The effect of market integration when forecasting day-ahead electricity prices

Jesus Lago

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June 30, 2017

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Outline

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Problems with renewable energy sources

Primary Problems

1. Bad predictability.
2. Intermittent generation.
3. Low inertia.

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Problems with renewable energy sources

Primary Problems

1. Bad predictability.
2. Intermittent generation.
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Result

How much *renewable energy sources (RES)* can be put into the electrical grid without compromising the operational safety?

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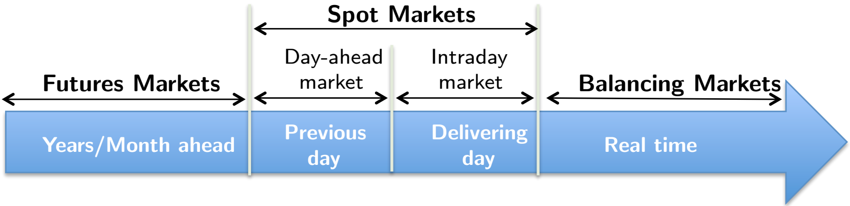
Role of renewable energy sources

Markets for renewable energy sources

- Energy price is settled in a continuous supply/demand trading.



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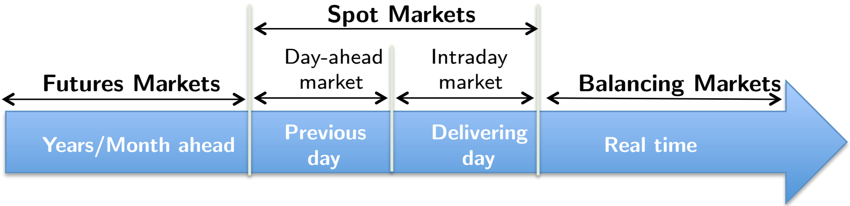
- Energy price is settled in a continuous supply/demand trading.
- Production of renewable energy depends on weather conditions
  $\Longrightarrow$ Energy production from RES is uncertain.



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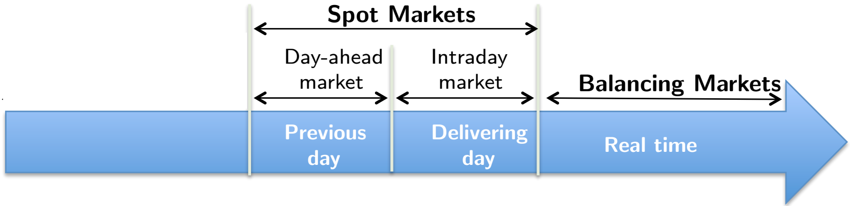
Role of renewable energy sources

Markets for renewable energy sources

- Energy price is settled in a continuous supply/demand trading.
- Production of renewable energy depends on weather conditions $\Longrightarrow$ Energy production from RES is uncertain.
- Most of the produced renewable energy can only be traded on the spot and real time markets.



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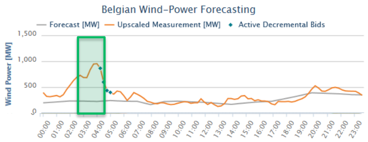
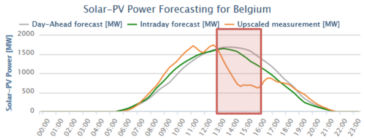
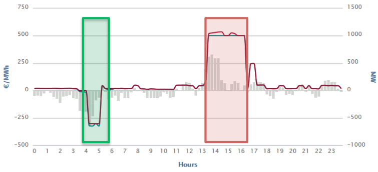
Role of renewable energy sources

Issues of RES in Energy Markets

1. Due to weather conditions, energy production from RES is uncertain.
2. Production uncertainty leads to volatile markets and imbalanced grids.
3. Volatility and imbalances make RES less attractive and profitable.
4. Market share of RES is limited.







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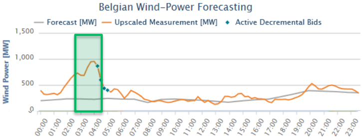

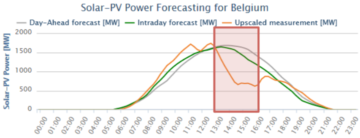

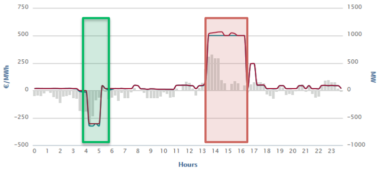

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Outline

1. PhD Outline
   - Energy Markets and RES
   - PhD Aim
2. Day-ahead price forecasting
3. Market Integration
4. Future Work

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Aim

PhD Aim

Support and stabilize the energy market to:

1. Allow more integration of RES.
2. Mitigate some of the negative effects of RES.

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Support and stabilize the energy market to:

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Facts

1. Low prices occur when generation is larger than consumption and high prices appear in the opposite situation.
2. Some of the problems of RES are related to these mismatches between generation and consumption.
3. Market agents have economic incentives to buy when prices are low, i.e. increasing the consumption, and reduce the consumption when prices are high.

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Procedure

Methodology

Development of control algorithms that can influence and stabilize the price of the energy market.

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First step: Forecasting

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Second step: Multi-market Controller

Model a multi-market controller that takes into account prices and uncertainty in all markets and selects economically optimal actions for various energy systems.

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Overview of day-ahead price forecasting methods

Available Forecasters

- Forecasting day-ahead electricity prices is an old research topic dating to the end of the 90's.
- Vast collection of methods has been proposed.

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- Vast collection of methods has been proposed.

State of the art models

- Discrepancy in the community regarding which are the best models.
- Performance depends on period and market under study.

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PhD research on price forecasting

Research on three different areas.

1. Reach consensus on the accuracy of forecasters by building a complete and large benchmark.
2. Develop a modeling framework based on deep learning. The framework obtains state-of-the-art results.
3. Investigate the effect of market integration in forecasting accuracy.

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Problem Definition

Facts

1. In the last decade, The EU has passed laws to pursue a single and integrated electricity market [MB08, JP05].
2. Evidence suggests that, in recent years, the level of integration across markets has been increasing [BG10].

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Scientific Gaps

1. Nonexistent analysis to study the influence of market integration in the accuracy of predicting prices.
2. Nonexistent general models to use market integration information to improve predictive accuracy.

Outline

1. PhD Outline
2. Day-ahead price forecasting
3. Market Integration
   - Definition
   - Analysis
   - Modeling Framework
4. Future Work

Analysis of Market Integration

Problem Statement

Defining:

1. The day-ahead prices $\mathbf{p} = [p_1, \ldots, p_{24}]^\top$ in a local market.

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2. The features $\mathbf{x} = [x_1, \ldots, x_{n_\mathrm{x}}]^\top$ in the same local market.

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4. A price forecaster $\mathbf{p} = F(\mathbf{x}, \mathbf{z})$.

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How important the external features $\mathbf{z} = [z_1, \ldots, z_{n_\mathrm{z}}]^\top$ are when predicting the day-ahead prices $\mathbf{p} = [p_1, \ldots, p_{24}]^\top$?

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Solution

Develop a feature selection algorithm based on Bayesian Optimization [BBBK11] and functional ANOVA [HHLB14] that:

1. Selects the optimal features as the x_i,z_i with relevant contributions.

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2. Analyzes the contribution of each x_i, z_i to the accuracy of $F(\mathbf{x}, \mathbf{z})$.

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Case Study - Description

Description

- Influence of features in the French market when forecasting day-ahead prices in the Belgian market.
- Input features:
  1. Past prices in Belgium and France.
  2. Day-ahead forecast of grid load in Belgium and France.
  3. Day-ahead forecast of available generation in Belgium and France.
  4. Holiday calendar in both countries.
- Four years of data (2010-2014) for estimating the model F.
- An extra year (2015) as validation set to perform the feature selection.

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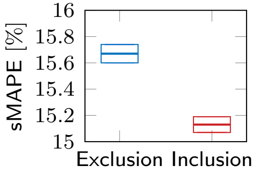
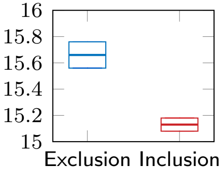
Case Study - Results

Table: Importance of input features

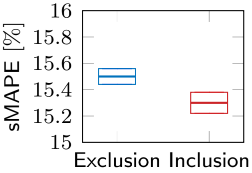
	Contribution to $\mathbb{V}_a$
Load France	28.4%
Prices France	25.7%
Generation France	4.78%
Load Belgium	1.0%



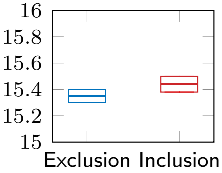
(a) French load.



(b) French prices.



(c) French generation.



(d) Belgian load.

Figure: Accuracy of F when including/excluding features

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Modeling Framework for Market Integration

Questions to be answered

1. The previous analysis considered a forecaster F. What F is exactly?

2. The analysis provided a qualitative assessment. How large is really the improvement? Is there statistical evidence to claim that market integration improves the predictive accuracy?

3. So far, market integration modeled with input features. Can the accuracy be improved by modeling other market integration effects?

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Base Forecaster F

Based on the results from the research in deep learning and benchmarking, the best model is a standard neural network with two hidden layers.

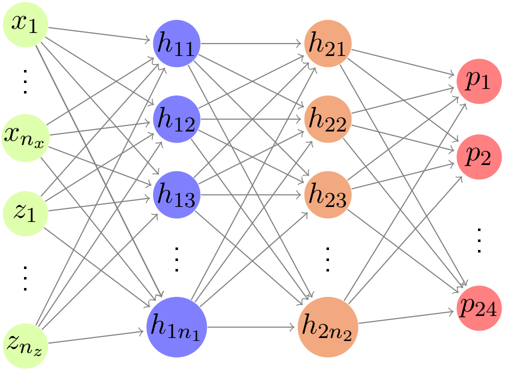

Figure: Deep neural network to forecast day-ahead prices.

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Statistical Analysis for Predictive Accuracy

Problem definition

Given:

- A time series vector $\mathbf{Y} = [y_1, \ldots, y_N]^\top$ to be forecasted.
- Two prediction models M_1 and M_2.
- Forecasting errors $\boldsymbol{\varepsilon}^{M_1} = [\varepsilon_1^{M_1}, \ldots, \varepsilon_N^{M_1}]^\top$, $\boldsymbol{\varepsilon}^{M_2} = [\varepsilon_1^{M_2}, \ldots, \varepsilon_N^{M_2}]^\top$.

Is the accuracy of M_1 statistically significant better than the one of M_2?

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Diebold-Mariano (DM) Test for Hypothesis Testing [DM95]

1. Null hypothesis H_0: the accuracy of M_1 is equal or worse than the accuracy of M_2.
2. Alternative hypothesis H_1: the accuracy of M_1 is better:

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Statistical Analysis for Market Integration

Description

- Deep neural network as the forecaster F.
- Five years of data (2010-2015) for training F.
- An extra year (2016) as test set to perform the statistical testing.
- DM test performed for every predictive horizon, i.e. hour of the day, at 5% significance level, i.e. with a p-value of 0.05.

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Statistical Analysis in Belgium Market

Description

DM test to compare accuracy between:

- Forecaster F_{MI} with market integration.
- Model F_{no} without market integration.

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Table: sMAPE Comparison

	sMAPE
F_{no}	15.7%
F_{MI}	13.2%

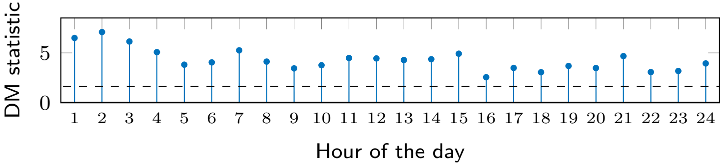

Figure: DM test comparing F_{MI} and F_{no}. Values above dashed line reject H_0 at a 5% significance level and are cases where the accuracy of F_{MI} is statistically significantly better.

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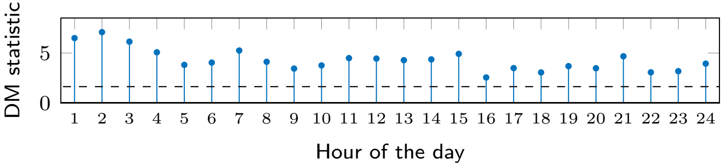

Figure: DM test comparing F_{MI} and F_{no}. Values above dashed line reject H_0 at a 5% significance level and are cases where the accuracy of F_{MI} is statistically significantly better.

Predictive accuracy of a forecaster with market integration is statistically significantly better than the accuracy of a forecaster without it.

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Dual-Market Forecaster for Market Integration

Definition

- Forecaster that predicts prices in two connected markets instead of a single one.

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Idea

- Prices in both markets are interrelated and have similar dynamics.
- By forecasting both markets in a single model we expect the neural network to model more accurate dynamics, to learn relations that are common to both markets, and to generalize better.

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Foundations

- Deep Neural Networks, which learn multiple similar tasks, can learn relations that can, to some extent, generalize across tasks [YCBL14].
- By forcing DNNs to learn auxiliary related tasks, the performance and learning speed can be improved [JMC+16, NH16, LZW+16].

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Dual-Market Forecaster for Market Integration

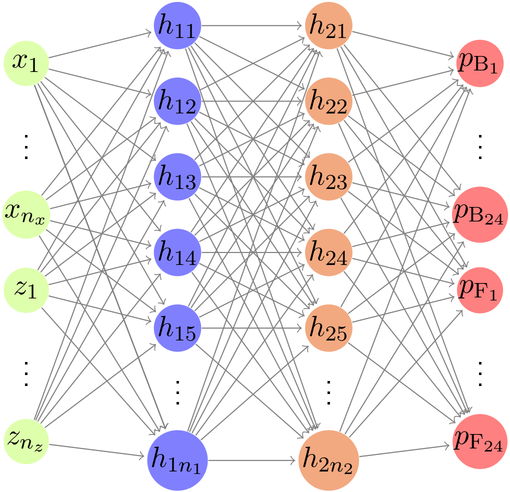

Figure: Deep Neural Network to simultaneously forecast day-ahead prices in the Belgian and French markets.

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Dual-Market Forecaster in Belgium

Forecaster Evaluation

Comparison between predictive accuracy of:

- Single-market forecaster F_{Single}.
- Dual-market forecaster F_{Dual}.

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Dual-Market Forecaster in Belgium

Forecaster Evaluation

Comparison between predictive accuracy of:

- Single-market forecaster F_{Single}.
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Table: sMAPE Comparison

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F_{Single}	13.2%
F_{Dual}	12.5%

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Statistical Analysis of Dual-Market Forecaster

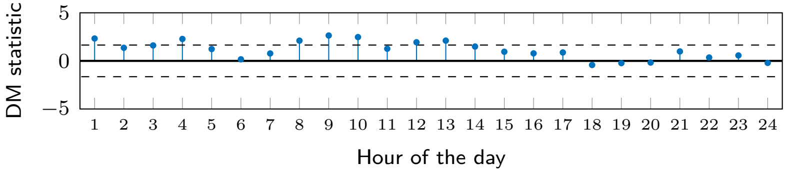

Figure: DM test results when comparing F_{Single} and F_{Dual}. Values above the top dashed line represent cases where, with a 95 % confidence level, F_{Dual} is significantly better. Values below the lower dashed line accept at a 95 % confidence level that F_{Dual} is significantly worse.

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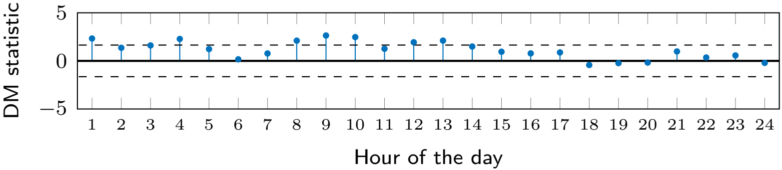
Statistical Analysis of Dual-Market Forecaster



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Observations

1. The H_0 in the regular test is rejected 8 of 24 times.
   $\Longrightarrow$ F_{Dual} statistically significantly better in 1/3 of the hours.
2. The $\hat{H}_0$ of the complementary test is never rejected. $\Longrightarrow$ F_{Dual} is never statistically significantly worse.

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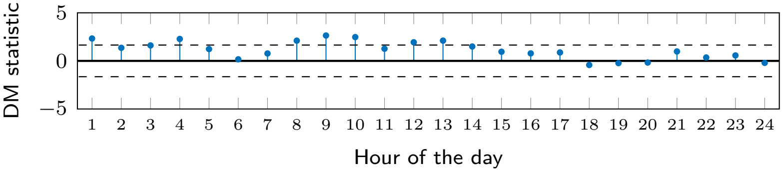

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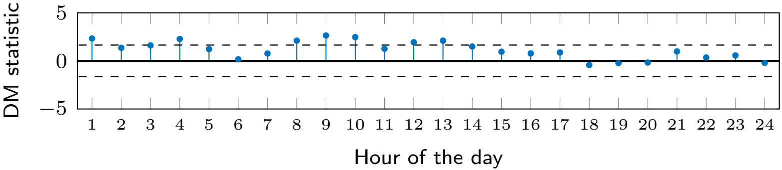

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Result

Predictive accuracy of the dual market forecaster is statistically significantly better than the accuracy of a single-market forecaster.

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Outline

Future Work

1. Implement forecaster for obtaining relations between day-ahead and real time market.
2. Develop a multi-market controller for the Ecovat system, a large water storage system.
3. Extend the forecasting to other markets.
4. Generalize the multi-market controller to more systems.

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Thank you. Any Questions?

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