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B O O K O F A B S T R A C T S

WINDOW SELECTION AND AVERAGING FOR PROBABILISTIC DAY-AHEAD ELECTRICITY PRICE FORECASTING

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Overview

Most day-ahead electricity price forecasting (EPF) studies focus on developing models that better represent the inter-variable dependencies or implementing faster and more efficient estimation algorithms. However, somewhat surprisingly, authors have almost completely ignored the problem of finding the optimal length of the calibration window. The typical approach is to select ad-hoc, a 'long enough' window. The problem is that there is no consensus in the literature as to the length of this window – training samples as short as two weeks and as long as six years have been used.
In this study we build on a recently introduced concept for point forecasting [1, 2], that averaging day-ahead electricity price predictions over calibration windows of various lengths produces better results than selecting, even ex-post, only one 'optimal' window length. Here, we extend this approach to probabilistic forecasts.

Methods

In order to test our methodology, we consider four autoregressive structures as forecasting models and utilise datasets from three major power markets that differ in geographic location and generation mix: Nord Pool (Norway, Denmark, Finland, Sweden), EPEX (Germany, Austria) and PJM (the United States). We apply a so-called variance stabilizing transformation (VST) and examine if models fitted to transformed input data yield better forecasting accuracy compared to those calibrated to raw prices. Like the majority of EPF studies, we consider a rolling window scheme. Initially, the first 1092 (= 3 § 364) days are used for calibration of the expert models, then we compute point forecasts for 1065 different calibration window lengths, ranging from 28 to 1092 days. We look at the variability of prediction errors and examine the performance of the arithmetic average of forecasts from different combinations of windows. Furthermore, we introduce a new, well-performing weighting scheme for averaging point forecasts, which assigns larger weights to windows that have performed well in the past.

Based on point forecasts, we construct prediction intervals (PI) using Quantile Regression Averaging (QRA) on multiple types of inputs. We consider averaging point forecasts and using the results as a single-vector input for quantile regression as well as using QRA on a multi-vector input of point forecasts. We also focus on the length of the calibration window for probabilistic forecasts – ranging from 7 to 364 days. Moreover, we look if gains in the accuracy of interval forecasts can be achieved by averaging quantiles obtained from different calibration windows.

Results

We show that averaging point forecasts across a mix of short- and long-term windows typically outperforms an average across all windows as well as every single calibration window. The combination of 56, 84, 112, 714, 721 and 728 day windows performs very well and – in most cases – is not significantly outperformed by any other forecast. It turns out that the proposed weighting scheme almost always outperforms the simple arithmetic average with equal weights. Moreover, when compared to simple averaging, the new scheme minimizes the negative impact of a poorly performing calibration window (or a window subset) on the resulting forecast, hence yielding an even more robust outcome.

Regarding probabilistic forecasts, we show that the accuracy of our method of constructing PI highly depends on the quality of point forecasts. Interestingly, a single-vector input of averaged point forecasts turns out to yield better results compared to a multi-vector input. We have also observed that significant accuracy gains can be achieved by averaging quantile forecasts obtained from different calibration windows. Once again the combination of short- and long-term windows has proven to perform very well across all datasets.

Conclusions

Our studies show that utilising such a simple method as averaging forecasts over different window lengths can significantly increase the accuracy of both point and probabilistic electricity spot price forecasts.
For probabilistic forecasting, a single-vector input of averaged point forecasts yields better results than a multi-vector input, both in terms of accuracy and computation efficiency. Moreover, it turns out that averaging forecasts across a number of short and long calibration window lengths, consistently (for all models and datasets, both for point and probabilistic forecasts) gives better results than selecting only one 'optimal' window length, which is risky and almost impossible to be done ex-ante.

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UNDERSTANDING INTRADAY ELECTRICITY MARKETS: VARIABLE SELECTION AND VERY SHORT-TERM PRICE FORECASTING USING LASSO

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Overview

Since the deregulation of government-controlled power sectors in the 1990s and 2000s and the introduction of competitive markets in many countries worldwide, electricity is traded under market rules as any other. In Europe, the workhorse of power trading has been the uniform price auction conducted a day before delivery, and a vast majority of research and applications has concerned day-ahead (DA) electricity prices. However, the expansion of renewable generation (mostly wind and solar), power grid modernization (including increase of interconnector capacity) and active demand side management (smart meters, smart appliances) have made the electricity demand/supply and prices more volatile and less predictable than ever before. This has amplified the importance of intraday markets, which can be used to balance deviations resulting from positions in day-ahead contracts and the actual demand. As a result, during the last few years we have observed a shifting of volume from the DA to intraday markets across Europe.

Method

Using a unique set of prices from the German EPEX market we take a closer look at the fine structure of intraday markets for electricity with its continuous trading for individual load periods up to 30 minutes before delivery. We apply the *least absolute shrinkage and selection operator* (LASSO) to gain statistically sound insights on variable selection and provide recommendations for very short-term electricity price forecasting.

Results

We have considered 12 models, including a naive benchmark, a parsimonious autoregressive structure inspired by the well-performing $expert_{DoW,nl}$ model of Ziel and Weron (2018) and a LASSO-estimated model with 349 to 372 potential regressors and ten different values of the *tuning* parameter. We have found that for an appropriately chosen value of λ, the LASSO model significantly outperforms the competitors, as measured by the Diebold-Mariano test. The most important explanatory variables turned out to be the most recent intraday price and the day-ahead (DA) price corresponding to the same hour. Also, the intraday and – to a lesser extent – the DA prices for late evening hours could be considered as regressors. On the other hand, in contrast to day-ahead EPF models, neither the previous day's price for the same hour nor weekday dummies were found to be important predictors.
Finally, we have shown that the LASSO can be used to build well-performing, parsimonious ARX-type models. In particular, an OLS-estimated model with regressors that have been selected by the LASSO at least 70% of time in a 364-day rolling 'selection' window, performs comparably to the best LASSO model.

Conclusions

Using a unique set of electricity prices from the German EPEX market, we have addressed the problem of the optimal choice of explanatory variables for forecasting intraday prices. Given that the literature on this topic is very scarce, our study is a major step forward towards understanding the intraday price dynamics and developing well performing predictive models for a market that many participants see as the future of electricity trading.

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SMILE MODELLING IN COMMODITY MARKETS

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Overview

An increasing number of derivatives written on Commodity Futures are traded on the market or are embedded within structured notes. Examples of these contracts are Autocallable, Accumulator or Swing Options. These derivatives are, due to their digital clauses, sensitive to smile effects. The most liquid hedging instruments in the Commodity markets are, in addition to the Futures contracts themselves, the Plain Vanilla Options on Futures and sometimes some exotics like Calendar Spread or Mid Curve Options. Therefore, we need to develop a pricing model for Futures able to reproduce the market smile that can be calibrated in a fast and robust way to market quotes. Moreover, for some underlyings, the market quotes Futures on different delivery periods. Therefore, we need a model that is flexible enough to link instruments indexed on different delivery periods.

Methods

The model for Futures is built starting from a one factor mean reverting process with local volatility. This process does not represent any tradable asset and therefore must not obey any non-arbitrage law. Model Futures are a transformation of the only state variable. This makes the calibration of the Futures curve immediate. This property also makes it possible to relate Futures with different delivery periods with a closed formula. The model Options on Futures are computed via a Dupire style equation. The calibration of the non-parametric local volatility is then performed with a fixed-point algorithm based on the asymptotic relations between local volatility and market volatility for small times and strike around the ATM. The convergence rate of the algorithm is also improved using an Anderson accelerator. Finally mean reversion calibration is performed on exotics such as Calendar Spread or Mid Curve Options whose values can be obtained efficiently by solving a Dupire style equation.

Results

In this research we show analytical and numerical results. Initially we show that Model Options solve an extended version of the Dupire equation and we show an asymptotic study of local volatility in terms of market volatility. Afterwards we study with some examples the performance of the algorithm based on these asymptotics. In all the cases shown, we are able to calibrate the non-parametric local volatility with a precision of half the basis point with less than 20 iterations. Finally, we show an example of mean reversion calibration against a set of WTI crude oil Mid Curve Options on different tenors. In this example, we obtain a good fit of the market prices by taking the mean reversion constant over time.

Conclusions

We present a local volatility model for derivatives contracts on commodity Futures. The model calibration is performed in a fast and robust way via an extended version of the Dupire equation and a fixed-point algorithm. We show that the model is able to recover exotic options quoted in the market, such as Calendar Spread Options.

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Sergei Kulakov and Florian Ziel
DETERMINING THE DEMAND ELASTICITY IN A WHOLESALE ELECTRICITY MARKET

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Overview

The main focus of researchers in energy markets is typically placed on the analysis of the supply side. The demand side, despite its critical importance, is a subject which still deserves a more profound academic investigation. In particular, the number of studies on the demand elasticity in a wholesale market is limited to merely several pieces. In this paper we extend this field of study and propose a new method for determining the demand elasticity. More specifically, we decompose the data observed in the wholesale market into individual supply and demand schedules of the market participants. This allows us to better understand their bidding behavior and thus make more precise inferences about the functioning of an electricity market.

Methods

The supply and demand curves recorded by the German EPEX SE build the foundation of our research. To proceed with our study, we rely on the papers of Knaut and Paulus (2016) and Coulon, et. al (2014). The former paper elaborates on the market participants of an electricity market (retailers, suppliers and utility companies) and on the integration of their supply and demand schedules into the market supply and demand curves. Following the paper, this integration can be carried out according to two methods: einther the bids and asks of market participants are simply aggregated with speculative behavior being prohibited or a wholesale market with existing opportunities for speculation is established. Naturally, equilibrium prices are identical in both markets, the demand curve is more elastic in the latter market, whereas the final equilibrum volumes are higher in the former one. The findings of the former paper are corroborated by the latter paper which states that in an extreme case the demand curve is inelastic. Note that assuming an inelastic demand curve is a commonly made assumption in e.g. fundamental modeling.
Our aim is to determine a combination of the two above described markets. This allows us to construct a more accurate fundamental model of the German electricity market, i.e. account not only for the deals arranged in the wholesale market, but also for e.g. the OTC and intraday deals. However, that the data we actually observe comes solely from the wholesale market. In turn, the knowledge of the precise market structure and of the schedules of the market participants is not available. We thus employ an optimization tool to decompose the initially observed wholesale supply and demand curves into the individual schedules of the market participants. Given these schedules, we can incorporate them into a single market by combining both above described methods to obtain a better fundamenal model of the German electricity market. To construct our model, we use a genetic algorithm tehcnique and aim to optimize our results with respect to the total load values recorded in the market.

Results

We demonstrate that our model outperforms the one in Coulone (2014) at least during the night hours in predicting the load values actually observed in the German electricity sector. This allows us to conclude that we can construct a more accurate fundamental model of the German electricity market using the wholesale market supply and demand curves and the knowledge of the market structure. Furthermore, it follows that the method for market decomposition we propose is indeed trustworthy. Moreover, the elasticity coefficients we have determied are of a non-linear nature and in the point of equilibrium are generally consistent with those provided in the single corresponding study by Knaut and Paulus (2016).

Conclusions

The present paper elaborates on a new method of market modeling. More specifically, we describe how the actually observed wholesale market data and the knowledge of the market structure can be used to obtain individual demand and supply schedules of the market participants. Aggregating these schedules in a single market allows us to construct a combination of the markets with an elastic and an inelastic demand curves, thereby obtaining a powerful fundamental model of an electricity maket. Having used the model for Germany, we showed that the model better describes the whole German electricity market and is suitable for e.g. determining the demand elasticity or even load forecasting.

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ECONOMETRIC MODELLING AND FORECASTING OF INTRADAY ELECTRICITY PRICES

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Overview

Constant development of weather-dependent renewable energy production in Germany requires flexible market, in which power plants can balance their production forecast errors that may be caused by changing, unpredicted weather conditions. Introduction of intraday electricity markets faces these problems and lets market participants trade the energy continuously until 30 minutes before delivery begins on the whole market and until 5 minutes before delivery begins within respective control zones. In the paper we analyse the ID3-Price on German Intraday Continuous Electricity Market using an econometric time series model. A multivariate approach is conducted for hourly and quarter-hourly products separately. We estimate the model using lasso and elastic net techniques and perform an out-of-sample very short-term forecasting study. The model's performance is compared with benchmark models and is discussed in detail. Forecasting results provide new insights to the German Intraday Continuous Electricity Market regarding its efficiency and to the ID3-Price behaviour.

Methods

In this paper we focus our attention on the ID3-Price index. We model it in a multivariate manner, which is a well-known technique in electricity price forecasting. We utilize an autoregressive approach, but we also make use of the continuity of the Intraday Continuous market. Our goal is to take advantage of all the information that is available on the market. Additionally, as external regressors we take into consideration the results of Day-Ahead and Intraday Auctions. We utilize variance stabilization transformation on the data and we estimate the model using least absolute shrinkage and selection operator (lasso) and elastic net regularization. We compare the model with benchmark models using MAE, RMSE and Diebold Mariano test. For the best performing models variable selection analysis is conducted.

Results

The results for hourly products are quite surprising. None of the compared models have beaten the naive model that models the ID3 price with the weighted-average price of transactions that take place no earlier than 15 minutes before forecasting time, which is 3 hours before the delivery. This is an indication of the efficiency of the market, as there is no arbitrage possible for risk-neutral traders, similarly to established financial markets. The results for quarter-hourly products are different – the proposed model is performing significantly the best. This suggests, that the quarter-hourly intraday market is not efficient and still autoregressive or deterministic structure can be found there.

Conclusions

The results for hourly products suggest that there is no more information, that we can get from the transactions data, despite the most recent price, which means that here we deal with an efficient market. Therefore, none of the considered models performed better than the naive most recent value. On the other hand, the results for quarter-hourly products have shown, that there is some space for improvement. For this market the most recent value did not give satisfying results. The reason for this may be lower number of transactions by the time of forecasting, when comparing to the market of hourly products. Variable selection analysis of this model has shown, that the most relevant regressors are: corresponding Intraday Auction price, most recent value of the corresponding product and most recent value of closest hourly product.

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A FIRST ATTEMPT TO BRIDGE THE GAP BETWEEN DERIVATIVE AND INSURANCE CONTRACTS: HEDGING METEOROLOGICAL RISK

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Overview
This contribution presents some preliminary results of a wider research project whose aim is to propose a range of hybrid contracts for hedging meteorological risk. Those contracts are structured in such a way that they may benefit of positive characteristics carried by both standard financial derivatives and insurance contracts without incurring in their drawbacks.

Methods
The first step for pricing these hybrid contracts is based on calibrating an autoregressive processes and long-term trends and on a subsequent simulation part (usually referred as burn analysis in related literature) that, creating a large number of possible scenarios, tries to replicate the effective behavior of meteorological events such as temperature and rainfall. In order to make this approach attractive for insurance companies, pay-offs are generated, according to the standard theory of coherent risk measures, by means of the Expected Shortfall (ES)

Results
The final part of this contribution illustrates some numerical results that display how the determination of the price of an insurance contract against adverse weather conditions affecting a limited area can be carried out and the potential effectiveness of this approach.

Conclusions
Financial derivatives traded on a regulated market are fairly priced but they end up being ineffective in hedging extreme and/of very localized events; on the other hand, insurance contracts are tailor-made so to tackle a specific risk but turn out being very expensive for the insured counterpart. The reduction in size of this normally huge gap could benefit both agents seeking insurance and insured companies. The first will receive a more appropriate amount of money in case a negative event strikes their belongings; the second might increase, due to more attractive prices, the number of issued insurance contracts.

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Options on Futures in Electricity Markets: An Affine Seasonal Stochastic Volatility Model

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Abstract

Futures contracts cover one of the most important types of derivatives in the electricity market. However, some properties of this source of energy lead to specific requirements in the pricing method for electricity futures as well as for options on these futures.

In particular, one has to handle the non-storability of electricity, which is therefore called a flow commodity. This characteristic is the reason why the spot has to be consumed immediately after receiving the good. Hence, electricity futures will be the derivatives of interest, which deliver the underlying over a period of time. A weight function has to be introduced to cover the delivery over a period. To add, seasonalities in the delivery month play an important role triggered by the non-storability of the commodity. Moreover, the Samuelson-Effect will be included to cover the volatility term-structure.

In addition, we investigate European options on monthly delivering electricity futures at the EEX. The well-known volatility smile can be observed in the related volatility surfaces and motivates a stochastic volatility model as proposed by Heston. The Heston model is applied to spot prices including a volatility dynamics modeled as a mean-reverting CIR process. We apply the model directly to the futures price embedded into a multi-factor framework and admit a seasonal long-term mean in order to include seasonalities in the trading day.

KEY WORDS: electricity futures options, option pricing, seasonal stochastic volatility

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Forward or backward simulation? Application to the pricing of energy facilities*

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Abstract

The aim of this study is to present algorithms for the backward simulation of several common stochastic processes and compare their computational effort to the standard sequential construction. The traditional Monte Carlo (MC) approach is based on the generation of trajectories forward in time over a time grid of d points $t_1, t_2, \ldots, t_d = T$. The computational cost of a such strategy depends on the particular stochastic process and the number of MC simulations. On the other hand, we are not restricted to generate the random points of the trajectory in sequence, the only strict requirement is to generate points with the correct transition density.

For a moment let us consider the simple case of a Brownian motion (BM); in the sequential generation the points are obtained forward in time, while for instance, the standard Brownian bridge construction fills the time grid simulating the last point first and then iteratively proceeding as shown in Figure (1a). The standard BB construction is not the only possible bridge construction, one can hook the left point to $t_0 = 0$ and obtain the backward simulation as shown in Figure (1b).

As far as we are aware of, an explicit backward algorithm has been only presented for a few processes: see Dutt and Welke [2], Pellegrino and Sabino [6] Hu and Zhou [3] for the backward construction of the standard Poisson, the Ornstein-Uhlenbeck (OU) and the CIR/Heston processes.

As first contribution of this study we extend the works of Ribeiro and Webber [7] and Avramidis and L'Ecuyer [1] on gamma bridge and obtain the backward construction of a Gamma process. Moreover, we are able to write a novel acceptance-rejection algorithm to simulate Inverse Gaussian (IG) backward in time therefore, using the time-change approach, we can easily obtain the backward generation of the Compound Poisson, the Variance Gamma (VG), the Normal Inverse Gaussian (NIG) processes and then the time-changed version of the OU process ($SubOU$) introduced by Li and Linetsky [4].

In principle the forward and backward constructions should have the same computational cost because they are based on the simulation of the same number of random points and rv's; the main difference is actually driven by the cost of generating the rv needed in the sequential or backward algorithms.

On the other hand, let us consider the pricing of a contract with complex American optionality with the Least Squares Monte Carlo (LSMC) approach introduced in Longstaff and Schwartz [5], (as often done for energy facilities such as gas storages, swings or virtual hydro power plans) what matters in the dynamic programming is the comparison between the intrinsic value and the continuation value at a given time step t. Therefore, one only needs to know the simulated prices

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or indices at time t and time $t+1$ only, nothing more. It means that if we assume a F-factor spot model with $N = 100$ simulations and $d = 365$ days, the sequential generation requires storing $365 \times 100 \times F = 36500F$ prices, for a one year contract, while in the backward solution a far lower number, $2 \times 100 \times F = 200F$, must be saved leading to a far lower computational burden.

We conclude our study conducting numerical experiments with the aim of pricing gas storages using a VG and IG time-changed OU process in a setting similar to the one published by Li and Linetsky [4].

We show how the advantage of using the backward simulation becomes therefore evident if the pricing solution is based on backward dynamic programming. The improvement becomes even more remarkable for longer maturities which makes the backward construction the native strategy for the implementation of the LSMC method.

(a) Standard bridge construction

(b) Backward construction

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Mariia Soloviova, Tiziano Vargiolu

Efficient representation of supply and demand curves on day-ahead electricity markets

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Overview

Supply and demand curves on day-ahead electricity markets are the results of thousands of bid/ask entries in the day-ahead auction, this for all the 24 hours. In principle, it would be possible to represent, and forecast, these curves by taking into account each production/consumption unit as a separate time series, and then joining these together to construct the final curves, and thus the resulting price. However, the huge number of these units (from several hundreds to thousands) makes this naive strategy infeasible, unless one has extremely high computing capacity with complex machine learning algorithms available.
In this talk, we present a much more parsimonious approach. In fact, the idea is to represent each curve using non-parametric mesh-free interpolation techniques, so that we can obtain an approximation of the original curve with far less parameters than the original one.
We consider the Italian electricity market (IPEX). IPEX consists of different markets, including a day-ahead market. The day-ahead market is managed by Gestore del Mercato Elettrico (GME) where prices and demand are determined the day before the delivery by means of hourly concurrent auctions. For each delivery day the market session starts at 8 a.m. of the ninth day before the day of physical delivery and closes at mid-day (12 p.m.) of the day before delivery.
The producers submit offers where they specify the quantities and the minimum price at which they are willing to sell. The demanders submit bids where they specify the quantities and the maximum price at which they are willing to buy. They are then aggregated by an independent system operator (ISO) in order to construct the supply and demand curves.
Accurate modeling and forecasting electricity demand and prices are very important issues for decision making in deregulated electricity markets. Different techniques were developed to describe and forecast the dynamics of electricity load. Short term forecast proved to be very challenging task due to these specific features. Functional data analysis is extensively used in other fields of science, but it has been little explored in the electricity market setting.

Methods

We are going to use a relatively new modeling technique based on functional data analysis for demand and price prediction. The first task for this purpose is to make an appropriate algorithm to present the information about electricity prices and demands, in particular to approximate a monotone piecewise constant function. The most promising technique to do so is the use of (integrals of) Radial Basis Functions (RBF), which are been used in several other applications (image reconstruction, medical imaging, geology, etc.) and allow a very flexible adaptation of the interpolating curves to real data. We will present different techniques for this interpolation, with their advantages and drawbacks, and with an application to the Italian day-ahead market.
The use of radial basis functions have attracted increasing attention in recent years as an elegant scheme for high-dimensional scattered data approximation, an accepted method for machine learning, one of the foundations of meshfree methods and so on.
Consider a set of N distinct data points $\{x_i\}_{i=1}^N \subset \mathbb{R}^n$ and a set of data values $\{y_i\}_{i=1}^N \subset \mathbb{R}$. We want to find a function $s : \mathbb{R}^n \to \mathbb{R}$ such that $s(x_i) = y_i$, $i = 1, \ldots, N$. Moreover, we want to find a basis for the solution, which depends on the data points. One simple way to do this is to choose a fixed function $\phi : \mathbb{R} \to \mathbb{R}$ and to form the interpolant as

$$s(x) = \sum_{i=1}^{N} \alpha_i \phi(\|x - x_i\|),$$

where the coefficients α_i are determined by the interpolation conditions $s(x_i) = y_i$. Therefore, the scattered data interpolation problem leads to the solution of a linear system

$$A\alpha = y, \text{ where } A_{i,j} = \phi(|x_i - x_j|).$$

The solution of the system requires that the matrix A is non-singular. It is enough to know in advance that the matrix is positive definite.
A radial function is a real-valued function whose value depends only on the distance from the center **c**. Some standard radial basis function are $\phi(r) = e^{-(\varepsilon r)^2}$ (Gaussian), $\phi(r) = e^{-\varepsilon r}(\varepsilon r + 1)$ (Matérn), $\phi(r) = (1 - \varepsilon r)^4_+(4\varepsilon r + 1)$ (Wendland), where $\varepsilon > 0$ denote a shape parameter, $r = \|x\|_2$.

Results

In our work we are using the data about supply bids from the Italian electricity market from the GME website **www.mercatoelettrico.org**.
Let $F(x)$ be a function which corresponds to the supply curve (i.e. piecewise non-decreasing constant function from $[0, M]$ to $\mathbb{R}^+$). We need to find a function $G(x)$, such that the difference between F and G is reasonably small.
Evidently, the approximation by polynomials does not suit to our problem. In order to keep monotonicity of supply curve we decided to use the integrals of RBF. Namely, we want to find an approximant of the form

$$G(t) = \sum_{i=1}^{M} \alpha_i \int_0^t \phi(\lambda_i \|x - x_i\|) \, dx,$$

where λ_i is a shape parameter for every center x_i.
We have shown that any supply curve (and any demand curve) can be approximated by a combination of error functions, which is the integral of a normalized Gaussian function, in the sense of L_2 convergence. The standard error function is defined as:

$$\text{erf}(x) = \frac{1}{\sqrt{\pi}} \int_{-x}^{x} e^{-t^2} \, dt = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} \, dt.$$

For the realization of our algorithm we are using standard function `lsqcurvefit` from MatLab Optimization Toolbox. The result of our program is the coefficients a_i, b_i, c_i of the function

$$G(x) = \sum_{i=1}^{k} a_i(\text{erf}(c_i \cdot (x - b_i)) + 1).$$

Conclusions

1. We are developing a parsimonious way to represent supply and demand curves, using a mesh-free method based on Radial Basis Functions.
2. We are dividing our problem into many local sub-problems in order to to manage computational costs.
3. Work in progress: solving analytically some of the optimization problem and theoretical error bounds.

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Antonella Basso, Giorgia Oggioni and Rossana Riccardi

EFFICIENCY VALUATION OF STOCKS AND GREEN PORTFOLIO CONSTRUCTION: A TWO STAGE APPROACH

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Overview

Nowadays, beside classical financial aspects, new relevant social requirements are perceived as important and need to be included in the construction of an investment portfolio. In particular, the environment is rapidly becoming a factor as relevant in an investment decision as more traditional financial elements such as liquidity or competition, since investors' mandates involve contributing to public policy goals, and one of the most important among these is climate mitigation.
Many initiatives are born around the climate change mitigation of investors' portfolios and this is one of the main theme identified by the sustainable finance literature.

Methods

In this paper, we evaluate and manage a “green” investment portfolio that integrates classical financial tasks with some environmental issues.
We first propose two synthetic indicators of environmental sustainability which effectively inform financial agents on the “greenity” of their investments. These alternative indicators could serve as an overall measure of environmental sustainability; they also overcome the drawback that limits the evaluation of green investments to the measurement of CO_2 emissions. Then, we propose alternative integrated methods for portfolio optimization that involves decisions on stock screening, stock selection, and capital allocation.
A two-step approach is adopted: in the first step, a wide set of relevant stocks are screened in order to find a group of potential investment targets that are simultaneously profitable and green. In the second step, we apply ad-hoc portfolio optimization models to determine the allocation of capital to each stock in the final portfolio.
The first step of the procedure is aimed at detecting the more promising stocks according to both a financial and an environmental performance. This stock screening and selection methodology is able to create a subset of best performing stocks that will be used for creating the green portfolio. We use a suitable data envelopment analysis (DEA) model with different selection methods for this selection procedure.
One of the main features of standard DEA models lies in the weight flexibility, which means that the models look for the optimal values of input and output weights and maximize the efficiency of the target unit without imposing particular restrictions on the weights; only positivity constraints are usually considered.
This fundamental feature of the DEA approach allows to highlight the input and output variables that put in the best light the units examined but it may sometimes lead to some drawbacks in the performance evaluation process. For example, a given unit may be evaluated as efficient despite having very high values of some inputs. In the DEA applications to mutual funds, for example, this could cause an investment fund to be assessed as efficient despite exhibiting a very high risk or requiring a very high initial payout (because of a high initial fee).
In a different situation, if we need to evaluate the performance of socially responsible investment funds or stocks (for example a green stock) and we include a measure of social responsibility (of environmental saving) as an additional output, a fund could be stated as efficient although its involvement in social responsibility is negligible, or it could be declared efficient even though its final value is very low.
In the cases in which it is advisable to ensure that we do not neglect some important input and output variables in the efficiency analysis, we can introduce some appropriate restrictions on the weights associated to these variables in the DEA model.
Moreover, a second reason that may suggest the introduction of additional weight restrictions in the DEA model is to somehow take into account eventual preference information of decision makers or experts on the respective importance of the variables that can be synthetized in a range for the weights.
It may be shown that the weights restrictions suggested in the literature often lead to models with a greater discriminatory power (see for example Angulo et al., 2002) that provide a lower number of efficient decision making units (DMUs). Especially when the number of DMUs is low, this feature may represent a third motivation for adopting a DEA model

with weights restrictions; an example of an effective increase in the discrimination obtained with weights restrictions is presented in Basso et al. (2017).
Several typologies of weights restrictions have been proposed in the DEA literature to reduce weight flexibility (for a review see Allen et al., 1997; Thanassoulis et al., 2004). In this work we will apply an assurance regions (AR) approach (Thompson et al., 1986), which impose restrictions on the ratios between the weights of inputs and/or outputs.
In our simulations we have considered three different cases: a symmetric case in which the bounds are the same for all input variables and two asymmetric cases in which the lower bound on the ratio between the weight of the final value and the weight of the green indicator is different from the lower bound of the reciprocal ratio, to stress the different importance that an investor could give to the two output variables. Indeed, we may have investors more prone to profit and others more prone to the environmental defense. A sensitivity analysis on the strictness of the bounds is also conducted.
The second step of the analysis is the creation of the green portfolio. Once the subset of more efficient stocks has been selected, a portfolio selection algorithm has been applied for capital allocation. Three different algorithms have been tested: the Markowitz portfolio selection algorithm, the Mean Absolute Deviation (MAD) algorithm and the Conditional Value at Risk (CVaR) one. To test the robustness of the procedure a dynamic version of the algorithm with periodical balance of the portfolio has been also tested.

Results

The analysis is carried out on a sample period of five years (taking as benchmarks the STOXX All Europe 100 index), using a three years moving window approach. At each iteration (one month period) the previous portfolio is disinvested and the proceeds are reinvested in the new rebalanced portfolio that is obtained with the application of the two step algorithm in the new 3-year time window (the moving windows). The capital invested in the rebalanced portfolio is equal to the final value of the investment in the previous time window.
Finally, the three algorithms have been tested with different risk level and several sensitivity analyses are also performed to evaluate the best methodology that can accomplishes the investor' preferences.

Conclusions

We introduce a set of environmental indicators for measuring the environmental performance of stocks. In addition, a two-step algorithm for the construction of a “green” portfolio is presented. In particular, we consider a dynamic version of the algorithm applying a self-financing strategy with periodical rebalance of the portfolio.
In doing this, we compare the results obtained with three different portfolio optimization algorithms (Markowitz, MAD, CVaR). In addition, we carry out a wide sensitivity analysis with respect to the width of the restriction on the weights associated to the DEA variables. Our empirical analysis confirms the applicability of the methodology proposed.

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RENEWABLES, FINANCE, AND GROWTH: CAUSALITY RELATIONSHIPS

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Overview

The global commitment to drastically curb greenhouse gas emissions towards a sustainable development is strongly connected to the development and usage of renewable energy (RE), such as solar and wind. Between 2006 and 2016, world's total RE consumption, excluding hydro-electricity, increased by almost 350% (from 93 to 420 million tonnes of oil equivalent), and RE investment grew from 47 US$ billion in 2004 to 279.8 billion in 2017 (BP 2017, FS 2018).

The effects of renewables on economic growth are examined by a growing body of empirical research which leads to the general result that increasing RE consumption or production leads to higher real GDP per-capita growth rates (see, among all, Sadorsky 2009, Tugcu et al. 2012, Aflaki et al. 2014, Omri 2014, Bhattacharya et al. 2016, Inglesi-Lotz 2016).

While there exists a well-established literature investigating the finance and growth nexus (the long-lasting strand shows the existence of a positive relationship between financial development and economic growth - among all, King and Levine 1993, Levine 2002, Levine 2005 - while recent contributions, that take on board lessons from the recent great recession, show that also financial structure matters - Demirgüç-Kunt et al. 2011, Gambacorta et al. 2014, Morganti and Garofalo 2018), the potential effects of the financial system on energy consumption, production or investment, are yet to be fully examined. It is reasonable to suppose that the financial system plays a crucial role in the RE and growth nexus, since either the overall financial development or the financial structure (bank- or market-based) of a country might influence the pace of its environmental development, to the extent that they can affect the financing of renewables investment (Mazzucato and Semieniuk 2018).

The aim of this paper is to empirically investigate the relationship between economic growth (measured by the real GDP per-capita growth rate) and renewable energy, by taking into account the role of financial development and financial structure. In particular, we will investigate the relationship between economic growth and renewables on the one hand, and renewables and financial structure and development on the other hand. The main questions addressed by the paper will be: i) Does exist a statistically significant relationship between RE and economic growth? ii) What are the effects across-countries and over-time in the long- or medium-run? iii) Does the financial system matter, and does its potential contribution to RE variables, mostly investment, vary according to the country's degree of economic and financial development? iv) What policy lessons can be learned?

Methods

The analysis will be conducted over the period 1990-2016 for a diversified sample of 38 countries, including both advanced and emerging economies.[1] Macroeconomic and energy data will be collected, respectively, from the World Bank's World Development Indicators (WDI) and International Energy Agency (IEA), while financial data from the World Bank's Global Financial Development Database (GFD). Environmental variables will mostly consist of RE production, consumption, and investment, as well as their shares over total energy. The role of the financial system will be examined by employing the financial development and structure indicators developed by Levine (2002).

We will consider two different datasets, cross-sectional and panel. The cross-sectional analysis serves to capture long-term relationships between RE and growth on the one hand, and RE and financial structure and development on the other hand, while the panel analysis serves to capture cross-countries and over-time variations of real GDP per-capita growth and RE growth in the medium-term. Following the methodology of the recent contributions in the finance and growth literature (see, for instance, Beck et al. 2014, 2016, Morganti and Garofalo 2018), we will consider both non-overlapping and overlapping 5-year windows (the latter allows us to exploit time series information, and thus also control for time fixed effects), and we will include country fixed effects in order to control for unobserved heterogeneity

[1] Countries selection stems from the need to find reliable and granular data on RE which can be obtained from OECD and IEA. Included countries, by region according to the World Bank classification, are: Australia, China, Japan, Korea Rep., New Zealand (East Asia and Pacific); Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Luxembourg, Netherlands, Norway, Poland, Portugal, Russian Federation, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom (Europe and Central Asia); Chile, Mexico (Latin America and Caribbean); Israel (Middle East and North Africa); Canada, United States (North America); India (South Asia). The sample, obtained by combining OECD and IEA economies, offers a wide range of variation across countries of energy consumption and production, as well as financial structure and development.

across countries and thus account for common factors and unobservable, time-invariant, country-specific effects on economic growth.

Results

In line with the existing research, we expect to find two broad outcomes: 1) a positive relationship between economic growth and RE consumption, or its share on total energy consumption, both in the long-run and in the medium-run, and 2) a statistical significant impact of the financial system, either considering financial development or financial structure, on the growth of RE consumption and investment, that affects positively economic growth. In addition, we expect to find evidence supporting the existence of i) reverse causality between RE and economic growth (the so-called "feedback hypothesis", Bhattacharya et al. 2016), implying that changes in RE consumption affect economic growth, and ii) a non-linear relationships between RE and growth according to the idea that renewables deployment remains negligible at low levels of growth whereas it increases once per-capita income reaches a given threshold and the demand for environmental quality rises (Aflaki et al. 2014).

Conclusions

The findings of our analysis might have important implications for the implementation of future policies promoting renewables access and investment, in line with a low-carbon path of sustainable development. RE consumption, or its share on total energy consumption, might be able to explain across countries and over-time variations of real GDP per-capita growth rates. In addition, the financial system should affect the energy and growth nexus to the extent that its overall development or its structure (bank- or market-oriented) might have a significant impact on renewables investment, which emerge to be a key variable in connecting the financial and real side of the economy in the energy and growth nexus.

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Investing in electricity production under a reliability options scheme

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1 Overview

In many electricity markets worldwide there are capacity remuneration mechanisms that explicitly remunerate power capacity. Among them, Reliability Options (ROs) have been implemented in Colombia (Cramton and Stoft, 2007), New England (FERC, 2014) and Ireland (SEM, 2015, 2016a, and 2016b) and are about to be implemented in Italy (TERNA, 2018, Mastropietro et al. 2018).

ROs give to their holder, the System Operator (SO), the right to ask the issuers, the power producers, to produce power when there is need for remuneration of power capacity, and to receive the (positive) difference between the market price of electricity and a predetermined price level. This price level is the strike price of the RO and is set in order to represent the value of the power at that specific level for which load is not shed. The issuer of the RO has the obligation to supply the SO with electricity when asked. It receives in exchange a predetermined payment for issuing the RO.

Andreis et al. (2018) discuss how the strike price and the stochastic parameters of the electricity price affect the price of the RO. They assume that a given power producer already exists and has to decide whether it wants to sell ROs to the SO or not. The difference in the value of the power plant with and without ROs determines the equilibrium price of the latter.

In this work, we discuss the case of a potential investor who is contemplating investing in a power plant when an RO scheme is in place. Our aim is to discuss how the implementation of an RO scheme affects the timing and the value of investments in power production.

2 Methods

We frame our analysis within the real option literature. The real options approach suggests that investment projects characterized by uncertainty and irreversibility are like call options in real assets in the sense that the potential investor has the right, but not the obligation, to pay the investment cost (strike price) in order to gain access to the cash flow under consideration (underlying asset).

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We first present and solve the problem of a potential investor who is investing in a power plant when no capacity remuneration mechanism is in place. We then address the same problem explicitly considering the case where a RO scheme is in place. In practical terms, the RO scheme is beneficial for the potential investor who can now account for a fixed cash flow unaffected by the fluctuations of the electricity price. However, the RO issuer is in turn obliged to apply a price cap to the electricity price that s/he can cash.

3 Results

We show in detail how the RO scheme affects the investment problem of the potential investor and we distinguish three cases.

First, if the predetermined price cap is high enough and the optimal investment threshold is reached first, we show that the investment takes place inefficiently early, a result that is also reflected in a lower investment option value.

If instead the predetermined price cap is reached first, then depending on the details of the RO, the investment can take place too early, too late or even right on time. However, as before, the application of the RO scheme results in a lower investment option value.

Last, if the predetermined price cap is chosen to be too low, the potential investor will decide to stay out of the market and no investment takes place.

4 Conclusions

Our preliminary results suggest that the implementation of an RO scheme is greatly affecting the timing and value of the option to invest in energy production. While the effect of the use of an RO scheme on the value of the option to invest is pretty straightforward, the effect on the timing of the investment is more ambiguous.

These are on their own novel and interesting results. However, there are issues that our current work is not addressing. For instance, how is the duration of an RO affecting the timing and value of the investment? In our analysis we assume that the RO has the same horizon as the power plant itself. However, this does not need to be the case. In principal, ROs last for relatively shorter time periods.

Another issue that we did not consider is the nature of the strike price and/or the periodic flow paid by the RO. In our model, both quantities are fixed and known to the potential investor. However, at least one of the two might be changing over time according to a predetermined or random pattern. We expect that this would greatly affect the behavior of a potential investor.

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ACTIVITY BASED MODELLING OF COMMODITY FUTURES MARKETS

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Overview

Commodity markets exhibit seasonal behavior, which can be traced back to characteristics of supply and demand. For example, the demand of energy is depending on the outside air temperature, which itself shows a seasonal behavior. If it is very warm energy is used to cool down houses, if the temperature is low for heating. On the other hand, renewable energy sources as solar energy, hydropower and wind energy rely on natural quantities as sunshine, wind and rain. Thus, we have periods of high activity in the market that alternate with those of low activity. Here the degree of activity is triggered by temperature, wind or sunshine. Consequently, these natural factors should be included into a stochastic model for commodity prices.

Methods

We use a time change approach to include these natural factors into our model. To do so, we use a time change of absolutely continuous type, that captures the activity in the market. In this setting, Borovkova and Schmeck (2017) develop a stochastic model for the spot market of electricity prices. This work is a continuation, where we explore the joint spot and forward market. Intuitively, the idea behind the time change method is the following: it can be observed that prices in financial markets are more volatile on days with a high amount of trading. Thus, in equally spaced calender time intervals, the activity in the market can be very different. Instead, one now introduces a new non-equidistant time grid, such that the amount of activity is the same in each interval. Then the resulting new time scale is said to evolve in operational time or business time. Consequently, asset returns in each such interval should have the same distributional properties. This has been empirically confirmed e.g. by Ané and Geman (2000) for the stock market and by Clark (1973) for the cotton market.

Results

We define the futures price as the conditional expectation of the spot under a suitable pricing measure, where we use the spot price model specified in Borovkova and Schmeck (2017). We characterize the resulting futures curve, the price dynamics as well as the risk premium. Doing so, we introduce *activity bonds,* which become a building block of the model. In the calculation of the futures price there are several operations involved: time change, measure change as well as taking the conditional expectation. We follow the question if or under what conditions these operations are commutative, and characterize conditions under which one can permute change of measure and change of time in our specific model.

Conclusion

We have included natural factors as temperature and wind into a stochastic model for commodity futures markets using the powerful approach of stochastic time change. This leads to a model with seasonal stochastic volatility and jump intensity. Activity bonds play an important role in our futures model.

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Short-term forecasting of Italian gas demand

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1 Overview

Natural gas is one of the most important energy sources in Italy: it feeds thermoelectric power plants, industrial facilities and domestic heating. Energy companies need to predict gas demand (GD) to reserve pipe capacity, plan stocks, and avoid financial penalties due to network unbalance. Moreover, GD is one of the most relevant inputs to draw scenarios for natural gas price. An extensive literature, reviewed in [3] and [4], covers the topic; however, to the best of our knowledge, no study has been carried out about Italian GD. Herein, one-day-ahead forecasting of daily Italian GD is addressed. In particular, the attention is focused on industrial and thermoelectric demand, as the residential component is studied in [1]. We address the GD forecasting problem in the framework of statistical learning, developing and comparing several two-step models, i.e. forecasters obtained by the suitable aggregation of first-level forecasts. The out-of-sample Mean Absolute Error (MAE) achieved on 2017 is 5.16 Millions of Standard Cubic Meters (MSCM), definitely lower than 9.57 MSCM obtained by the forecasts issued by SNAM, the Italian Transmission System Operator (TSO).

2 Method

Three time series were considered: Residential Gas Demand (RGD), Industrial Gas Demand (IGD) and Thermoelectric Gas Demand (TGD), whose sum makes the total Italian Gas Demand (GD). We started by investigating the main features of the series and their relationship with exogenous variables, mainly temperature. We found that, differently from RGD, IDG and TGD present a weak yearly seasonality, a strong weekly periodicity and are loosely correlated with temperature. Then, we developed several two-step models for TGD and IDG. In the first step, 9 different models, including Gaussian processes, random forest, neural networks and a toroidal model [2] were used to produce predictions, to be selected and aggregated by second-step models. We used years 2007 to 2013 as training set and from 2014 to 2017 as test set.

3 Results

Results are summarised in table 1. We found that the different features of RGD, IGD and TGD result in models performing differently on each series. As long as RDG and TGD are concerned, neural networks achieve the lowest MAE, due to their superior ability to capture the non-linear dependency on temperature. On the other hand, if IGD is considered, seasonal phenomena become predominant, and Gaussian processes can better follow such patterns. In all cases, we found that the introduction of the second-step model improves the performance: by averaging the predictions of first-step forecasters, model-specific errors are attenuated.
The improvement achieved by two-step models is less evident for the total Italian GD: support vector regression achieves a MAE of 5.32 MSCM, while the best 2-step model can get to 5.23 MSCM. It is interesting to note how complex second-step models, like support vector regression, are not as effective as simpler ones, like averages. In particular, the lowest error is achieved by a simple arithmetic average over the 3 least correlated first-step outputs. As table 1 shows, the improvement in performance obtained

by aggregation is most evident in RGD, where both seasonality and exogenous factors are relevant, even though in different periods of the year.
The reference benchmark for Italian GD forecasting are the predictions issued by SNAM, only available from 2017 onward. Using 2017 as a test set, our two-step model achieves a MAE of 5.16 MSCM, while SNAM's MAE is 9.57 MSCM.

4 Conclusions

We developed and compared several models to perform one-day-ahead forecasting of the three main components if daily Italian gas demand: residential, industrial and thermoelectric. The problem is made challenging by the fact that the three series show distinctive features in terms of periodicity and dependency on exogenous factors. Thus, the best suited model can well differ from one series to another. It was found that in all cases a 2-step procedure can help improving the overall accuracy. Even if the results are more than satisfactory, some further improvements may be possible, e.g. by introducing other inputs, such as power demand, which is naturally correlated with thermoelectric gas demand.

Model	RGD	IGD	TGD	GD
Lasso	3.16	0.75	4.03	6.23
Ridge regression	3.16	0.75	4.04	6.22
Elastic net	3.17	0.75	4.04	6.23
K-nearest neighbours	5.43	1.58	5.78	9.15
Support vector regression	2.62	0.62	3.79	5.32
Random forest	3.27	0.84	4.65	6.66
Gaussian processes	2.60	0.63	3.85	5.47
Toroidal model	2.79	0.99	4.47	6.48
Neural network	2.62	0.68	3.90	5.47
Simple average (2S)	2.34	0.60	3.75	5.23
Correlation-optimised average (2S)	2.36	0.62	3.78	5.23
Weighted average (2S)	3.09	0.72	3.95	5.89
Support vector regression (2S)	2.45	0.69	3.91	5.29

Table 1: Mean Absolute Error on test set (2013-17) of single- and two-step models - the latters are identified by "(2S)": two-step models outperform single-step models.

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LIFE CYCLE COSTING for financial and environmental assessments: A renewable energy project.

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Overview

The objective of Life-Cycle Costing is a multi-dimensional assessment of the financial and environmental impact of engines, plants and eco-systems according to different scenarios and different methodologies. For the success of companies, the insertion of environmental concerns into innovation processes is an important step and LCC can help to basic technological changes in green innovations economies. In this paper, the LCC assessment is applied to a renewable energy project located in the Maldives Islands. A water desalination plant will be powered by a photovoltaic plant. The small economy and the fragile environment of the Maldives need local and clean resources for electricity generation. Renewable energy-fed desalination is an excellent solution for areas lacking electrical grid connection or any other source of energy. However, the economic feasibility of renewable energy-fed desalination compared to desalination using grid energy must be carefully analyzed as well as alternative ways of providing the atolls of drinkable water.

Methods and software

The economic and social impact of tree scenario is as follows:

1) Benchmark: the current situation of water supply in Maldives;
2) Installation of a reverse osmosis desalination plant powered by fuel;
3) Installation of a reverse osmosis desalination plant powered by PV panels.

RetScreen Expert [1] is a **Clean Energy Management Software** system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis. It is used to evaluate the environmental assessment together with the financial one for each scenario.

Results and conclusions

Through LCC assessment, it is proved that the water desalination plant powered by PV panels can be a sustainable solution. It has a good return of investment in term of CO2 emissions reduction and payback period of 7 years.

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Equilibrium price of carbon certificates and the electricity sector

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Overview
The price of emission certificates, in particular carbon certificates, has been the object of several theoretical and econometric papers (e.g. Hintermann, 2011, Mansanet and Kopler, 2010). The two types of contributions happened not to converge to a common understanding. Empirical contributions have identified quite successfully which factors drive carbon price. However, theoretical papers have kept quite distant from econometrical findings. Theoretical models have focused particularly on the probability that the emissions cumulated by the industrial sectors included in an ETS will exceed the maximum limit fixed by the authority before a given final date. Keeping the aim of providing a general framework, theoretical contributions (e.g. Carmona et al. 2010) have neglected the features of different kind of emissions and of different industrial sectors. However, turning to the major example of emission market (i.e. the EU-ETS), the electricity sector dominates the percentage of the CO2 emissions. It turns out that facts like the high pass-through coefficient of variable generation costs to the final electricity price, the (two) most influent technologies driving the price of electricity have a relevant impact on the equilibrium price of carbon certificates.

Methods
The problem is treated analytically. The model provided for the equilibrium price of the emission certificates leverages on the absence of arbitrage opportunities.

Results
This work obtains an analytical expression of the equilibrium price of the emission certificates in a discrete time setting. It elaborates on the probability that the final payoff of a certificate can be equal to the so called "indifference" or "parity" price of fuels, next to the values of zero and the penalty usually accounted in the theory emission markets. Indeed, the analysis shows that the chances that the demand of certificates matches exactly the quantity issued by the authority are not zero, even assuming that such value (the maximum emissions fixed by the authority) is a continuous value. Key to this finding is the predominating role of the electricity sector (in "consuming" the CO2 emission certificates) and the presence of two technologies (i.e. gas and coal) to drive the price of electricity.

Conclusions
The work extends the traditional digital option framework proposed in the literature for the price of emission allowances. The extension reconciles significantly theoretical and econometric literature on this topic.

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A DETERMINISTIC MODEL FOR GENERATION AND TRANSMISSION EXPANSION PLANNING WITH HIGH SHARES OF RENEWABLES

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Overview
This contribution presents a deterministic model for the joint generation and transmission expansion planning of energy systems with high penetrations of intermittent renewable energy sources. Given forecasts of future values of load, fossil fuel prices and investment costs, the proposed model defines how the capacity mix should evolve in order to meet the demand for electricity and fulfill policy targets at minimal cost.

Methods
Investments in new capacity are defined by means of a mixed integer linear model that aims at minimizing the sum of operational, investment and decommissioning costs. In order to accurately study the integration of large shares of renewable energy sources, a high level of temporal detail is required in this analysis. Given the long time horizon of expansion planning problems, these kind of models can become computationally intractable. To obtain a high accuracy without dramatically increasing computational cost, a clustering analysis on input data is performed in order to select a set of representative days.

Results
The final part of this work illustrates some numerical results on Italian market that display how the proposed model can offer a professional guidance and support in strategic decision to the different actors involved in electricity transmission and generation.

Conclusions
The proposed mixed integer model determines an investment schedule for the decommissioning of existing thermal plants and the construction of new generation capacity and of electrical regional interconnections that results in the minimum cost. Policy goals and environmental targets such as fossil fuels and CO_2 emissions reduction are explicitly considered in the expansion plan. To reduce computational cost, most generation and transmission expansion planning models employ a rather low level of temporal and technical detail. By selecting representative days, the proposed approach allows maintaining a high level of temporal detail, resulting ideally suited to analyze scenarios with high penetrations of intermittent renewable energy sources. Given the long-term horizon of expansion decisions, the system conditions throughout the planning horizon are generally uncertain. Therefore, the forthcoming work will investigate the introduction of stochasticity in the expansion framework.

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HOW TO GUARANTEE THE GENERAL CHARGES OF ELECTRICITY IN THE LIBERALIZED ENERGY VALUE CHAIN

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Background
The Italian liberalized power sector has been designed as a linear chain composed of manifold actors, from energy generation to consumption by the end-client, each of which playing a different role within the chain.
In analogy with other principal public utility network services in Italy, the power sector is characterized by a system in which payment for a good or service occurs subsequently to the actual consumption/use of the former; it is hence evident that an inherent weak point of such a system design is represented by the possibility that part of the good or service may be consumed/used even if the subsequent payment does not occur.
With reference to the energy sector, the total amount due for consumption/use of service is composed of the following two components: costs directly connected to electricity, such as the cost of the commodity, the costs of marketing, or the cost of transport and the cost of balancing on one hand, and of costs called "general charges" on the other; general charges, as identified by the legislator, are a cost component of the electricity bill and are used to finance objectives of general interest. The collection of general charges, as provided by law (aca "decreto Bersani"), is managed within the electric chain, as an increase of the cost of transportation. General charges are set in proportion both with the type of end-client, and with the consumption of power withdrawn from the network.

Problem
General charges are closely connected to targets pertaining to the environmental sustainability of the power system, among which the development of the renewables and energetic efficiency, as well as to broader social goals, such as fuel poverty (e.g. financing bonuses), and finally to targets of economic policy, such as support for nuclear decommissioning. General charges circulate within the energy chain from end-clients towards their final destination, represented by specific accounts managed by the CSEA (Cassa per i servizi energetici e ambientali - Energy and Environmental Services Fund) or GSE (Gestore dei servizi energetici - Energy Services Manager).
General charges are, by definition, not within the direct interest of a singular actor of the electricity chain. Hence, failure to collect them does not directly affect any specific link. Rather, general charges are necessary to guarantee a financial yield that is consistent with budgetary expectations necessary to pursue the general interests established by law. It is therefore necessary to identify a system of guarantees that is appropriate to achieve such a goal in a low risk manner.
The guarantees given by the current actors are inadequate, so it is proposed to use accounting measure in order to make a rating of these corporate structures.
These tools consist in the assessment of the business risk both operational and strategic through algorithms such as COSO or the Delphi method.
We propose to introduce the financial analysis of accounting data in order to improve the rating models of each group of actors in the power chain.

Outline
Similarly also to what was recently introduced into the European banking system legislation, it is necessary to identify appropriate tools able to guarantee a shield for each group of actors in the power chain in cases of failure to collect general charges due to the default of any one actor within the same group. It may therefore be useful to analyze the possibility of introducing specific guarantee systems for each group of actors, proportionate to the risk of failure of the other components of the same group; in this case every group of actors of the chain would guarantee the payment of its own group, either through mutual systems or by using internal resources.

Conclusions
Work in progress.

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