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Julie Byrne 2
Michael Coulon 2
Peter Deeney 3
Chiara di Modica 3
Stein-Erik Fleten 4
Hayette Gatfaoui 4
Silvia Golia 5
Tim Janke 6
Takashi Kanamura 6
Rüdiger Kiesel 7
Carlo Lucheroni 7
Katarzyna Maciejowska 7
Matteo Manera 8
Carolina Garcia Martos 8
Michał Narajewski 9
Weronika Nitka 9
Andrea Roncoroni 10
Alessandro Sapio 10
Derek Scully 10
Benedikt Sommer 11
Stefan Trück 11
Tiziano Vargiolu 12
Tomasz Weron 12
Florian Ziel 13

No real option for solar in Ireland: a real option valuation of utility scale solar investment in Ireland

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The Irish Government recently unveiled plans to have 70% of electricity in the state generated from renewable sources by 2030. Currently very little electricity is generated by solar in Ireland. We apply a real options framework to assess the economic feasibility of utility scale solar in Ireland. We identify electricity prices as the main source of uncertainty and use the Least Square Monte Carlo method to price the real option. We find that, in the absence of comprehensive policy support, large scale investment in solar in Ireland is not commercially viable and that, where the real option has value, the optimal strategy is to defer investment. We then analyse the effect on utility scale solar PV of introducing a Solar Renewable Energy Credit (SREC) support system. Our results suggest that introducing a credit system would immediately incentive investments in the solar industry.

Wind park valuation and risk management in the German intraday power markets

Michael Coulon, University of Sussex (United Kingdom)

The rapid growth of renewables in Germany in the last decade has led to various new modeling challenges for many energy firms. Wind park owners and operators in particular require valuation and risk analysis techniques which capture the high volatility and intermittency of wind power generation, the dynamics of intraday prices and their correlation with changes in wind forecast levels. Under typical contract terms, owners of wind parks receive production volume times the spot price minus a premium, while managers receive revenues dependent on how they nominate the power and rebalance their positions in the day-ahead and intraday markets. Here we discuss managers' trading and hedging strategies, also usable for determining a fair premium, which can vary significantly across wind parks. This valuation and risk management problem is of significant interest to many market participants, including investors and policy makers looking to further grow the penetration of renewables.

A real options based decision support tool for R&D investment: Application to CO2 recycling technology

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We propose a real options based decision support tool to aid in the practical evaluation of R&D investments in technology, using a novel Poisson process to simulate the discrete progress typical of R&D breakthroughs. We take explicit account of the technical risk of an R&D project, while the market risk and the effect of learning-by-doing in operational technologies are also explicitly modelled. We present a compound real option structure, where a European real option is used to model the fixed length term typical of early phase research, which is exercisable into an American real option to model later phase R&D. In this later phase, a successful outcome will be acted on immediately to operationalise the technology. We propose a Monte Carlo simulation approach, which models R&D progress in a stylised logistic function or 'S-bend' form, capturing the typically slow rate of R&D progress at the start of the early phase, through to more rapid improvement as the R&D advances, which then slows again as the limitations of the R&D are approached. We demonstrate that this method is applicable for evaluating the R&D investment potential in CO2 recycling technology, where an energy commodity (such as methane) is produced, using appropriate modelling for the price of the energy commodity. The method may be applied widely to R&D technology projects.

Online forecast reconciliation in wind power prediction

Chiara di Modica, Technical University of Denmark (Denmark)

Increasing digitization of the electric power sector allows to further rethink forecasting problems that are crucial input to decision-making. Among other modern challenges, ensuring coherency of forecasts among various agents and at various aggregation levels has recently attracted attention. A number of reconciliation approaches have been proposed, from both game-theoretical and statistical points of view. However, most of these approaches make unrealistic unbiasedness assumptions and overlook the fact that the underlying stochastic processes may be nonstationary. We propose here an alternative approach to the forecast reconciliation problem in a constrained regression framework. This relies on a multivariate least squares estimator, with equality constraints on the coefficients (denoted MLSE). A recursive and adaptive version of that estimator is derived (denoted MRLSE), hence allowing to track the optimal reconciliation in a fully data-driven manner. We also prove that our methods by design guarantee the coherency property for any out-of-sample forecasts (reconciliation by design). We show the effectiveness of our forecasting methods using a Danish wind energy dataset with 100 wind farms.

Sequential investment: empirical evidence of real options effects
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Tord Olsen, Norwegian University of Science and Technology (Norway)
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This paper presents an empirical analysis of the real options to postpone and cancel sequential investments with time-to-build. Using generator level data we consider investments in gas-fired combined cycle and combustion turbine electric power generators. We find strong evidence of real options effects. Regulatory uncertainty and profit uncertainty increase the probability of postponing investments. We also find evidence that regulatory uncertainty increases the probability of canceling investments.

A dynamic study of the U.S. natural gas market integration
Hayette Gatfaoui, IESEG School of Management (France)

We investigate the potential convergence of natural gas prices at one hub and several city gates in the United States. First, we estimate the fundamental natural gas price component. Second, we gauge if U.S. regional natural gas prices follow the law of one price. Our findings confirm the difference between West and East natural gas prices, but also highlight discrepancies between West and other regional natural gas prices. Third, we measure the distance between the fundamental gas price component and both Henry hub and city gate prices. The proximity/remoteness of regional gas prices with the fundamental gas price component supports market integration/segmentation. We show that the U.S. natural gas market shifts towards a more integrated structure after August 2004. Such shift results from the delayed impact of recent FERC reforms and the development of interstate pipelines. However, intrastate pipeline-deficient regions require an enforced development and improvement of natural gas infrastructures.

Machine learning models for the prediction of Italian electricity prices. Do they really outperform the benchmark?

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Silvia Golia, University of Brescia (Italy)
Matteo Pelagatti, University of Milano - Bicocca (Italy)

In this paper we have estimated Random Forest (RF) and SVM models in the time period January 2015 - August 2019 to forecast electricity prices on the Italian spot market and introducing information about intra-daily markets within a set of explanatory variables which enable to improve the forecasting performance of the model. RF (Breiman, 2001) belongs to the family of ensemble learning models, with the decision tree, which is applied also in the time series context (Ahmed et al., 2010), as base learner. Ensemble learning models are methods developed for reducing model instability and improving the accuracy of a predictor through the aggregation of several base learners. RF combines k decision trees based on bagging and random selection of input features; Petropoulos et al. (2018) have explored the applicability of bagging for time series forecasting. The variables involved are a response variable and a set of covariates. In addition to the predictor, it is possible to compute, for each covariate, a variable importance (VI) measurement, which is defined as total heterogeneity reduction produced by a given covariate on the response variable when the sample space is recursively partitioned. It was observed that VI measures tend to favor covariates having more values, so the method introduced by Sandri and Zuccolotto (2008) was used in order to eliminate this kind of bias. Support Vector Machines (SVM; Hastie et al., 2009) are machine learning models that attempt to pass a linearly separable hyperplane through a dataset in order to fit a function relating a set of variables to a dependent variable. This hyperplane is a linear separator for any dimension. RF and SVM have been estimated for all physical zones through which the Italian market is organized: North, Centre- North, Centre-South, South, Sicily, Sardinia. For each zone we have collected hourly spot prices, prices in each of the 4 intra-daily markets (MI1, MI2, MI3, MI4), one-day ahead forecasted electricity demand and one-day-ahead forecasted wind generation. The eight months of 2019 have been left out for forecasting purposes. Observed spot prices have been compared with one-day-ahead forecasts obtained through a rolling window procedure with constant estimates conditional to the end of 2018 using linear AutoRegressive models. Taking advantage of the variable importance index, which is intrinsically computed by the RF we have been able to rank regressors according to their relevance in different zones.

From point forecasts to statistical scenarios using implicit generative ensemble post-processing

Tim Janke, Technische Universität Darmstadt (Germany)

Optimal decision making under uncertainty requires prediction models that correctly report the forecast uncertainty. As decision making problems in power system often are of multivariate nature, e.g. short-term planning in space and/or time, multivariate probabilistic forecasts are of particular interest in this domain. In this talk, we present a framework for combining implicit generative models with an ensemble of point forecasting models. Our approach allows to draw multivariate samples from the predictive distribution without making parametric assumptions about the underlying probability distribution. We demonstrate our approach for the task of probabilistic electricity price forecasting and compare it empirically against well-established benchmarks. As our model works on top of an ensemble of domain specific expert models, it can readily be deployed to various forecasting tasks.

A model of price correlations between clean energy indices and energy commodities

Takashi Kanamura, University of Kyoto (Japan)

This paper theoretically and empirically examines the relationship between environmental value embedded in clean energy indices and energy value obtained from energy prices by focusing on the influence of energy risk on clean energy business including renewables. We propose a supply and demand-based correlation (CR) model of clean energy indices and energy prices that takes into account the influence of energy on clean energy business including renewables. We also propose a market risk model based on CR model to conduct the risk management for stocks of clean energy firms appropriately. Empirical studies estimate the model parameters using the stock indices and energy prices including S&P Global Clean Energy Index (GCE), Wilderhill Clean Energy Index (ECO), S&P/TSX Renewable Energy and Clean Technology Index (TXCT), S&P 500, WTI crude oil prices, and Henry Hub (HH) natural gas prices. It is shown by using the model that the correlations between GCE or ECO and WTI crude oil or HH natural gas prices be positive and be an increasing function of the corresponding energy prices. Results seem reasonable because the values of renewable energy businesses, which sell electricity in the spot market, are enhanced by the increase in energy prices, considering that electricity spot prices tend to increase in line with energy prices. In contrast, it is also shown that the correlations between S&P 500 and WTI or HH prices be still positive but be a decreasing function of the energy prices. This sharp contrast may come from the fact that the S&P 500 listed companies' businesses can be damaged by high energy prices while not applicable to GCE and ECO companies. Regarding TXCT, the correlations with WTI are positive and are a decreasing function of WTI while those with HH tend to be positive and are an increasing function of HH. It may suggest that TXCT is not fully functioning but still developing as a clean energy index, taking into account the results of GCE and ECO. Regarding market risk, CR model demonstrates different VaR from ordinary normal distribution (OND) model because CR model includes more upward or downward sloping demand curve shape reflecting the reality of the markets than the exponential in OND model, resulting in positive or negative impacts of prices on the volatilities in high clean energy index regions, respectively. We compare CR model with existing dynamic conditional correlation (DCC) model. Since CR model demonstrates the same level of the correlations from DCC model, CR model can work well as the correlation model.

Optimal market making on intraday power markets
Rüdiger Kiesel, University of Duisburg-Essen (Germany)

We present an approximate solution for the pricing of a market maker on the intraday market for power deliveries in Germany who optimizes cash and penalizes herself for inventory held during and at the end of her trading period. The prices emerge from a model for that market which has two important features incorporated, namely stochastic bid-ask spreads and time dependence as well as clustering of the occurrences of events which have an impact on the price and bid-ask spread. The dependence of the solution on the inventory penalties is negative. The larger the bid-ask spread, the smaller the market maker chooses her marks. The larger her marks are, the smaller is the impact of excitement on them. A backtest of the strategy reveals that the outperformance of a naive strategy is substantial, whereas a strategy with only clustering missing is not outperformed massively.

ETS models and recurrent neural networks
Carlo Lucheroni, University of Camerino (Italy)

ETS models, like for example the ETS(A,N,N), are short-term memory stochastic dynamic linear models with latent variables, based on exponential smoothing techniques, often used in econometrics (and less often in energy finance) to do point and interval forecasting. Even though ETS don't seem to be connected with Recurrent Neural Networks (RNN), it will be shown that they are deeply connected with them. Moreover, on one hand it will be shown how to generalize ETS models into RNNs, and on the other hand how to recover an ETS model from some specific RNN. Some consequences of this relationship will be discussed. For example, being ETS models particularly useful for modeling nonstationary time series, this property could be carried over to RNNs, and more in general to neural networks which in turn could be used to model nonstationary energy finance time series.

Structural VAR analysis of price forecast errors - decision support in day-ahead and intraday electricity markets
Katarzyna Maciejowska, Wrocław University of Science and Technology (Poland)

Structural VAR models allow to model jointly a set of random variables and decompose their forecast errors into structural shocks. In this research, SVAR model is applied to German electricity market, which enables identificaiton of two speculative shocks (day-ahead and intraday) together with weather and demand shocks. In order to capture the dynamics of the system, contemporaneous responses are conditioned on the level of residual demand. Finally, the variance of innovations is allowed to cluster and therefore is modeled via an ARCH model. The model specification is verified and the nonlinear responses are tested. The results are next used as a decision support in a trade strategy choice of a small RES utility.

Robust tests of normality for gasoline prices

Andrea Bastianin, University of Milano-Bicocca and CefES (Italy)
Matteo Manera, University of Milano-Bicocca, CefES and FEEM (Italy)

The sample skewness and kurtosis of macroeconomic and energy time series are routinely scrutinized in the early stages of model-building and are often the central topic of studies in economics and finance. Notwithstanding the availability of several robust tests, most scholars in economics rely on the method-of-moments approach that is known to be very sensitive to outliers. We carry out an extensive Monte Carlo analysis to evaluate the performance of different tests for normality. We consider several statistical distributions that approximate the range of data generating processes of major macroeconomic and energy time series. We study the properties of both the asymptotic and the bootstrapped distributions of each test. The application considers Canadian gasoline prices data to assess the presence of Edgeworth cycles.

Estimation of 1-in-20 year national gas peak daily demand in some European countries

Carolina Garcia Martos, Technical University of Madrid (Spain)

Regulation 994/2010 on security of gas supply imposes the obligation on EU Member States (MS) to fulfill the infrastructure standard. This means that every MS has to be able to satisfy the 1-in-20 year national gas peak daily demand (Dmax) after the failure of its largest infrastructure. Thus, an accurate estimate of Dmax is needed. Here we provide several approaches to the problem, including univariate and multivariate time series models, bootstrap methods and Monte Carlo simulations. Limitations and advantages of the proposed methodology are discussed. The obtained estimates can be compared with the estimates delivered by the Competent Authorities of the countries.

Ensemble forecasting for intraday electricity prices: simulating trajectories
Michał Narajewski, University of Duisburg-Essen (Germany)

The German Intraday Continuous is still relatively new and not fully discovered electricity market. Nevertheless, researchers do not investigate it as willingly as the Day-Ahead Market. This results in a scarce literature regarding the electricity price forecasting (EPF), especially the probabilistic forecasting, on this market. Recent studies concerning the point EPF have shown that the Hourly German Intraday Continuous Market is weak-form efficient. Thus, in the following paper we approach the electricity price forecasting in an advanced way. A probabilistic forecasting of the intraday electricity prices is performed by simulating trajectories of the prices to receive a realistic ensemble. It can be applied to evaluate further applications, like trading strategies. The prices are assumed to follow the skew student t-distribution. Then the generalized additive model for location, shape and scale is utilized in order to estimate not only the expected value of the prices, but also the higher moments: variance, skewness and kurtosis. The model consists of both autoregressive effects and exogenous variables, e.g. the time to maturity or the most recent price of the nearby products. This way we obtain a probability distribution that can be used in purpose of ensemble forecasting of the intraday prices. This includes a recursive algorithm that gives a new probability distribution at each step of the forecasting horizon. In the study a rolling window is applied and various forecasting horizons are considered as well as various versions of the considered model. The forecasting results are evaluated using different scores like the energy score and compared with benchmark models.

Balancing RES generation: profitability of an energy trader
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Weronika Nitka, Wrocław University of Science and Technology (Poland)
Tomasz Serafin, Wrocław University of Science and Technology (Poland)
Rafał Weron, Wrocław University of Science and Technology (Poland)
Tomasz Weron, Wrocław University of Science and Technology (Poland)
Przemysław Zaleski, Wrocław University of Science and Technology

Motivated by a practical problem faced by an energy trading company in Poland, we investigate the profitability of balancing intermittent generation from renewable energy sources (RES). We consider a company that buys electricity generated by a pool of wind farms and pays their owners the day-ahead system price minus a commission, then sells the actually generated volume in the day-ahead and balancing markets. We propose and evaluate different trading strategies which base on publicly available data and time series models. We compute the expected profit and market risk faced by the company as a function of the commission charged and the adopted trading strategy. Additionally, we note the importance of contract design in mitigating the risk of the energy trading company.

A new integrated risk-management policy for the newsvendor position
Andrea Roncoroni, ESSEC Business School (France)

In the context of a newsvendor model featuring random price and demand, we show that integrating the optimal combined hedge developed in Guiotto and Roncoroni (2018) with the optimal procurement policy allows an agent to obtain a significant enhancement in terms of mean-variance utility as well as both risk and return. This gain may be traded off for either a reduction or an increase of operational effort.

Greener, more integrated, and less volatile? A quantile regression analysis of Italian wholesale electricity prices
Alessandro Sapio, University of Naples Parthenope (Italy)

This paper provides estimates of quantile regression models of Italian day-ahead electricity prices, augmented with explanatory variables accounting for the supply of renewables in the 2006-2015 time window. The results confirm the merit order effects detected in the existing literature, both for photovoltaics and wind power, more strongly in market conditions characterised by moderately low price levels and with an implied increase in volatility. The effects of renewables have been stronger in the second half of the sample, possibly because of a complementarity with a new cable linking Sardinia with continental Italy. Effects from photovoltaics are more sensitive to robustness checks. Differences across zonal markets are nonetheless detected.

Through the looking glass: Ireland's Climate Action Plan and the energy transition
Derek Scully, Energia (Ireland)

In 2019, the Irish Government published an ambitious all of Government Climate Action Plan outlining 183 specific actions designed primarily to reduce Ireland's greenhouse gas emissions in the period to 2030. The Plan sets out a number of specific targets to be achieved by 2030, including; (1) 70% renewable electricity; (2) 500,000 home retrofits; (3) 1 million electric vehicles; (4) energy communities and microgeneration, and; (5) a trajectory for carbon tax increase to get to (at least) €80/t. This paper considers some of the implications of these targets for Ireland and for the energy transition more generally, and poses a number of important questions that require urgent attention. The energy transition will require an unprecedented level of investment across the relatively short time frame to 2050 and as such presents various and varied opportunities for utilities. These opportunities will be realised primarily by those with access to capital and, with the ability to adapt and operate in this new energy paradigm. For consumers, the transition will not be free and, at a time of complex and dynamic change for the sector, stability and certainty from policy-makers and Governments will be necessary to minimise the additional costs.

Online distributed learning in wind power forecasting
Benedikt Sommer, Maersk and Technical University of Denmark (Denmark)

Forecasting wind power generation up to a few hours ahead is of utmost importance for the efficient operation of power systems and the participation in electricity markets. Existing statistical learning approaches exploit the available spatial-temporal patterns in wind power generation between geographically dispersed sites to improve the forecasts. Learning space-time models in this setting requires the access to the explanatory variables of each site. Generally, explanatory variables can contain data which wind farm operators are unwilling to share. This explains the recent interest in data privacy-preserving distributed algorithms for learning space-time models. A limitation of the available algorithms is that the forecasting model's coefficients are estimated on a batch of historic data without the opportunity to re-estimate them computationally efficient when new data arrives sequentially. This paper presents two data privacy-preserving distributed algorithms with efficient model coefficient re-estimation techniques for learning high-dimensional space-time models. The first algorithm is a variation of the well-known Alternating Direction Method of Multipliers (ADMM), while the second algorithm is inspired by mirror descent approaches to be computationally more efficient. A qualitative simulation study allows to underline the convergence and tracking ability of both algorithms in settings with time-varying model coefficients. The ability to produce accurate forecasts of wind power generation is verified on a large real-world dataset of 311 wind farms.

Power Purchase Agreements and solar securitization: modelling risk factors and returns
Stefan Trück, Macquarie University, Sydney (Australia)

Over the last decade, there has been substantial growth in the number of solar photovoltaic (PV) installations around the world. This paper examines the financial viability of enhancing rooftop electricity generation through Power Purchase Agreements (PPA) with capital provided through an Asset Backed Security (ABS). We provide a framework that extends the literature on securitization of solar photovoltaic assets in several dimensions: the developed model allows for an ABS structure with several investment tranches and different risk profiles. It further considers the price differential between electricity consumed by households and the surplus electricity that is fed into the grid. Finally, the model allows to examine the financial impact of combining solar PV systems with storage options such as lithium-ion batteries. In a case study, using actual consumption and production data from NSW, Australia, we illustrate the economic benefits of a PPA ABS for PPA consumers, the originator of the ABS and investors for various scenarios.

Optimal installation of solar panels with price impact: a solvable singular stochastic control problem

Tiziano Vargiolu, University of Padova (Italy)

We consider a price-maker company which generates electricity and sells it in the spot market. The company can increase its level of installed power by irreversible installations of solar panels. In absence of the company's economic activities, the spot electricity price evolves as an Ornstein-Uhlenbeck process, and therefore it has a mean-reverting behavior. The current level of the company's installed power has a permanent impact on the electricity price and affects its mean-reversion level. The company aims at maximizing the total expected profits from selling electricity in the market, net of the total expected proportional costs of installation. This problem is modeled as a two-dimensional degenerate singular stochastic control problem in which the installation strategy is identified as the company's control variable. We follow a guess-and-verify approach to solve the problem. We find that the optimal installation strategy is triggered by a curve which separates the waiting region, where it is not optimal to install additional panels, and the installation region, where it is. Such a curve depends on the current level of the company's installed power, and is the unique strictly increasing function which solves a first-order ordinary differential equation. Finally, our study is complemented by a numerical analysis of the dependency of the optimal installation strategy on the model's parameters.

Enhancing load, wind and solar generation forecasts in day-ahead forecasting of spot and intraday electricity prices

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Tomasz Weron, Wrocław University of Science and Technology (Poland)

In recent years, a rapid development of renewable energy sources (RES) has been observed across the world. Intermittent energy sources, which depend strongly on weather conditions, induce additional uncertainty to the system and impact the level and variability of electricity prices. Predictions of RES, together with the level of demand, have been recognized as one of the most important determinants of future electricity prices. In this research, it is shown that forecasts of these fundamental variables, which are published by Transmission System Operators (TSO), are biased and could be improved with simple regression models. Enhanced predictions are next used for forecasting of spot and intraday prices in Germany. The results indicate that improving the forecasts of fundamentals does not bring any gains in case of the spot market, but leads to more accurate predictions of intraday prices. Finally, it is demonstrated that utilization of enhanced forecasts is helpful in a day-ahead choice of a market (spot or intraday) and results in a substantial increase of profits.

Estimation and simulation of the transaction arrival process in intraday electricity markets
Florian Ziel, University of Duisburg-Essen (Germany)

We examine the novel problem of the estimation of transaction arrival processes in the intraday electricity markets. We model the inter-arrivals using multiple time-varying parametric densities based on the generalized F distribution estimated by maximum likelihood. We analyse both the in-sample characteristics and the probabilistic forecasting performance. In a rolling window forecasting study, we simulate many trajectories to evaluate the forecasts and gain significant insights into the model fit. The prediction accuracy is evaluated by a functional version of the MAE (mean absolute error), RMSE (root mean squared error) and CRPS (continuous ranked probability score) for the simulated count processes. This paper fills the gap in the literature regarding the intensity estimation of transaction arrivals and is a major contribution to the topic, yet leaves much of the field for further development. The study presented in this paper is conducted based on the German Intraday Continuous electricity market data, but this method can be easily applied to any other continuous intraday electricity market. For the German market, a specific generalized gamma distribution setup explains the overall behaviour significantly best, especially as the tail behaviour of the process is well covered.

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