Contribution ID: **101** Type: **not specified**

A probabilistic merit order for electricity price forecasting

Friday 27 March 2026 14:30 (20 minutes)

Introduction
Electricity price forecasting has become increasingly complex due to the growing integration of renewable energy sources, whose weather-dependent generation introduces significant volatility and non-linear dynamics into power markets. Probabilistic forecasting is essential in this domain because the uncertainty itself evolves over time, periods with high renewable generation exhibit different price distribution characteristics compared to conventional generation-dominated periods. This is particularly evident in markets like Germany, where abundant solar generation in summer creates **bimodal price distributions** (with one mode near zero during high PV output and another around 90 EUR/MWh during conventional generation periods), while winter months typically show unimodal, positively skewed distributions with frequent price spikes. Traditional point forecasts fail to capture these complex distributional dynamics, leaving market participants exposed to significant financial risks.

State of the art
Current approaches to probabilistic electricity price forecasting fall into two main categories: data-driven statistical methods and fundamental models. **Data-driven approaches**, including prediction intervals, quantile regression, distributional forecasting (e.g., GAMLSS with Johnson's SU distribution), and ensemble methods, effectively capture statistical patterns from historical prices but lack interpretability and causal structure. **Fundamental models**, which simulate market mechanisms through merit-order curves, offer strong interpretability but have traditionally been deterministic or limited to few predefined scenarios, failing to comprehensively represent uncertainty. This gap represents a critical limitation, as electricity price formation depends on multiple stochastic inputs including renewable generation (driven by volatile weather conditions), electricity demand (with behavioral patterns), fuel prices (subject to politico-economic events), and power plant availability (affected by maintenance and outages).

Novelty
We propose the **first fully probabilistic fundamental model for electricity price forecasting** that bridges this divide. Our framework **explicitly captures individual uncertainty sources** by fitting probabilistic distributions to all key drivers: load, renewable generation (PV, onshore and offshore wind, hydro), fuel prices (gas, coal, oil), CO_2 prices, and available capacities across all generation technologies. Unlike previous approaches, we model each input's full conditional distribution using a recursive GAMLSS-type framework, with LASSO regularization enabling efficient online updates. Crucially, **we preserve dependencies between inputs** through an empirical copula approach with a 365-day rolling window, capturing important correlations such as those between onshore and offshore wind generation.

The core innovation lies in integrating these probabilistic inputs into a fast fundamental merit-order model. For each time point, we sample from the joint distribution of all input variables and feed these samples into a merit-order calculation that constructs supply stacks from marginal costs of available generation technologies. The model computes lower and upper marginal costs for each technology based on sampled fuel/CO_2 prices and expert-estimated efficiency parameters, then constructs individual supply curves that are properly aggregated (accounting for overlapping cost ranges) before intersecting with sampled demand to determine prices. **This process generates multiple realistic price scenarios per hour, creating non-parametric predictive distributions that naturally reproduce complex market phenomena including multimodality, price spikes, and regime shifts between high- and low-renewable conditions**.

Data

Our model is calibrated to historical German market data (2018-2025) to maximize probabilistic forecast accuracy, measured by Continuous Ranked Probability Score (CRPS). Results demonstrate significant improvements over benchmark methods. The model successfully captures seasonal distributional shifts without requiring parametric assumptions about the output distribution. Calibration plots confirm reliability across all input variables.

Summary
This work makes three key contributions:
(1) explicit probabilistic modeling of all fundamental price drivers with dependency preservation via copulas;
(2) integration of these distributions into a computationally efficient merit-order framework that generates realistic price scenarios while maintaining causal interpretability; and
(3) data-driven calibration that optimizes probabilistic forecast skill.

The resulting framework retains the transparency and causal consistency of fundamental models while providing comprehensive uncertainty quantification, enabling market participants to assess tail risks, optimize bidding strategies, and manage financial exposure in increasingly volatile electricity markets. By bridging the gap between fundamental and statistical approaches, our methodology establishes a new paradigm for interpretable, uncertainty-aware electricity price forecasting that can be readily extended to other energy markets undergoing similar energy transitions.

Author: GHELASI, Paul (Universität Duisburg-Essen, House of Energy, Climate and Finance)

Co-author: Prof. ZIEL, Florian (Universität Duisburg-Essen, House of Energy, Climate and Finance)

Presenter: GHELASI, Paul (Universität Duisburg-Essen, House of Energy, Climate and Finance)

Session Classification: Electricity Price Formation & Forecasting