Modelling and Analysis of Negative Electricity Prices:
The case of Germany

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Agenda

- Goal
- Theoretical Background
- German Electricity Market
- Unit Commitment Model
- Regression Analysis
- Regression Models
- Future Scenario
- Conclusions

Goal

- Conduct an analysis of negative electricity prices
- Investigate the fundamental drivers that give rise to negative electricity prices
- Develop regression models that replicate as many hours with negative electricity prices as possible encompassing predictors from a U.C model
- Development of negative electricity prices in the year 2030

Characteristics of Electricity Prices

- Seasonality
- Extreme Spikes
- Mean Reversion
- Volatility

German Electricity Market

- Fully liberalized in 1999
- Still the “Big Four” own 80% of the generation capacity and possess most of the nuclear & lignite power plants
- New power companies encounter numerous obstacles
- Electricity traded in EEX spot market
- Renewable Energy Act EEG (Erneuebare-Energien-Gesetz)
  - Long term feed-in tariff depending on the RES & capacity
  - RES priority rule feed-in
  - RES curtailment only in extreme situations

Nature of Negative Electricity Prices

- Not a theoretical concept
- Inflexible power generation meets low demand and RES do count in
- Negative Electricity Prices occur under 3 cases
  - Power plants cannot vary their output cost efficiently
  - May have to stay online for security reasons
  - RES producers can bid with negative prices

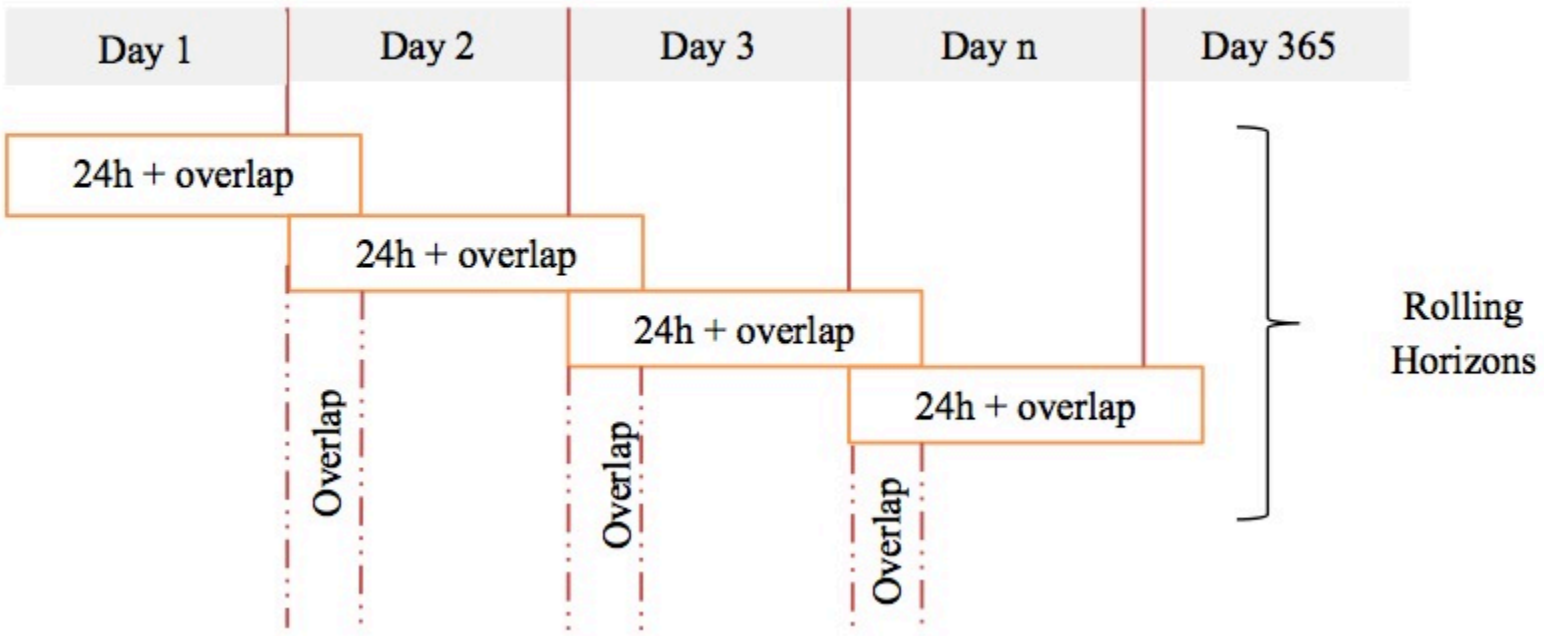
Market Coupling

- 2010 CWE market coupling
- Coordinated calculation of prices and flows
- Optimizing cross border capacities
- More frequent negative prices and price spikes if markets were not coupled

Unit Commitment Model

- MIP problem
- Minimize total system costs
- Simulates Germany(27 regions) and the neighboring countries
- Input
  - Power Plant Unit characteristics
  - Fuel Costs
  - Transmission Lines Data
  - Residual Load
  - Heat Load
- 8 different power plant technologies
- Optimizing 32 hr. (8 hr. overlap)

Rolling Horizons Method



Linear Regression

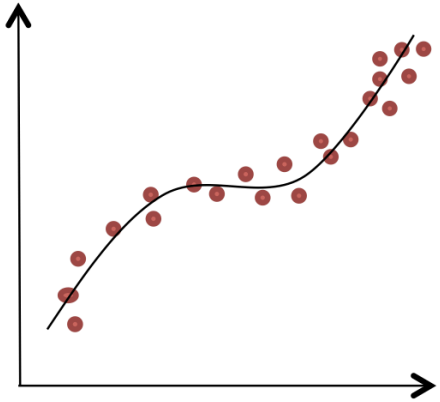
- Regression analysis: Models the relationship between dependent/independent variable
  - Describing the relationship
  - Predictions
- $Yi=b_o+b_1X_1+b_2X_2+ ....+ b_nX_n$
- Linear Regression Assumptions
  - Linearity
  - Independence
  - Homoscedasticity
  - Normality
- Violation of Assumptions ?

Regression Input

1. Residual Load & Wind Generation
2. U.C variables
   - Marginal Cost of Electricity
   - Capacity Utilization factors of base load power plants
3. Categorical variables for modelling seasonality

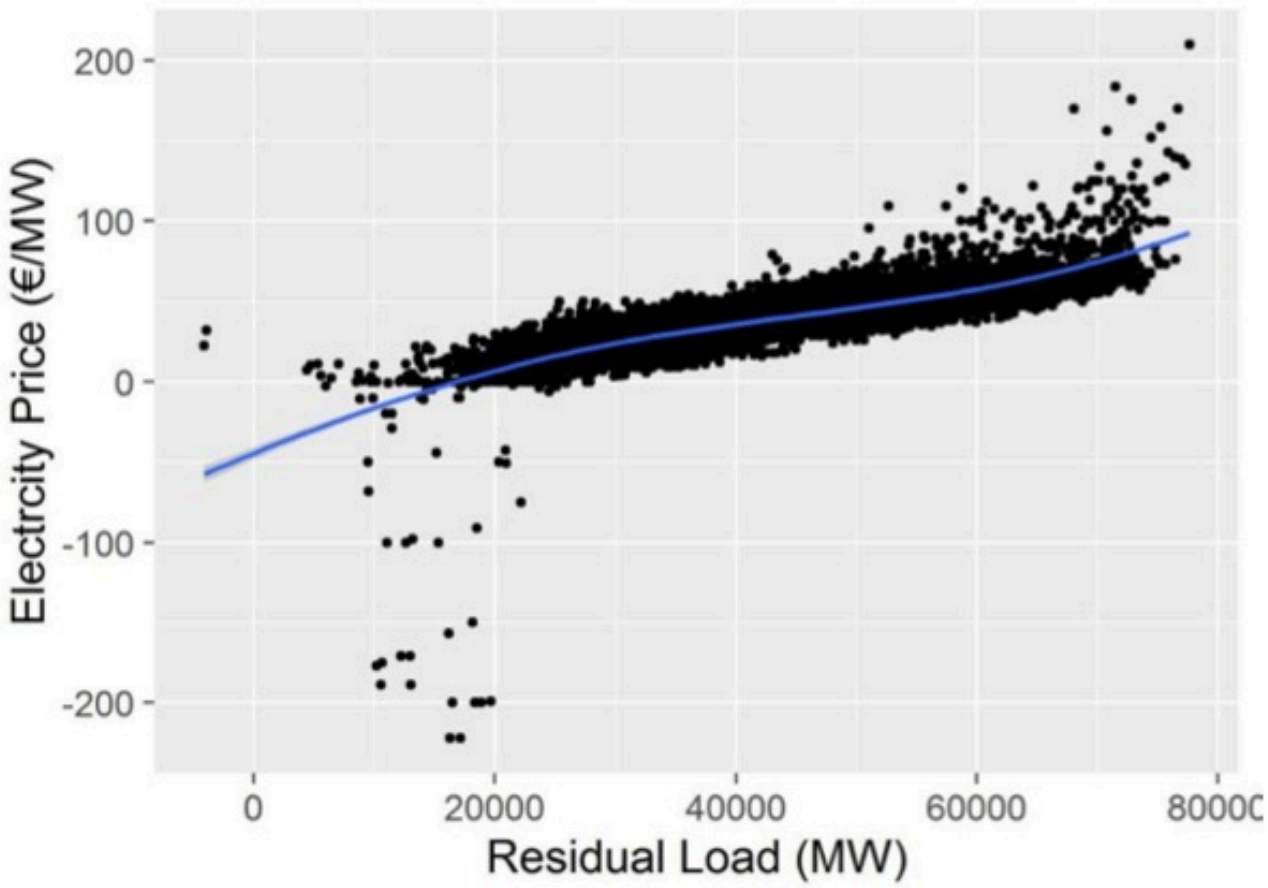
Residual Load & Wind Generation

- Residual= Load-Wind-Solar-Bio-Hydro
  - Wind, Solar: Hourly generation profiles (Weather model)
  - Pearson's (linear)=0.76
  - Spearman's rho (monotonic)=0.86
- Wind Generation



	Wind Power (GW)	Wind Power (GW)
	Whole Data Set	Negative Hr. Data
Min	0.049	3.658
Mean	5.72	15.54
Max	25.38	25.83

Residual Load



U.C Variables

- Marginal Cost of Electricity
  - Equals the spot market price in a perfectly competitive market
  - In reality results are overestimations or underestimations
- Capacity utilization factors
  - Capturing the inflexibility of base load power plants

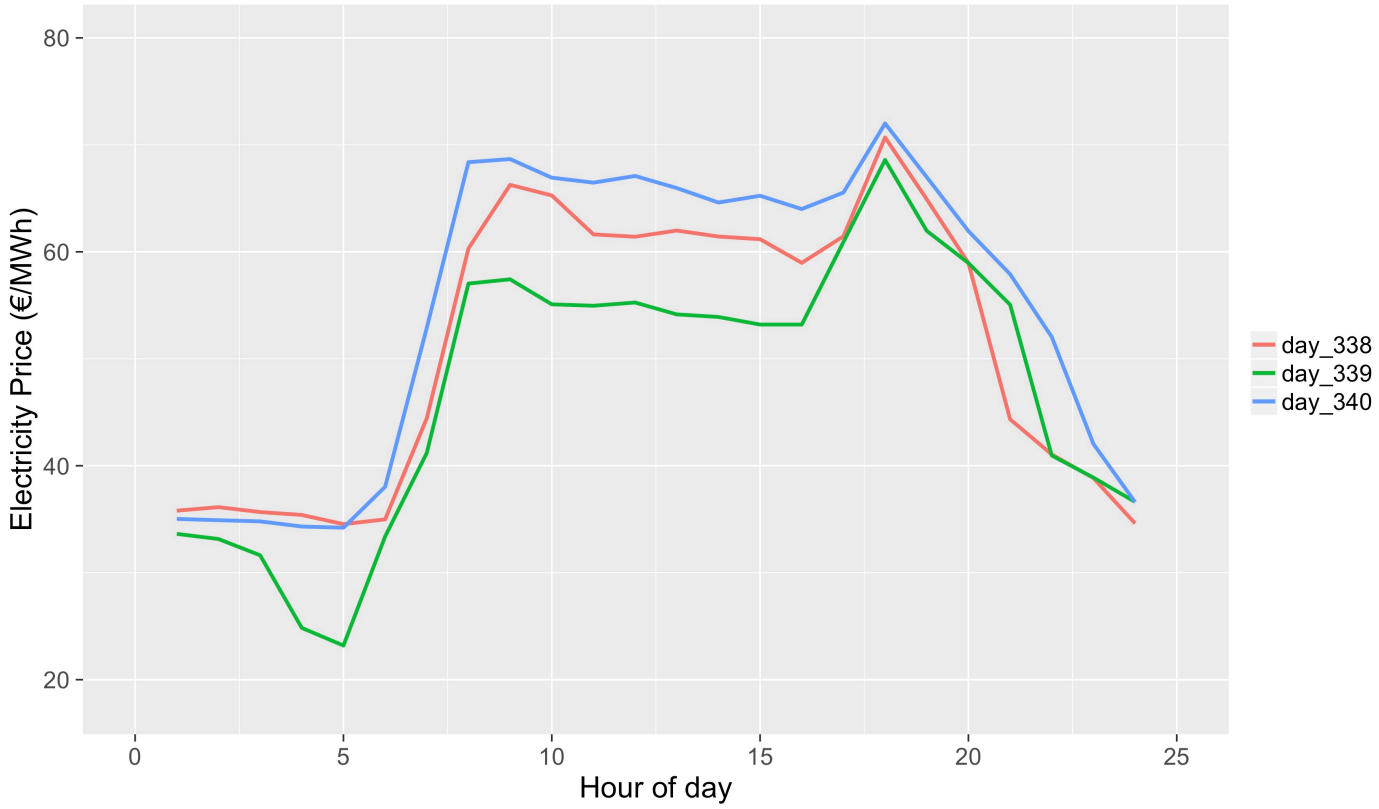
Capacity Utilization Factors Decrease (%)	
Nuclear	58.85
Lignite	20.83
F_Other	39.87
Coal	84.41

Seasonality Variables

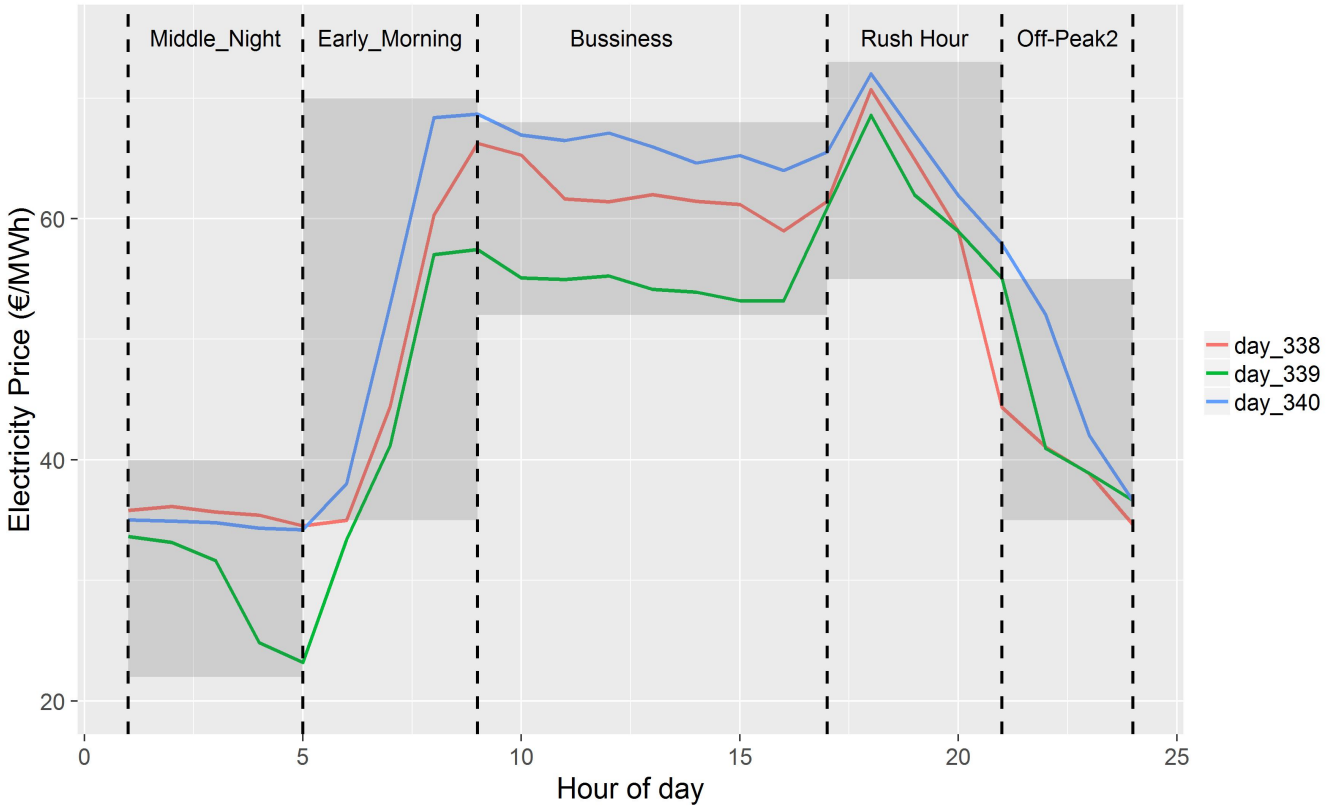
- Seasonal patterns repeating over know or fixed periods of time
- Included quarterly and daily seasonality
- Categorical variables for daily seasonality

	Hours
Middle-Night	1 to 4
Early-Morning	5 to 8
Business	9 to 16
Rush Hour	17 to 20
Off-Peak 2	21 to 24

Daily Seasonality



Daily Seasonality



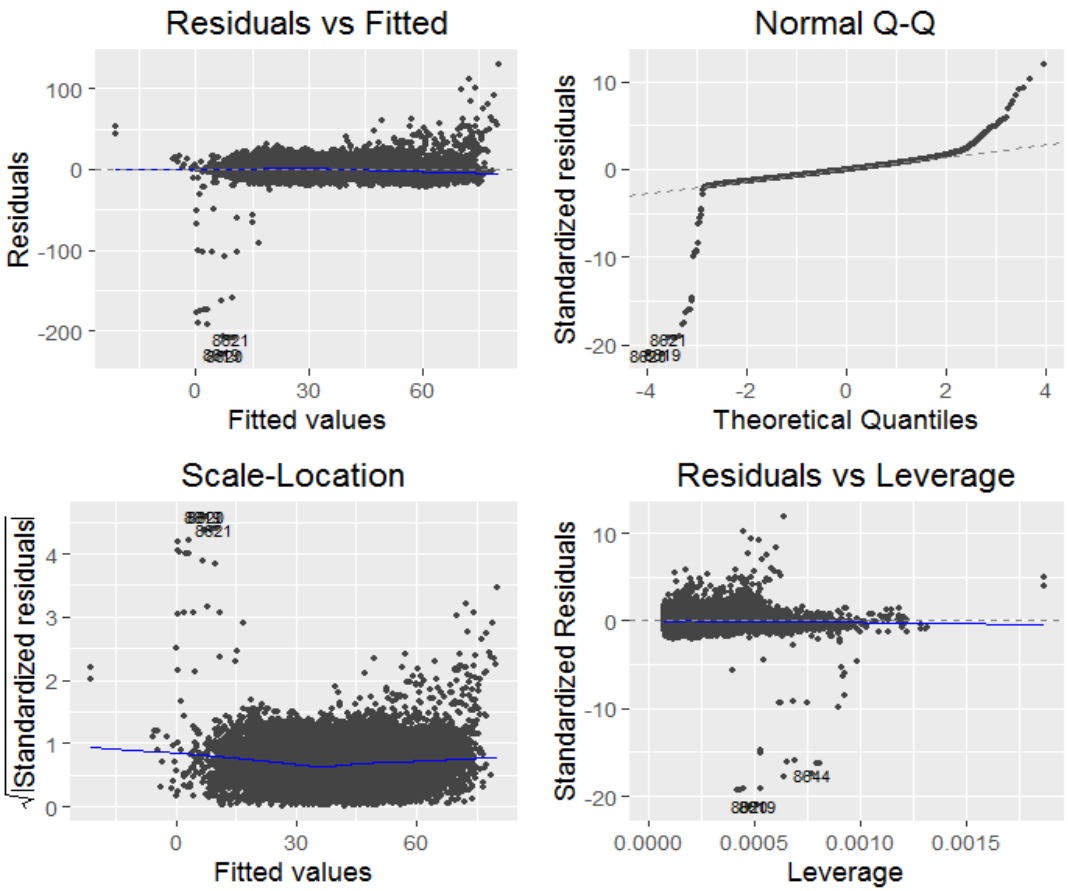
Linear Regression Model

- Hourly values of residual load and wind generation

$$El.\ Price = 10.69 + 1.241 * 10^{-3} * Residual\_Load + 2.562 * 10^{-4} * Wind\_Generation$$

- 3 out 83 hours where electricity prices went negative
- P-values < $2 * 10^{-6}$
- Variation inflation factors < 2
- But…

Linear Regression Diagnostics

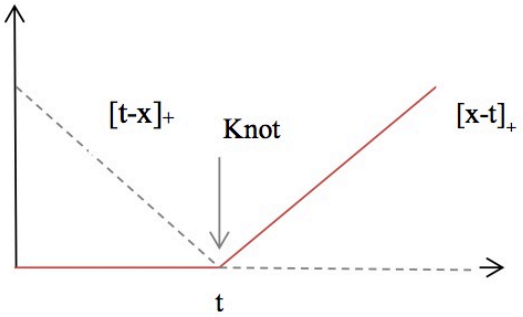


Multivariate Adaptive Regression Splines (MARS)

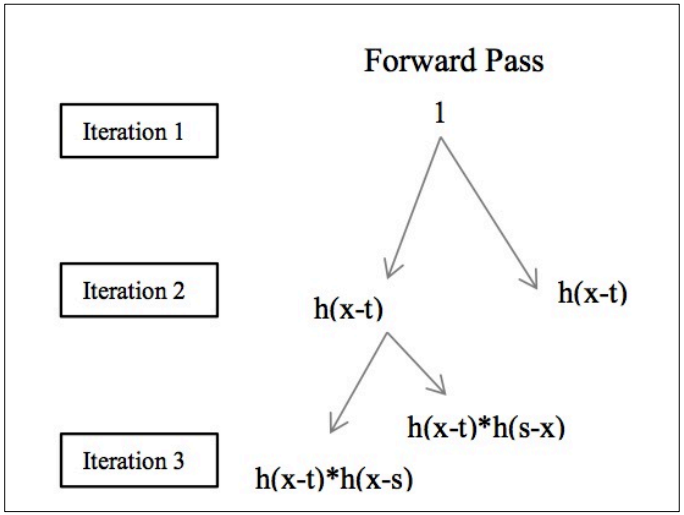
Hinge Functions

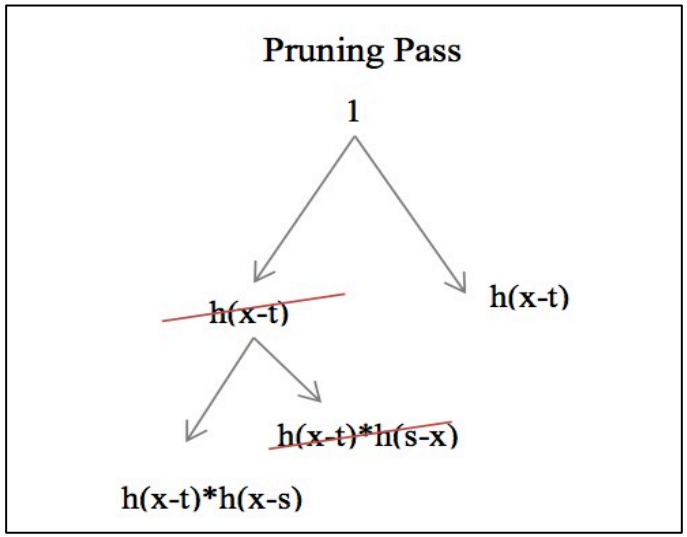
$$h(x-t) = [x-t]_+ = \begin{cases} x-t, & if\ x > t \\ 0, & if\ x \le t \end{cases}$$

$$h(t-x) = [t-x]_+ = \begin{cases} t-x, & if\ x < t \\ 0, & if\ x \ge t \end{cases}$$



Fitting Process

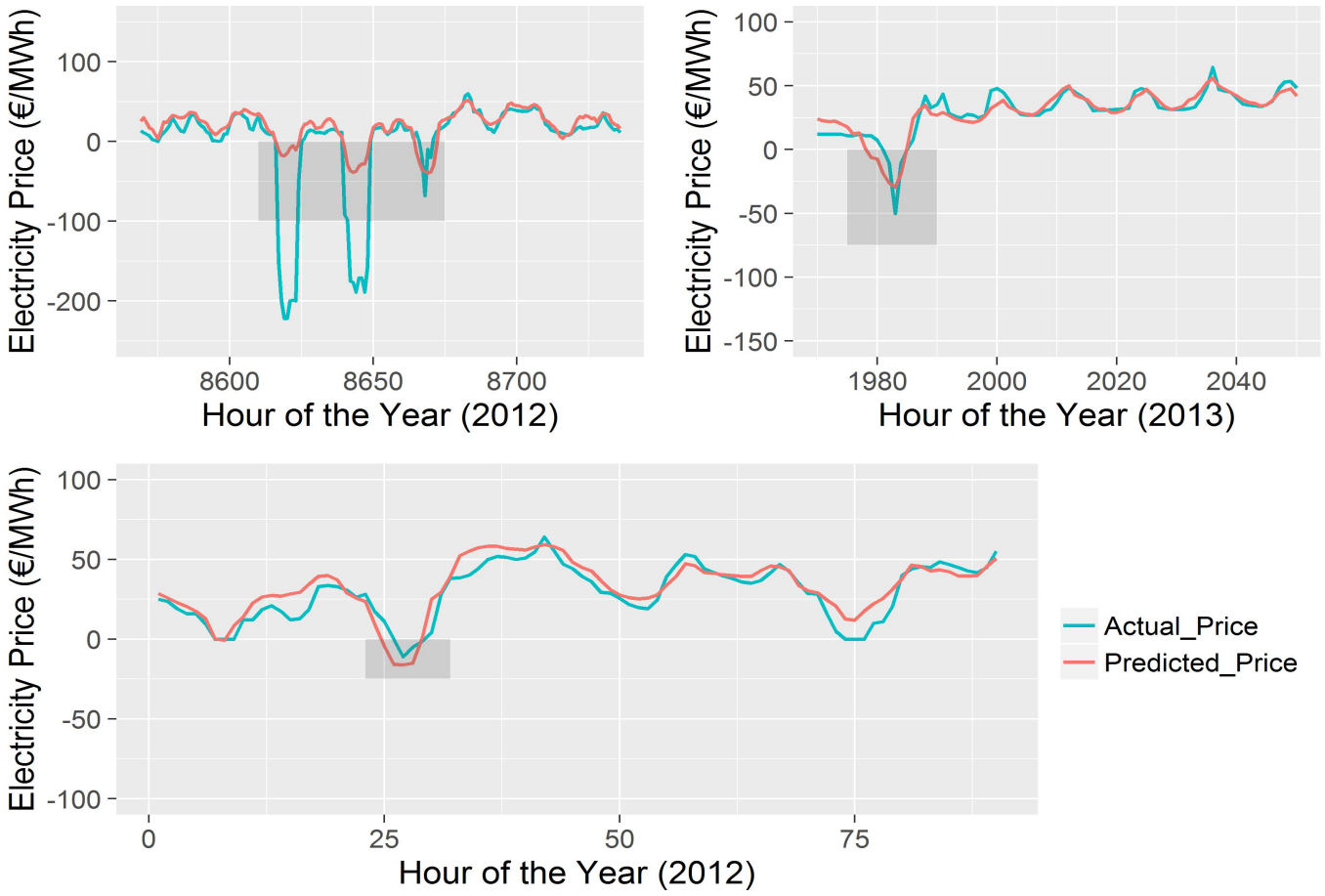




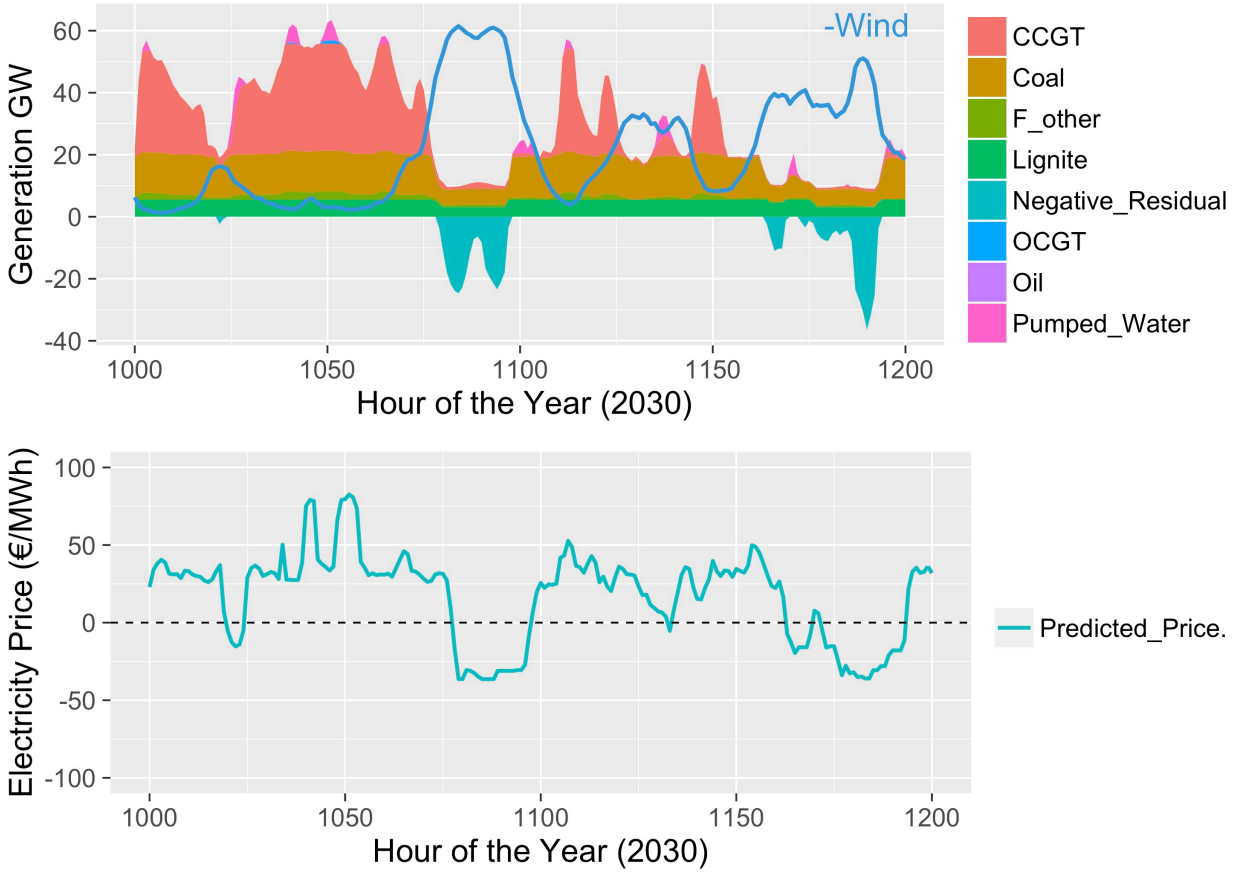
MARS Models

		Model_1	Model_2a	Model_2b	Model_3
Train Set	Negative Hr. Predicted	60/83	61/83	62/83	53/83
Test Set	Negative Hr. Predicted	9/31	12/31	12/31	0/31
	GRSq	0.698	0.702	0.702	0.719
	Out of Sample R^2	0.684	0.654	0.672	0.617

Model_2b


Electricity Price (€/MWh)
100
0
-100
-200
8600
8650
8700
Hour of the Year (2012)
Electricity Price (€/MWh)
100
50
0
-50
-100
-150
1980
2000
2020
2040
Hour of the Year (2013)
Electricity Price (€/MWh)
100
50
0
-50
-100
0
25
50
75
Hour of the Year (2012)
Actual_Price
Predicted_Price

Year 2030



	Negative Hr. Predicted
Model_1	2437
Model_2a	1630
Model_2b	2007
Model_3	1509
Agora (2020)	>1200
BMWi	100-600

Conclusions & Future Prospects

- Flexible method for modelling electricity prices
- Electricity markets are not considered static entities (next steps in market coupling)
- Adjustment reactions from supply-demand side

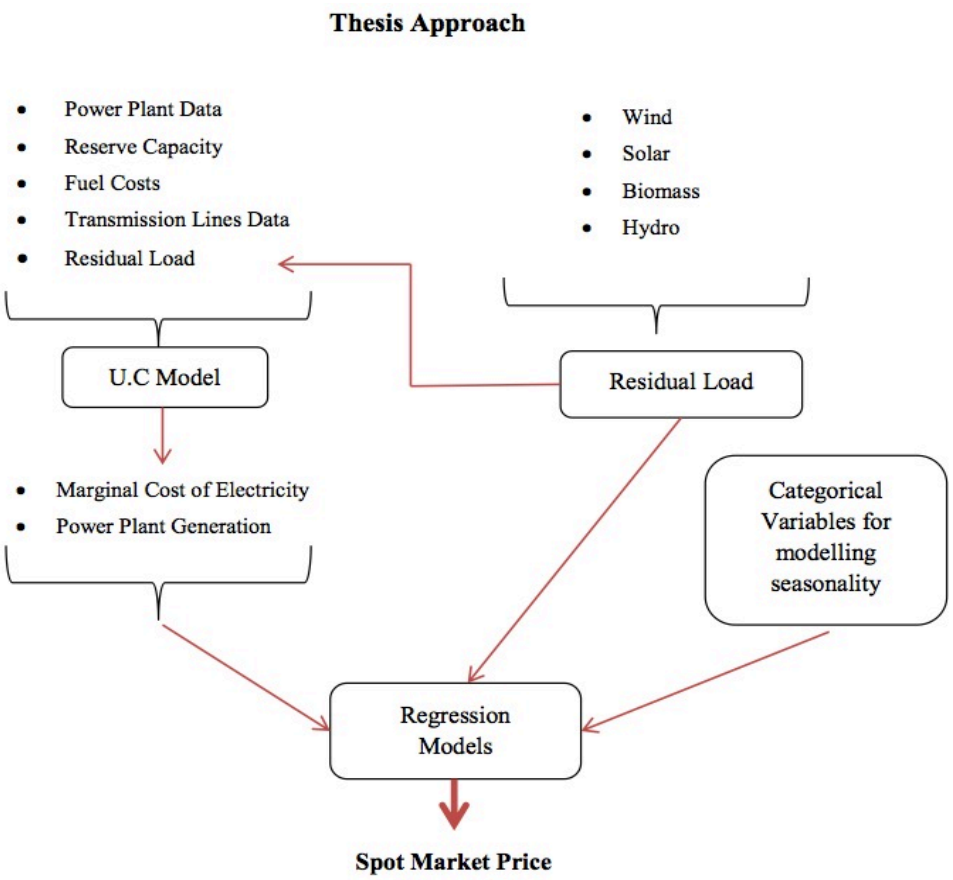
Possible Enhancements

- U.C model
- Use of other predictors e.g. solar PV generation

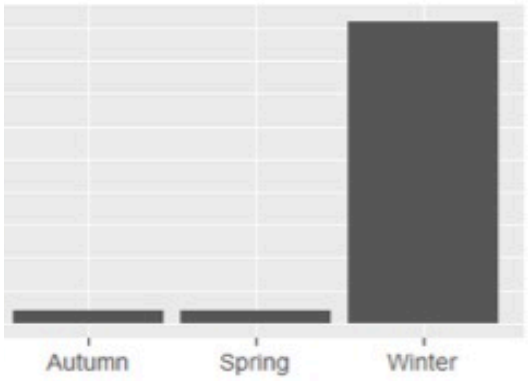
Thank You!

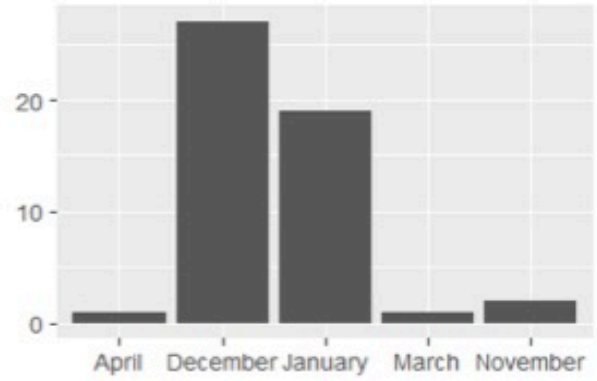
Appendix

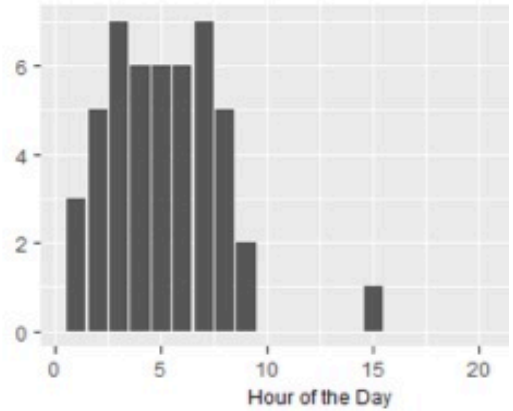
Thesis Methodology

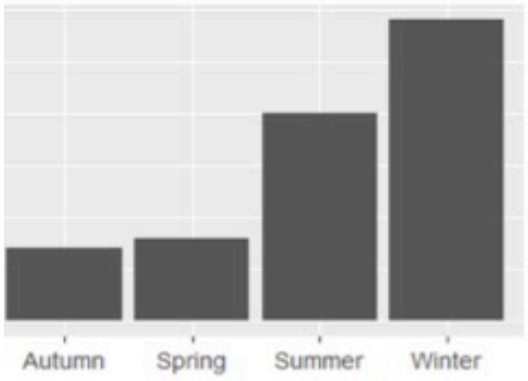


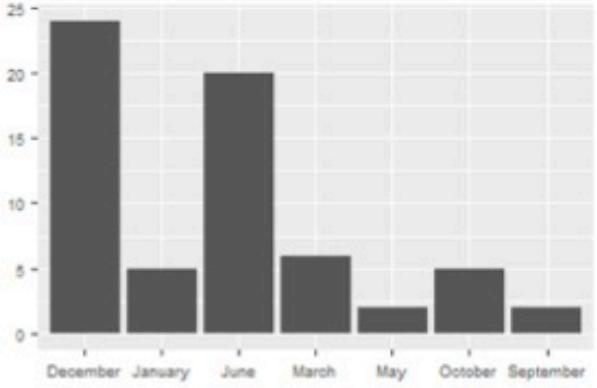
Distribution of Negative Prices for the years 2012-2013

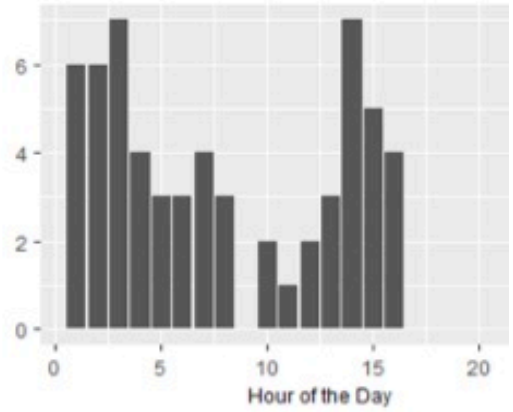




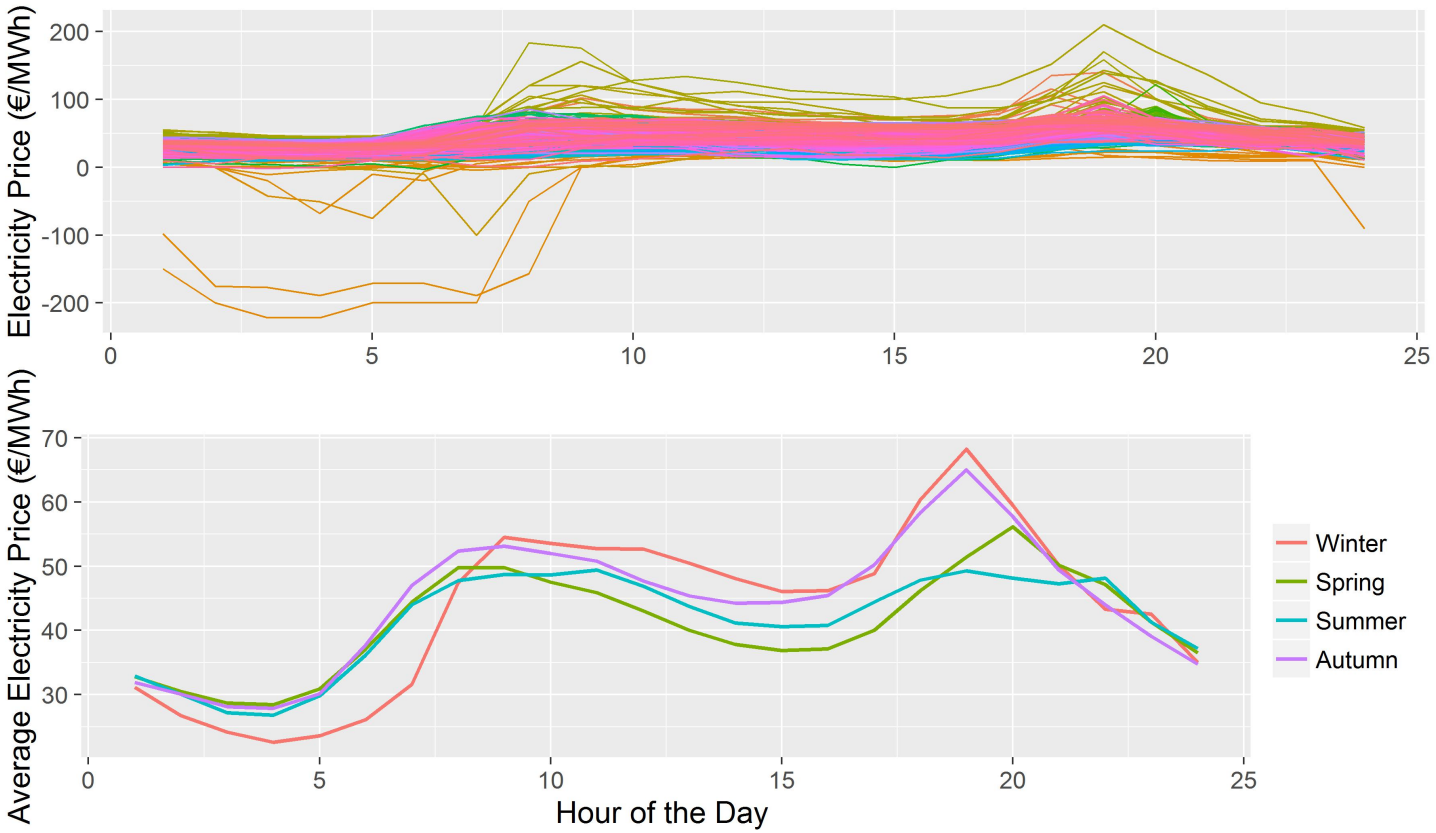




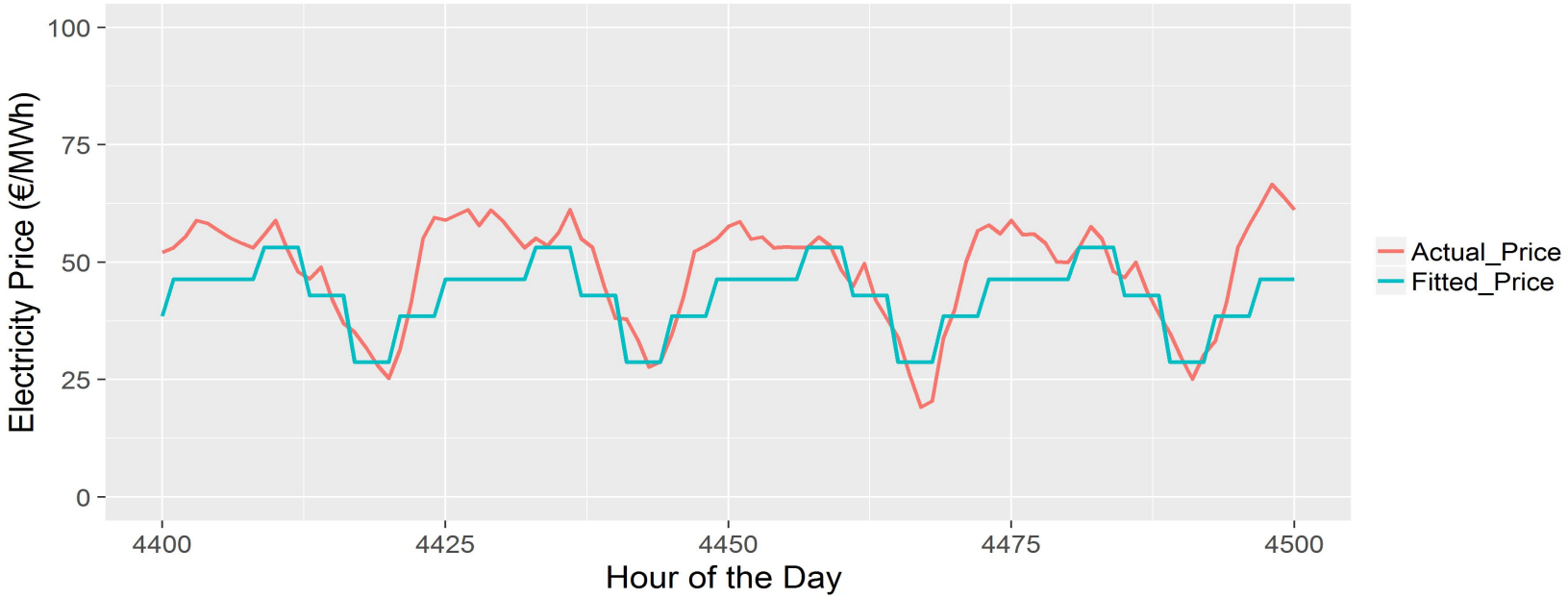




Seasonality



Linear Model for Daily Seasonality



GCV

- Compares the performance of model subsets in order to choose the best subset
- *GCV=RSS/N * (1-Effective Number of Parameters/N)^2*
- *Effective Number of Parameters= Number of MARS Terms + Penalty * (Number of MARS Terms - 1)/2*

$$GCV = \frac{\frac{1}{N}\sum_{i=1}^{N}[y_i - f(x_i)]^2}{\left[1 - \frac{\bar{C}(M)}{N}\right]^2}$$

Model_2b

Spot_Market_Price =

-754.462 + 0.00021(Wind_Gen) + 5.23767* Business + 4.01506* Rush_Hour - 3.19661*seasonWinter + 0.00899*h(Residual_Load-10163.3) + 0.00503*h(24760.7-Residual_Load) - 0.00798* h(Residual_Load-24760.7) + 0.0197* h(Residual_Load-74352.8) + 8.14228* h(Marginal_Cost-27.6073) - 1.26438* h(Marginal_Cost-32.5078) + 6.89611* h(119.975-Marginal_Cost) - 6.19322* h(Marginal_Cost-119.975)*

Variables Importance			
	nsubsets	**gsv**	**rss**
Residual_Load	12	100	100
Marginal_Cost	10	30.9	31.1
Business	8	25	25.1
Rush_Hour	7	20.2	20.4
seasonWinter	3	10.1	10.3
Wind_Gen	1	5.4	5.5

Predicted Electricity Prices in the Year 2030

	Model 1	Model_2a	Model_2b	Model_3
Mean	-46.15	-39.41	-38.88	-38.90
Max	95.08	665.17	94.24	98.88
Median	13.56	25.30	21.53	35.84
Mean	10.25	65.21	15.16	27.72
Total Negative Hr.	2437	1630	2007	1509

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