EUR/MWh}$ in the simulation and $40.06\ \mathrm{EUR/MWh}$ in the historical time series are comparable. Standard deviations are also similar for both time series. Despite the good match of the historical and simulated price duration curves, the mean absolute error of the simulated prices is $8.06\ \mathrm{EUR/MWh}$ and the root mean squared error is $12.06\ \mathrm{EUR/MWh}$. The correlation of the two time series is 0.64 indicating that AMIRIS reflects the price function over time reasonably well. However, all three measures hint to non-negligible deviations between both time series not visible in the price-duration plot.

Table 2: Statistical summary of simulated and historical day-ahead prices in EUR/MWh

	Simulated	**Historical**
Mean	40.20	40.06
Std.	12.88	13.09
Min.	1.20	-59.78
25%	32.21	32.92
50%	39.34	39.21
75%	48.51	47.98
Max.	107.89	121.46

Figure 3 compares simulated and historical prices over the course of a full week in November 2019. Simulated prices mostly follow the typical daily pattern of historical prices with higher prices in morning hours and evening hours, and lower prices during the night. Deviations take the form of delayed price ramps (November 13th), missed price peaks (November 16th), or missed price lows (November 18th).

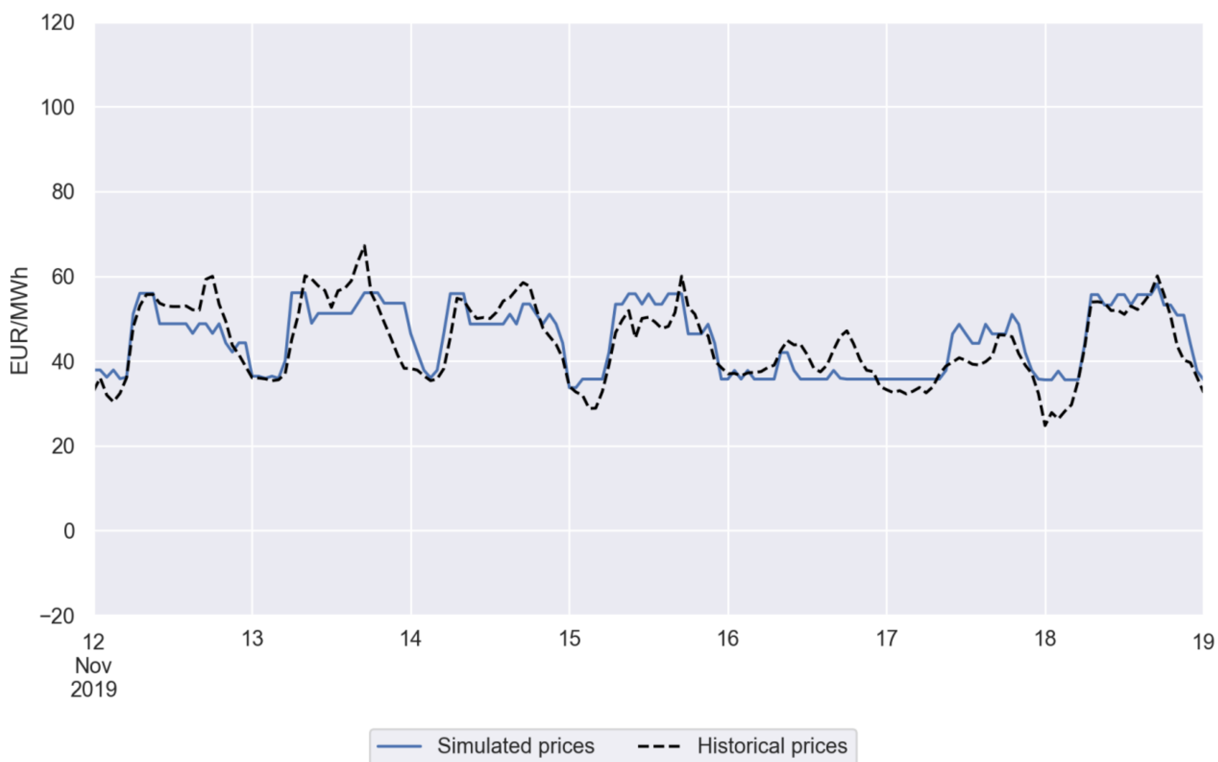

Figure 3: Detailed view on simulated and historical day-ahead prices in November 2019

Figure 4 shows a week in January 2019 which has an overall higher price level. The high spikes of historical prices from January 23rd–25th 2019 are not accurately reproduced by AMIRIS. Two modelling aspects of AMIRIS can explain this difference. Firstly, AMIRIS does not model situation-dependent pricing for conventional power plants. Thus, ramp-up costs and other strategic considerations are currently not reflected in the bids from traders. Real-world traders, however, consider ramp-up cost and opportunities for strategically higher bids. Secondly, AMIRIS employs an electricity storage dispatch algorithm that minimises system cost within a one-week time horizon. In Figure 4, this becomes apparent as higher prices on January 23rd and 25th are avoided, whereas the price level on the following days are slightly increased.

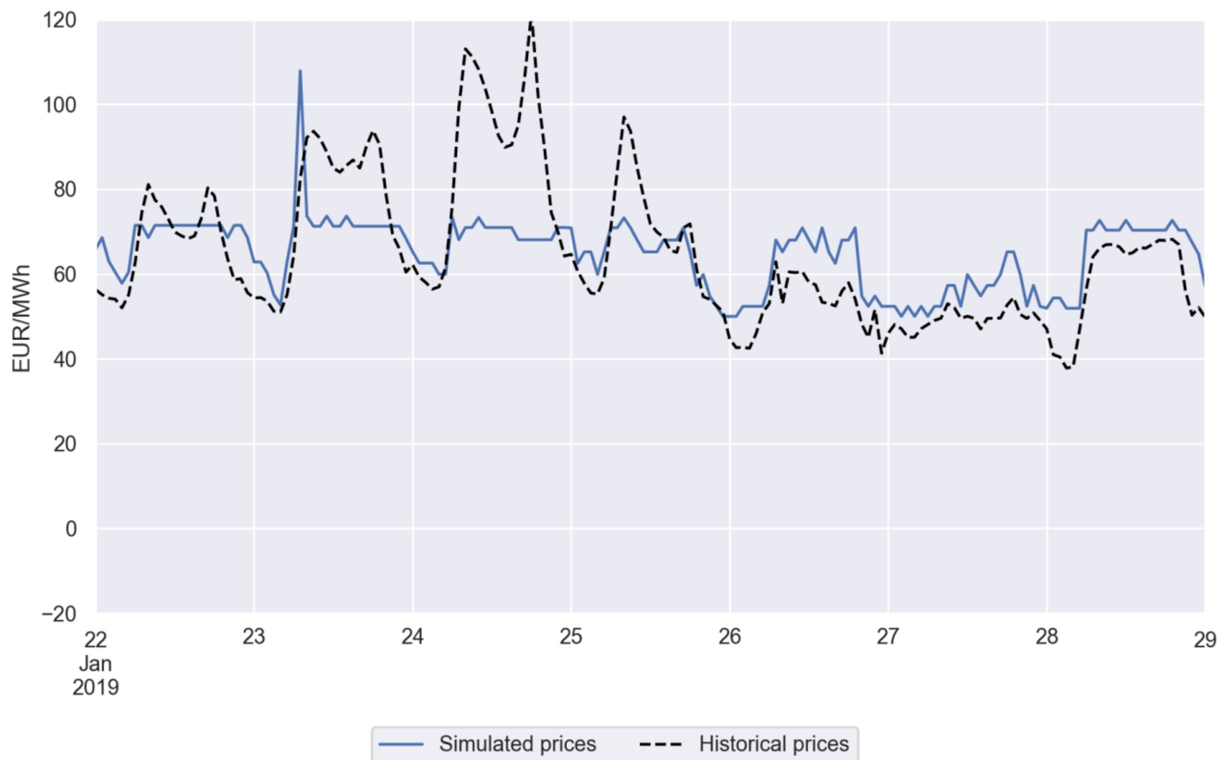

Figure 4: Detailed view on simulated and historical day-ahead prices in January 2019

This storage representation is particularly apparent in Figure 5, which shows a week in April 2019. The simulated prices stay relatively flat (April 26th & 28th–29th), whereas the historical prices show more fluctuation. This is accomplished by a perfect foresight forecast of the impact of storage dispatch on the system costs. Also, only a single flexibility agent is used that has full control over the electricity storage operation. Compared to the historical prices, the AMIRIS storage operator achieves less profit but significantly reduces price fluctuations due to its dispatch.

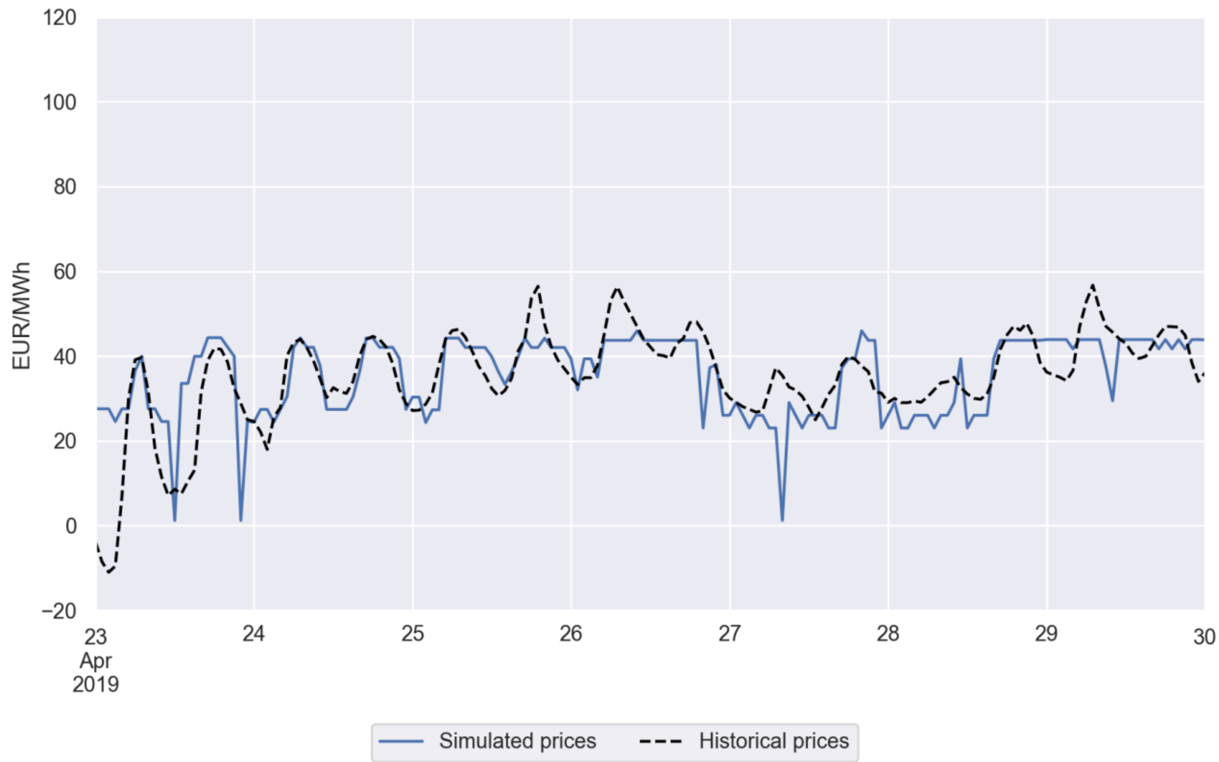

Figure 5: Detailed view on simulated and historical day-ahead prices in April 2019

When equipped with a strategy to maximise[3] its profits [24], the storage operator allows a wider spread of the electricity price. This effect can be seen in Figure 6 which shows the same time period as Figure 5 but with a profit-maximising storage strategy. As a result, the storage operator has better arbitrage opportunities, makes better profits, and the simulated prices on April 26th match the historical ones more closely. However, the storage operator is in full control of the storage portfolio again, using its market power to create very low prices in many other hours. Therefore, accounting for the whole simulation period, the profit-maximisation strategy leads to significantly less correlation with the historical price than with the system-cost minimising strategy.

[3] Feature is in preparation for open source publication.

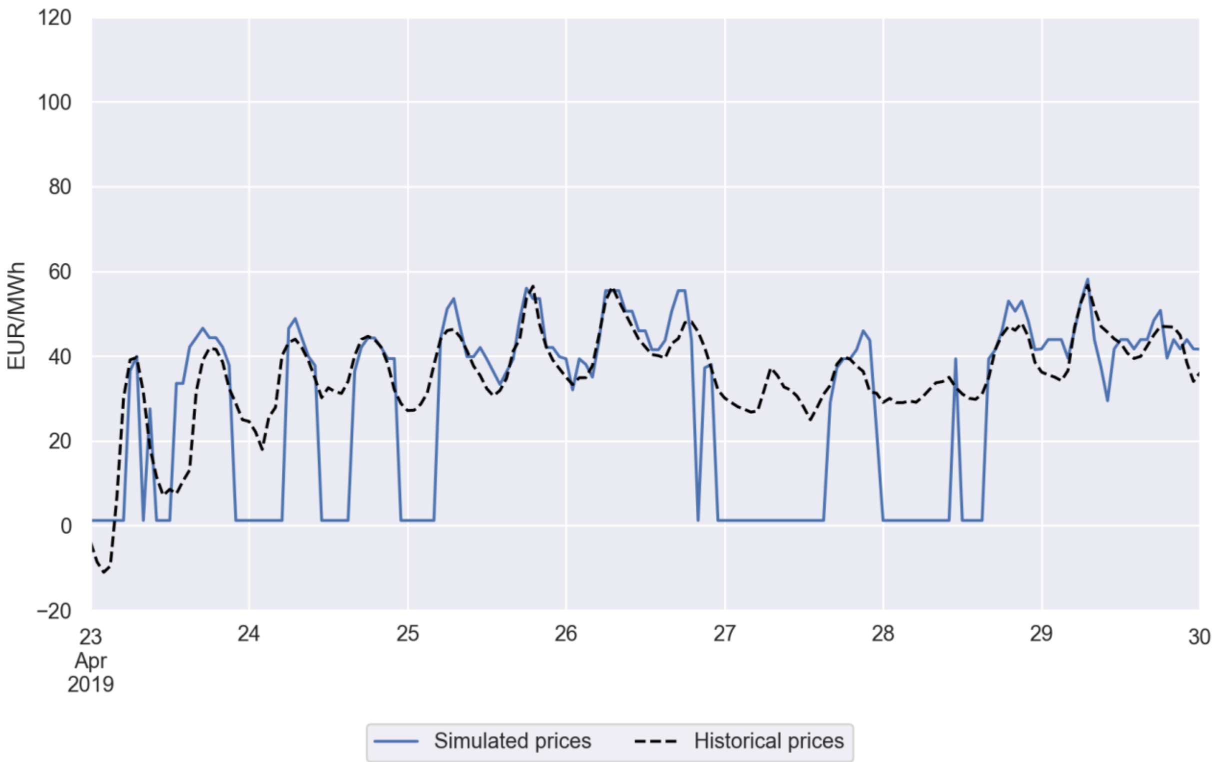

Figure 6: Detailed view on simulated and historical day-ahead prices in April 2019 in an additional run where the storage operator aims at maximizing its profits

A current limitation of AMIRIS is the simultaneous modelling of multiple flexibility options and accounting for their competition. This requires improvements in the price forecasting mechanisms and the implementation of more comprehensive strategies considering actions of other flexibility options. Machine learning methods prove to be a promising approach to address this issue [25], [26].

When parameterized in an even higher level of detail (e.g. endogenous modelling of neighbouring countries, more comprehensive representation of competition, more detailed remuneration of renewable energies), we expect to improve the goodness of fit. It is shown in [4] that ABM is a powerful method to simulate the integration of renewable energies in the German electricity market. AMIRIS was parameterized for the German market in [5], and yielded a high goodness of fit between simulated and historical prices, with a coefficient of correlation of 0.81. The brief examination in this work demonstrates that AMIRIS is also capable of simulating the Austrian electricity market, albeit with a slightly less goodness of fit.

5 Conclusion

We presented the agent-based electricity market model AMIRIS and demonstrated its capabilities to model the Austrian electricity market. For this purpose, we described the model architecture and the different agent types. Parameterized with open access data we simulated prices of the Austrian day-ahead electricity market and back-tested them against the historical price time series. Our resulting prices have a reasonable quality regarding a statistical assessment of mean, median and quartiles. Price duration curves match well. As many electricity system models, AMIRIS has difficulties accounting for negative prices. This, however, is affecting only a minor amount of the total hours in the simulation run. Therefore, we conclude that AMIRIS is a flexible and powerful tool to model current electricity markets. As described, it is applied in a wide range of projects and scenarios. To further improve the goodness of the model fit for the Austrian electricity market we suggest to extend AMIRIS to include strategic bidding effects for flexibility options (e.g. electricity storage) and renewable power plant marketers.

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