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Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Understanding bidding behavior in the electricity spot market:

an empirical study of European Markets in 2022

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ABM4Energy Conference 2025

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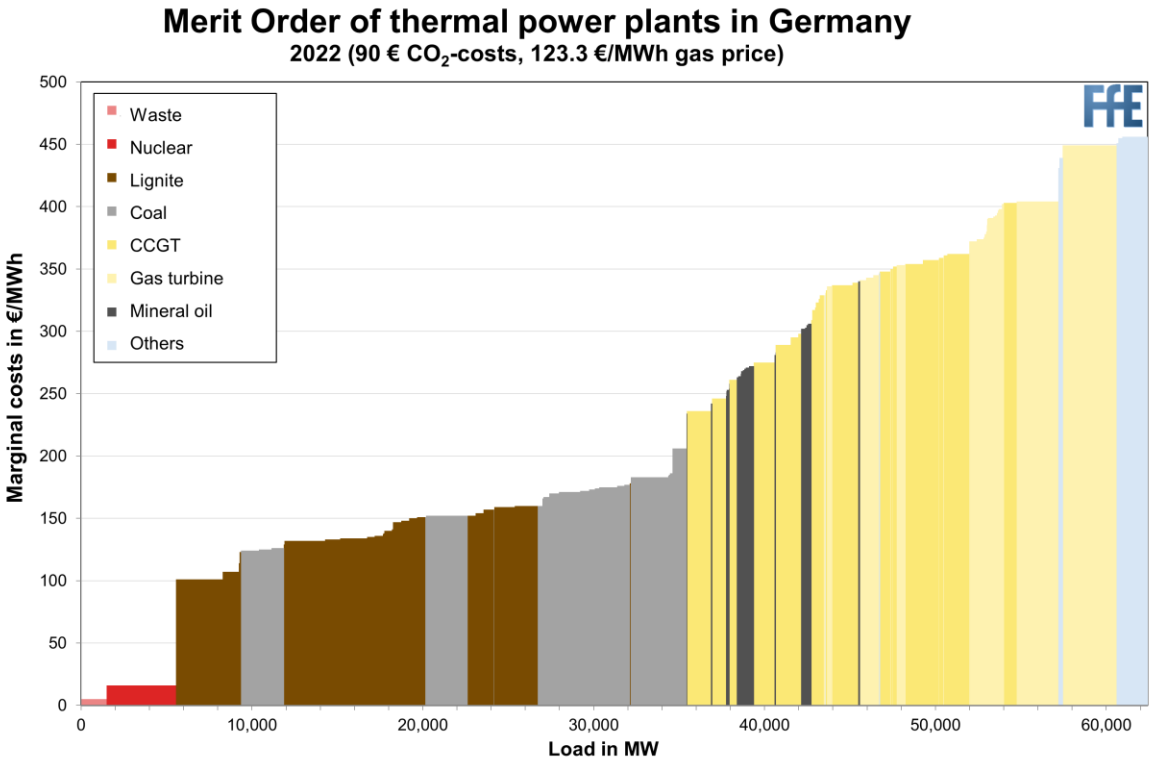
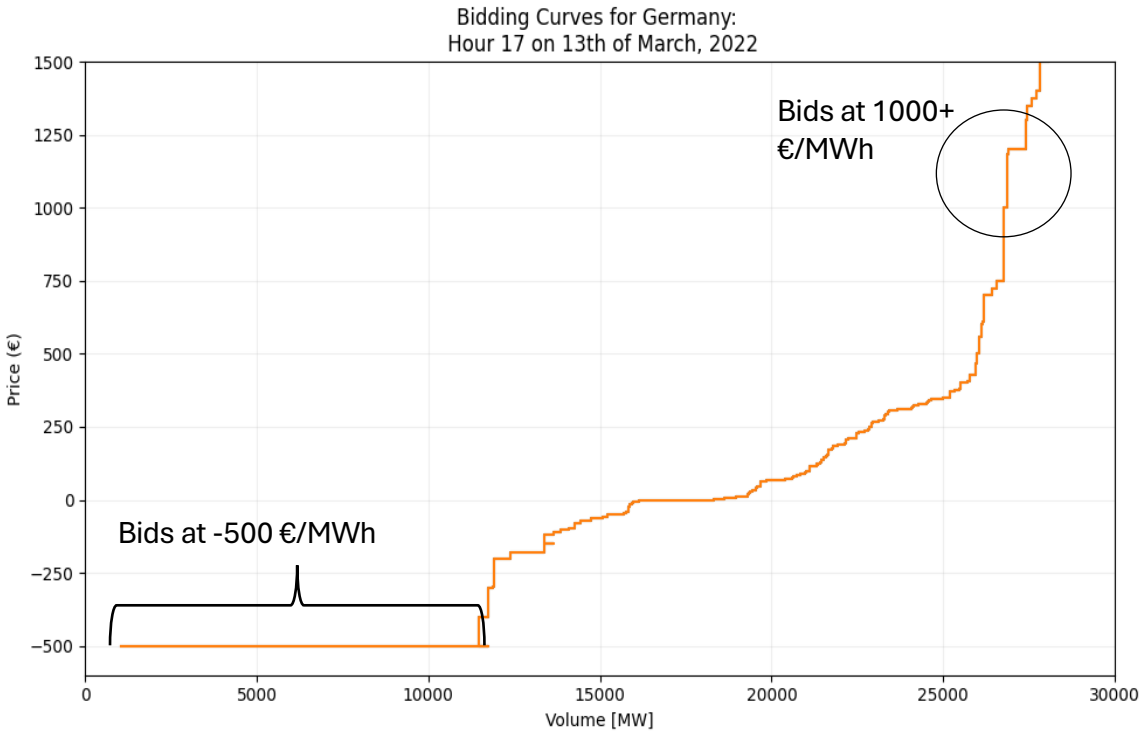
Introduction

Models assume bidding according to Marginal Cost



Theoretical MC-based supply curve from [1]

Empirical bidding is significantly different:



Empirical Bidding Curve for Hour 17 for the 13th of March 2022, Germany

=> Can we understand **Empirical Bidding** better?

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Research Questions & Goals

1. Define *Expected* bidding behavior
   - What is regular empirical bidding like?
   - How is this influenced by market drivers?

PART 1: Clustering of Curves

2. Investigate bidding *Anomalies*
   - What deviations from this expected bidding do we observe?
   - What drives such deviations?

PART 2: Anomaly Detection

1. Understand **Expected bidding** and **Deviations from empirical data**
2. Define the empirical bidding of realistic actors
3. Implement in spot market models (ABM/…?)

Our Study

Contribute to ABM?

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Methodology (1) – Clustering

- Cluster similar curves => based on **shape,** following methodology of [2]
- Area * weights at each price

⇒**1 distance value** per pair of N curves

- Weights ~ Frequency of bids at each price
- NxN Distance matrix => *Hierarchical Clustering*
- Calculate mean driver data per cluster

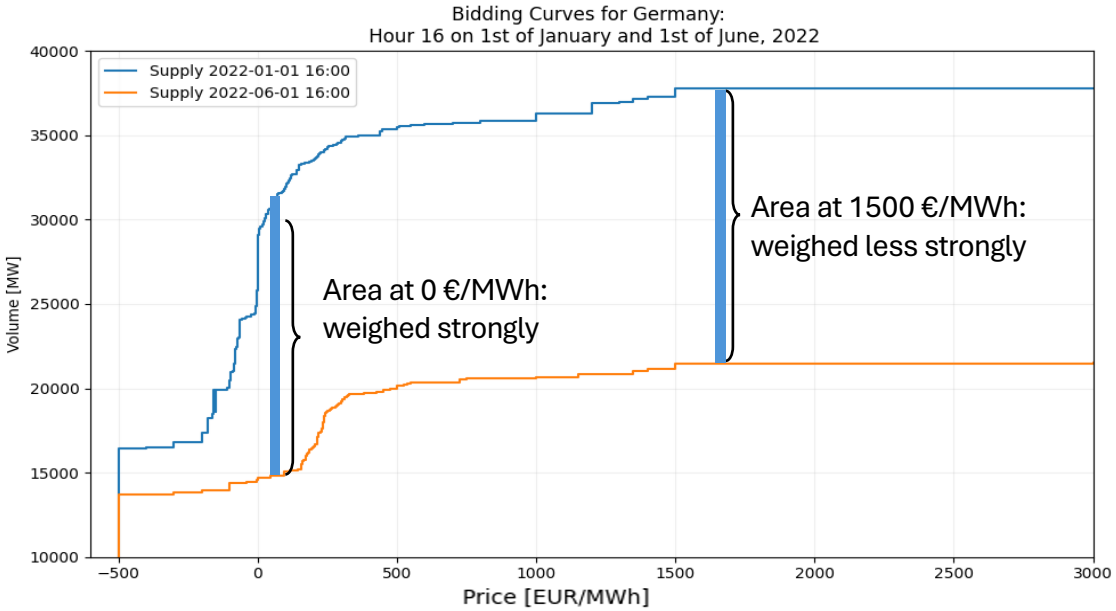
=> Relate *Expected* bidding curves per cluster to the driver data per cluster

Use Case:

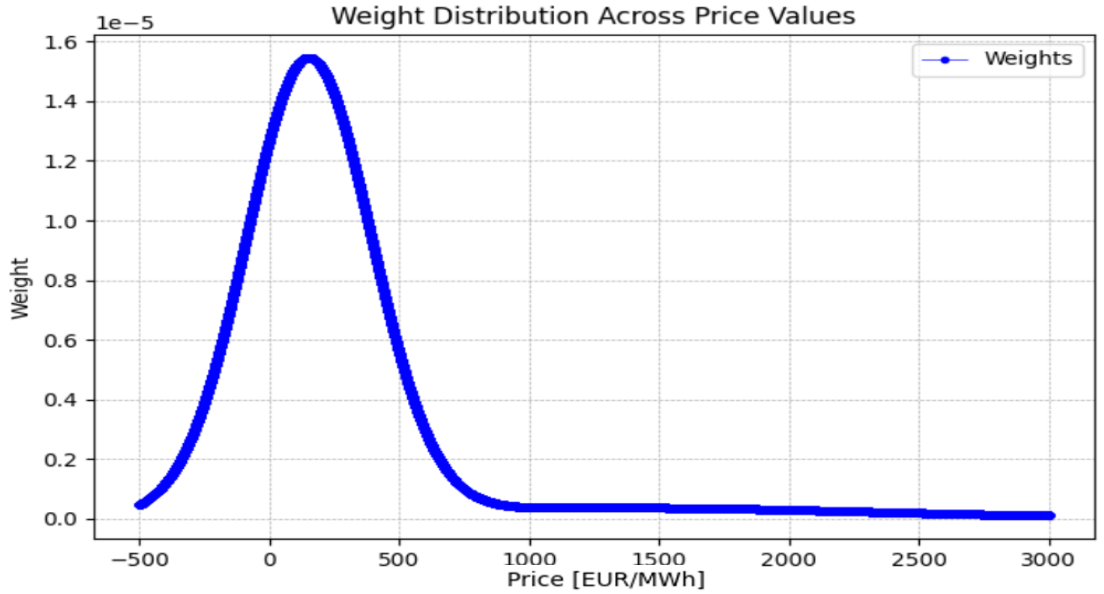
- 2022: Energy Crisis/War

=> Interesting year to test Method

8760 Aggregated bidding curves from EPEX Spot [3]



Method to determine inter-curve distances



Clustering weights applied at each price

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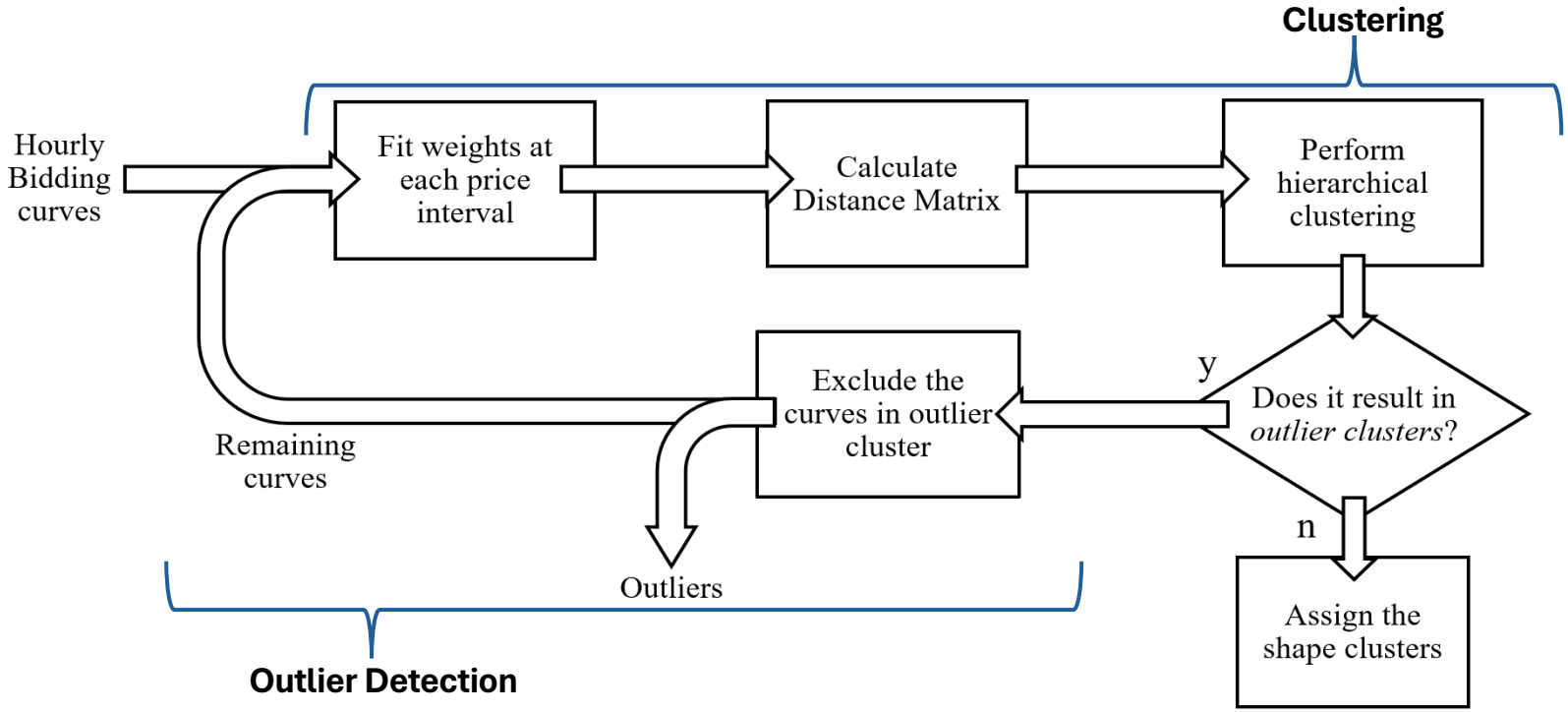
Methodology Anomaly Detection (1) - Outliers

1. *Hierarchical Clustering*: groups alike curves
2. Creates extremely small cluster? => Indicates **curves deviate significantly from all other curves**
3. *Outliers* are excluded, clustering reiterated

=> Until **No more Outliers found, large bidding curve clusters remain**



Methodology to generate clusters and detect outlier clusters

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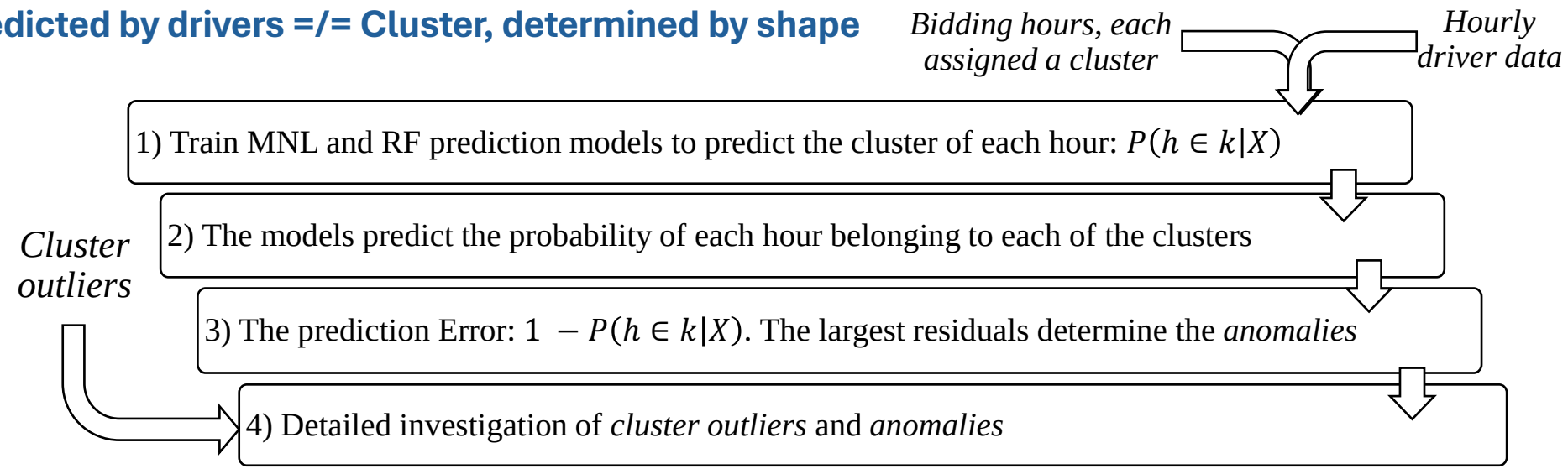
Methodology Anomaly Detection (2) – Cluster Prediction

- Every hour is assigned a Cluster
- **What if driver data X_h deviates from other hours in cluster?**
- Predict Probability P that hour $h \in$ Cluster (k) based on X_h
  1. MultiNomal Logit (MNL) model
  2. Random Forest model
- X_h = Hourly driver data:°C, Load/Generation forecast, VRE, Fuel prices[1]
- Prediction Error defines *Anomalies*:

$$P\left(\hat{Y} = k \mid X\right) = \frac{e^{-\beta_k^T X}}{\sum_{j=1}^{K} e^{-\beta_j^T X}},$$
$$for\ k = 1, 2, \ldots, K$$

MNL Prediction Model

Cluster, predicted by drivers =/= Cluster, determined by shape



Methodology to determine Anomalies

[1] *Data from Entso-E [4]*

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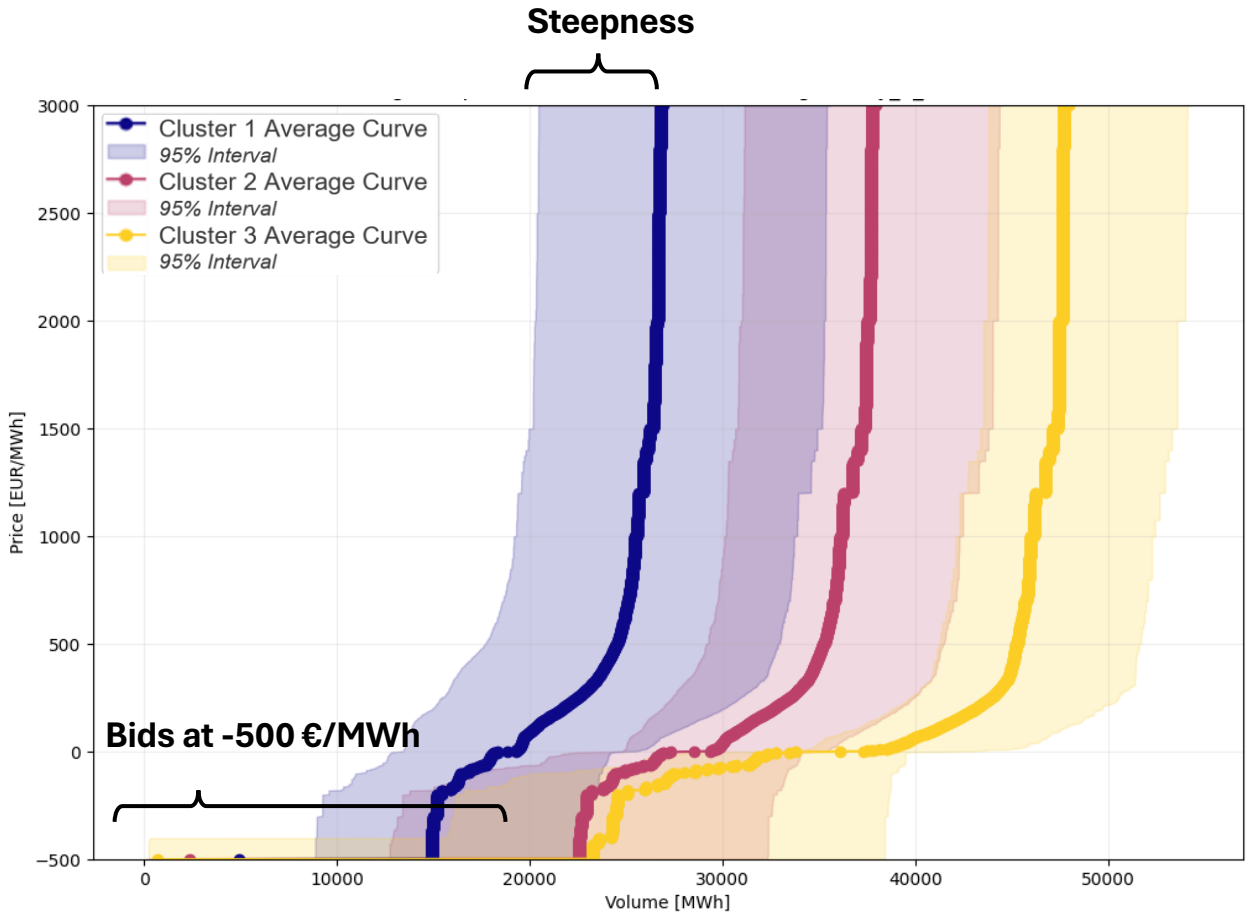
Case Study: Germany 2022

- **3 Clusters**
- Cluster 1 – Cluster 3 differ in:
  - *Bids at minimum price*
  - *Steepness of curves*
- Driver Data:
  - *Cluster 1: Low VRE*
  - *Cluster 2: Moderate VRE*
  - *Cluster 3: High VRE*
- VRE determines the *expected bidding* curves in Germany
- Belgium: very similar findings.
- Denmark1: Wind is the only differentiator between Cluster:

=> Significance of Wind vs Solar in driving bids depends on capacity in zone



	Temp. °C	Solar MW	Wind MW	Generation MW	Load MW	Price €/MWh	Gas €/MWh	Oil €/kBarrels	Coal USD/t	Carbon €/tCO2
Cluster 1	8.86	3096	12100	53541	54992	264.5	136.0	46.7	290.8	80.7
Cluster 2	14.39	14758	17713	63808	60205	181.4	126.5	46.0	288.7	82.5
Cluster 3	13.09	14322	29260	66954	56812	44.3	100.6	45.0	272.7	83.7

Average Curves and driver data for the three clusters of the German Market, 2022

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Results (2) – Outlier Anomalies Germany

20 Outliers detected for Germany

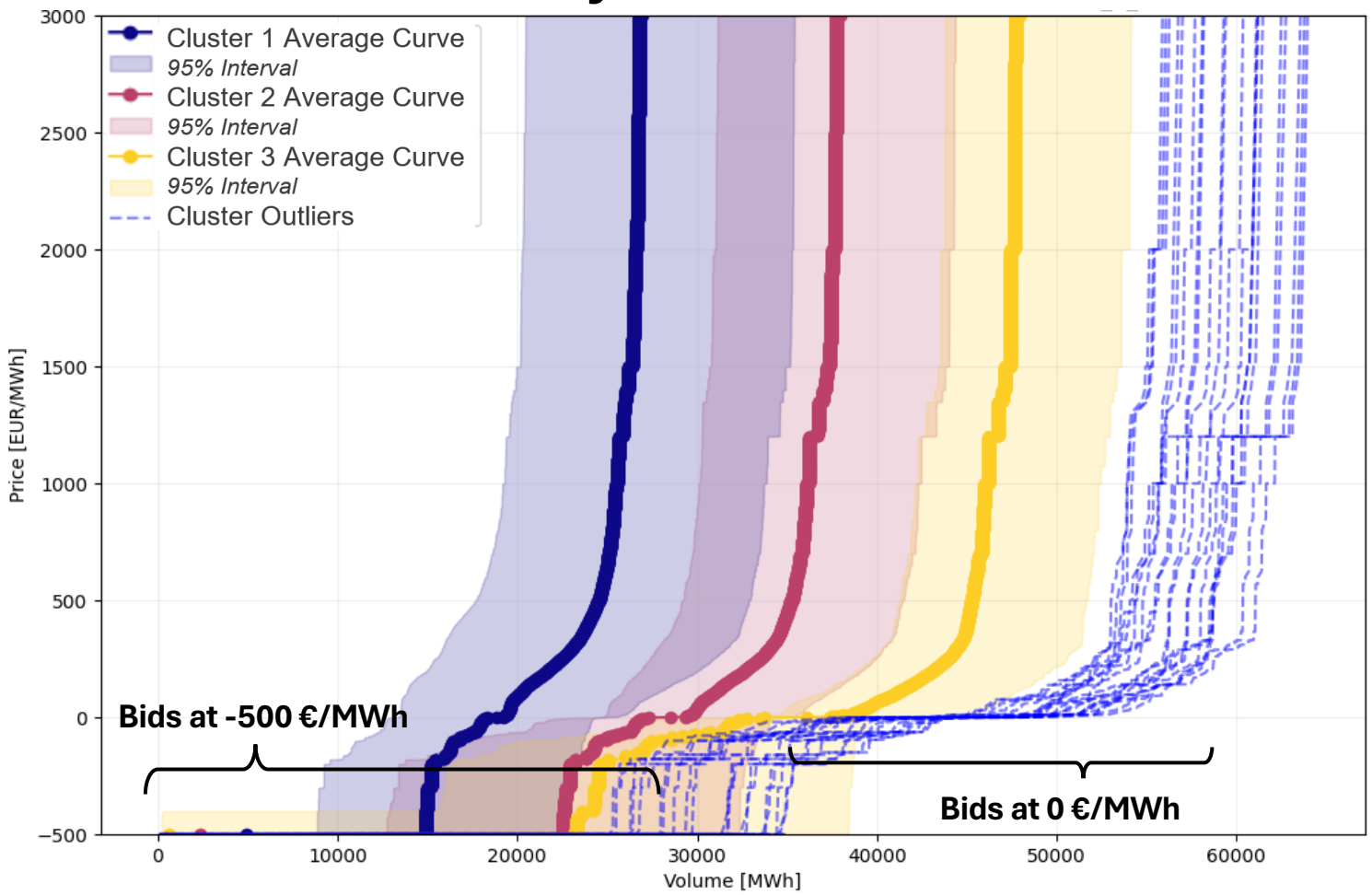
- Very high volumes at -500€/MWh
- Very high volumes at 0 €/MWh

Driver Data:

⇒ VRE exceeds Cluster 3 means

⇒ Extreme Wind + Solar hours

Extremes in Renewables causes extremes in bidding



	Temp. °C	Solar MW	Wind MW	Generation MW	Load MW	Price €/MWh	Gas €/MWh	Oil €/kBarrels	Coal USD/t	Carbon €/tCO2
Cluster Outliers	11.79	21397	33325	70740	57135	-3.2	90.3	44.9	287.1	83.3
Cluster 3	13.09	14322	29260	66954	56812	44.3	100.6	45.0	272.7	83.7

Average Curves and Cluster Outliers for German Market, 2022

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Results (2) – Outlier Anomalies Belgium

(1) Some Outliers due to extreme VRE

(2) Outliers indicate **low Generation in market**

=> NOT indicated by domestic drivers:

	Temp. °C	Solar MW	Wind MW	Generation MW	Load MW	Price €/MWh
Cluster Outliers (2)	5.68	14	1985	10032	9269	399.3
Cluster 1	12.13	769	1297	10121	9460	44.3

DE & FR drivers give explanation:

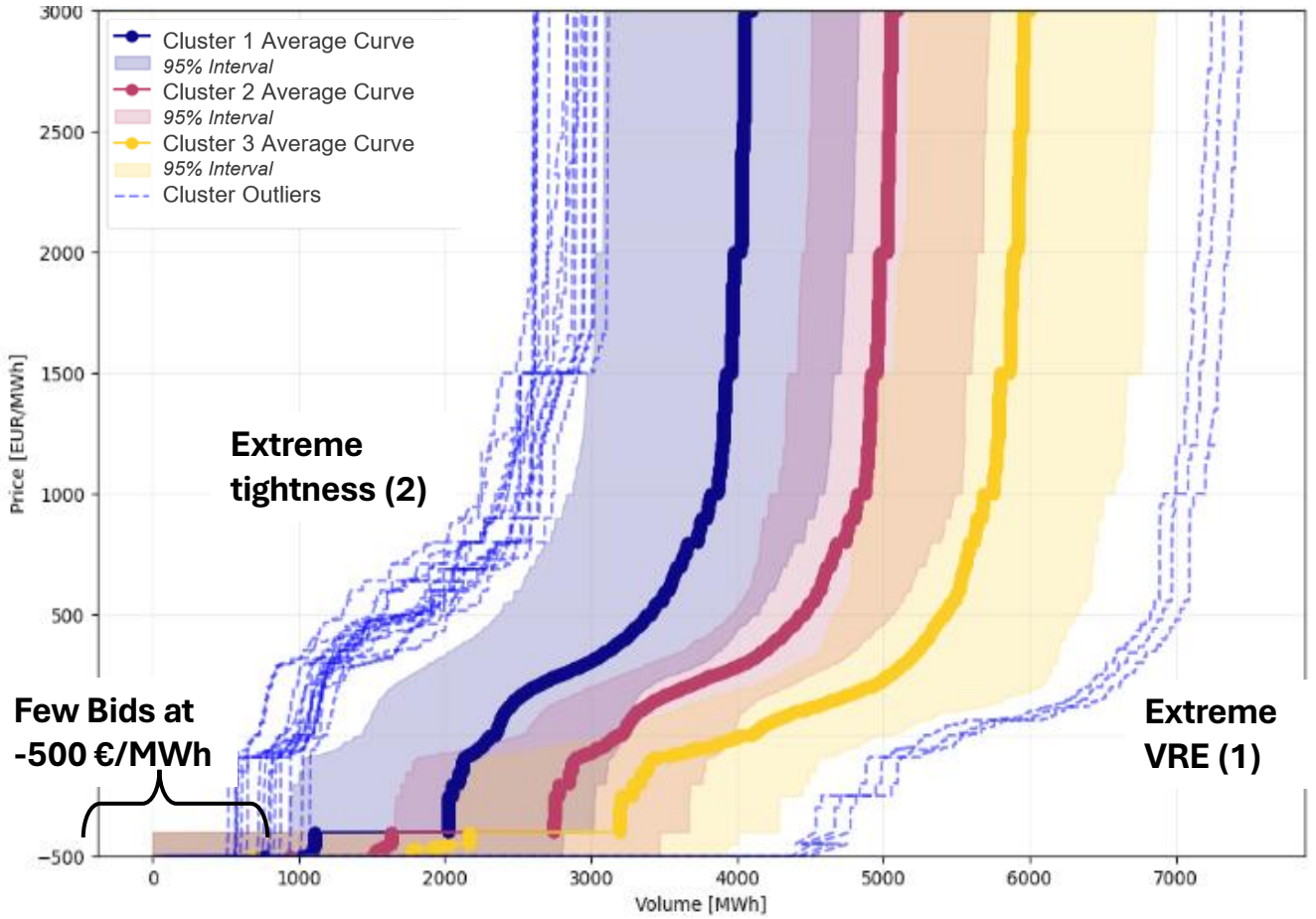
	FR Price €/MWh	FR Generation	FR Load	DE Price €/MWh	DE Generation	DE Load
Cluster Outliers (2)	402.27	56886	57833	388.85	51922	53079
Cluster 1	296.84	47574	51169	250.44	56946	56297

Lack of Generation in France and Germany,

+ high French Load

⇒Sets high price across zones

⇒Belgium traders bid cross-border



Average Curves and Cluster Outliers for Belgian Market, 2022

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Results – Prediction Anomalies

- Cluster mispredictions:
- **Cluster, predicted by drivers =/= Cluster, determined by shape**

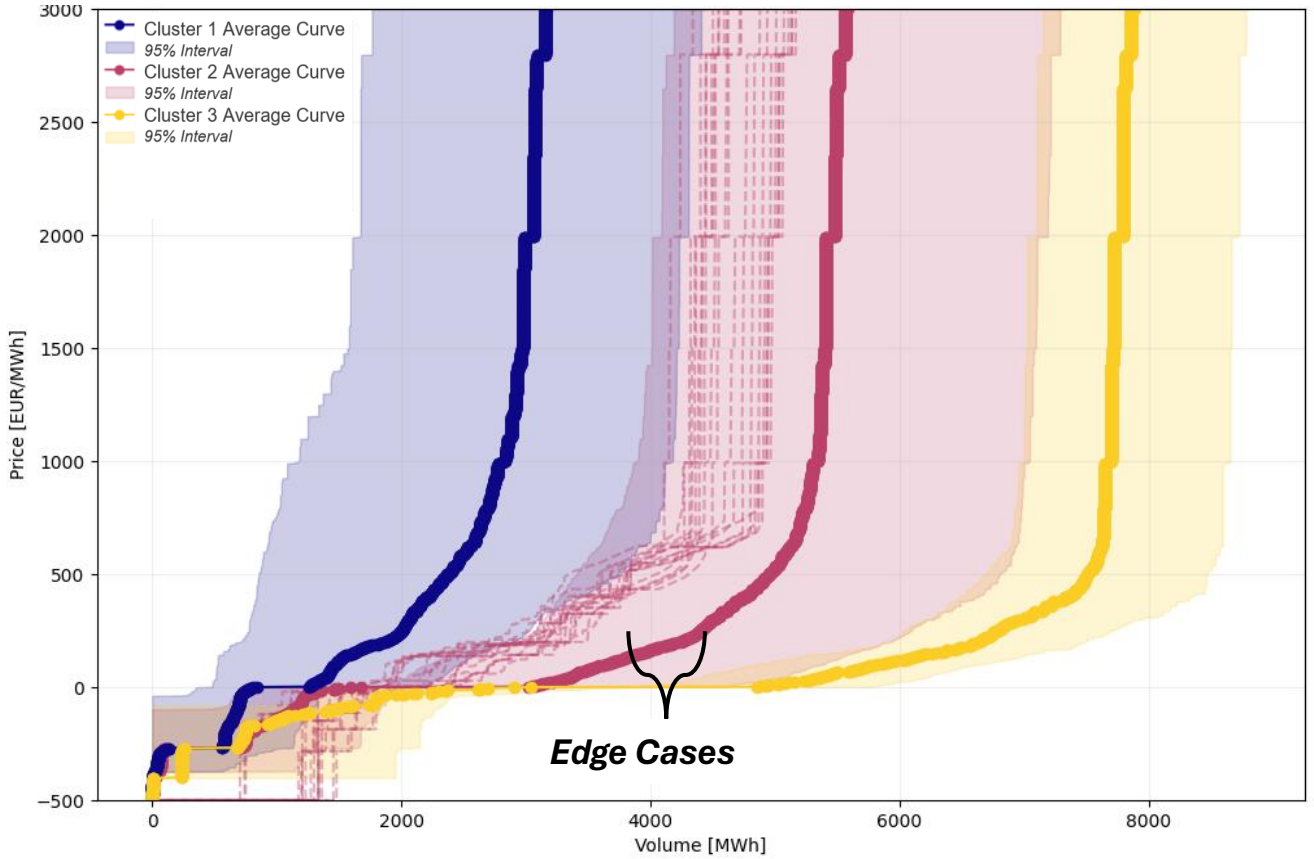
Some can be explained more quickly:

- **Edge Cases**: Cluster 2 Anomalies:

=> Curves assigned **cluster 2 based on shape, predicted cluster 1 based on drivers**

⇒Curves on the *Edge* between Cluster1 and 2:

Difficult to predict



Edge Case Anomalies for Denmark 1 zone

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Results – Prediction Anomalies

- **Other Anomalies required hands-on Investigation:** *Germany 22/06*
- Cluster 2 Anomalies: Very different curves from Cluster 2 average

High offered volumes at minimum price ⟺ Very low flexibility offered in market

	Temp. °C	Solar MW	Wind MW	Generation MW	Load MW	Price €/MWh
Anomalies	18.88	3059	3647	47314	53998	359.1
Cluster 2	14.39	14758	17713	63808	60205	181.4

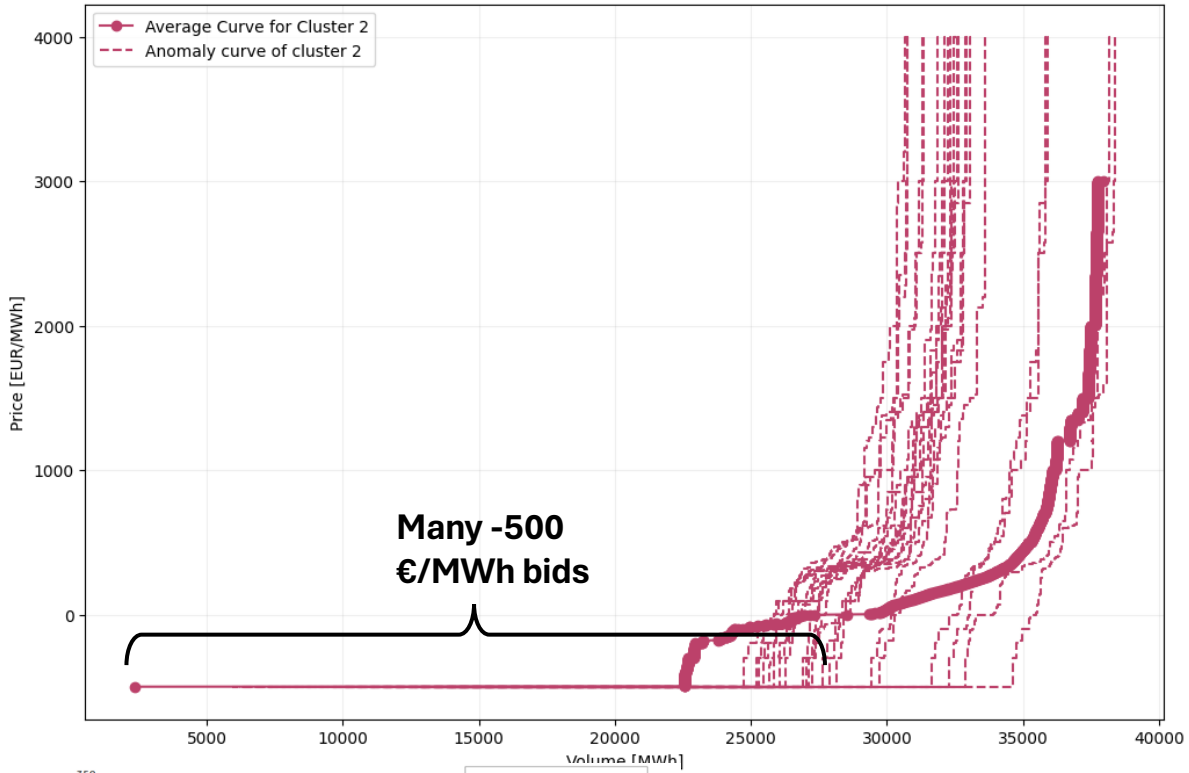
- Driver data **distinct from Cluster 2**, yet shape closest to Cluster 2 => causes *misprediction*

- **Hypothesis: Three factors coincide:**
  1. **Low flexibility**: High generation unavailability for this period
  2. **Steep curves:** Reduction of gas exports => Gas price increase
  3. **Changes in policy announced: Opening of Coal Plants**

  => Possibly, fulfilling of forward contracts by traders caused many -500 €/MWh Bids? [6]

Low Generation In market

Anomalies and Average Curve for Cluster 2, Germany



Gas Price 2022, Germany [4]

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Conclusions

Contributions

From empirical data, our method can:

1. Define e*xpected spot market bidding,* based on market drivers
2. Detect anomalies from this expected bidding behavior

Applied to 2022: Results

1. Renewables determine the *expected bidding*:
   - Bidding curves differ mostly in bids at -500€/MWh and steepness of curves
   - Significance of Wind vs Solar determined by installed capacity of each
2. Empirical bidding also shows significant anomalies, with varying causes:
   - Extremes in VRE Generation => Extreme bidding curves (Outliers)
   - Unforeseen EU-wide events (Energy Crisis)
   - Cross-Border trading
   - …

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Future Outlook

Expand the Method

- Apply method to other time period/bidding zones
- Implement Intra-day/Forward Market Data to improve analysis of anomalies

Use in ABM?

1. As exogenous input

- ABMs often use *theorized* bidding curves **=> Use Empirical Curves instead:**
- Depending on driver data
- The mean Bidding Curve for Cluster 1, 2, or 3, can be used as exogenous input

2. Empirical Trading strategies:

- Anomalies might show *empirical trading strategies*, to be implemented in Trading-Agents

=> Our Study can contribute to more accurate spot market modelling

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