İSTANBUL BİLGİ UNIVERSITY

Institute of Social Sciences

Turkish Electricity Spot Prices Volatility Modelling

Ahmet Saklıca

Istanbul, June 2016

İSTANBUL BİLGİ UNIVERSITY

Institute of Social Sciences

Turkish Electricity Spot Prices Volatility Modelling

Submitted by

Ahmet Saklıca

114621007

Asst. Prof. Serda Selin Öztürk
(Dissertation Advisor)

Assoc. Prof. Ender Demir

Umut Keskin

Keywords

1- Turkish Electricity Market,
2- Electricity Spot Price Volatility
3- Stochastic Volatility
4- Efficient Importance Sampling
5- Energy Trading and Risk Management

Anahtar Kelimeler

1- Türkiye Elektrik Marketi
2- Spot Electrik Fiyat Volatilitesi
3- Stokastik Volatilite
4- Efficient Importance Samling
5- Enerji Ticareti ve Risk Yönetimi

ÖZET

Bu tezde enerji ticareti ve risk yönetimi için çok önemli olan Türkiye Elektrik Piyasası Gün Öncesi Market fiyatları üzerinde çalışma yapılıp fiyat volatilitesi ve fiyatı etkileyen temel etmenler değerlendirilmiştir. Çalışma verisi Ocak 2015 ile Şubat 2016 (dahil) arasını kapsamaktadır. Ordinary Least Square yöntemi ile saatlik elektrik fiyatlarına etki eden anlamlı açıklayıcı değişkenler belirlenmiştir. Bu değişkenleri kullanarak daha kesin tahmin ve test istatistik sonuçları üreten Maximum Likelihood modeli ve Efficient Importance Sampling metodu kullanılarak saatlik elektrik fiyatlarının stokastik volatiliteleri hesaplanıp elektrik fiyatı volatilitesine etki eden anlamlı etmenler stokastik volatilite sürekliliği ve stokastik volatilite standart sapma değerleri üzerinden değerlendirmeleri yapılmıştır.

Abstract

In this paper, stochastic volatility model of Turkish Electricity Market Day-Ahead Market prices are studied to develop fundamental drivers of price volatility which is so important for electricity trading and risk management. The data from January 2015 to February 2016 (included) is estimated via Ordinary Least Square approach to determine significant fundamental drivers of electricity prices. Together with estimated significant variables, stochastic volatility of hourly electricity prices is estimated with Maximum Likelihood modelling using Efficient Importance Sampling method. More accurate estimates of likelihood and related test statistics are calculated with this approach. Volatility persistence and standard deviation of volatility are evaluated to understand significant fundamental drivers and price fluctuations over time.

Keywords: Turkish Electricity Market, Electricity Spot Price Volatility, Stochastic Volatility, Efficient Importance Sampling, Energy Trading and Risk Management

Energy is future.

ACKNOWLEDGEMENTS

I am thankful to my supervisor Serda Selin ÖZTÜRK who supported me from the first day of this study and provided resources for me to finish up this study with success. I feel myself lucky for having the chance of working with her. I wish to express my sincere thanks to my colleagues for giving me the opportunity and help me to do this study. Finally, but significantly, I would like to thank my wife for supporting me spiritually throughout writing this thesis.

Contents

1 Introduction 1

2 Literature Review 5

3 Data 7

4 Methodology 15

5 Results 17

6 Conclusion..26

7 References 27

List of Figures and Tables

Figure 1: Structure of Turkish Electricity Market ……………………2

Figure 2: Turkish Electricity Day-ahead market prices ……………..4

Table1: Regression Estimation Results for Monday ………………..19

Table2: Regression Estimation Results for Weekday ………………20

Table3: Regression Estimation Results for Saturday and Sunday 21

Table4: Regression Estimation Results for All Day Types ………...21

Table5: Estimation results for stochastic volatility for Monday ……22

Table6: Estimation results for stochastic volatility for Weekday…..23

Table7: Estimation results for stochastic volatility for Saturday …..24

Table8: Estimation results for stochastic volatility for Sunday ……25

1 Introduction

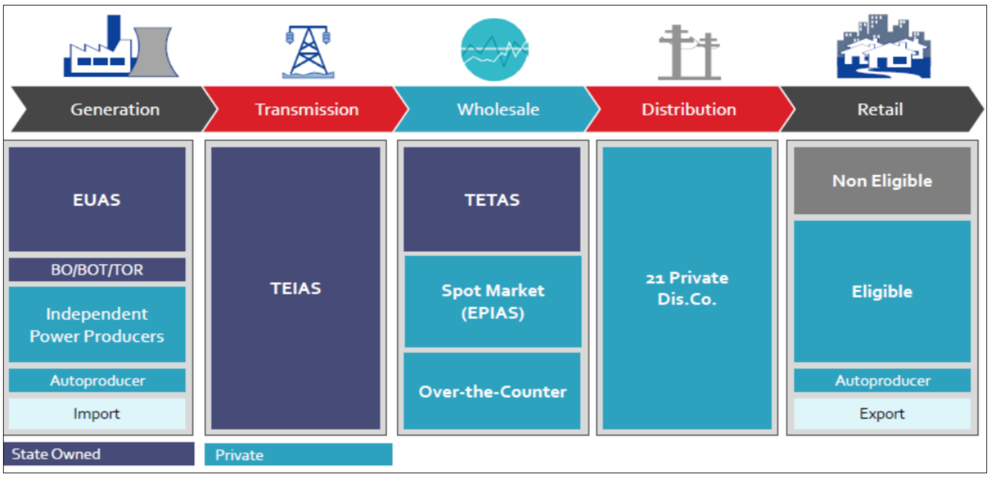
Turkish Electricity Market was dominated by state owned company, Turkish Electricity Authority (TEK) like in many European countries in the beginning of 1980s. Generation, transmission, distribution and sales management were derived by TEK which was a vertically integrated company. Early 1980s, the government intended to attract private participation (Build, operate (BO), Build, Operate and Transfer (BOT), Transfer of Operational Rights (TOR)) into the industry in order to reduce the pressure of investments on the public budget. The private sector was also allowed to build power plants of their own and to sell electricity they produced to TEK in 1982.

The alteration in Turkish Electricity Market proceeded in 1994 with TEK separation into two state-owned companies; TEAS (Turkish Electricity Generation and Transmission Company) which was responsible for generation and transmission and TEDAS (Turkish Electricity Distribution Company) which was responsible for distribution and retail sales activities.

The Electricity Market Law (EML) No. 4628 has come into operation in 2001 to liberalize the electricity market in Turkey establishing a financially strong, stable, transparent and competitive electricity market. TEAS was separated into three state owned companies with inspiration of law 4628, EUAS (Turkish Electricity Generation Company) which is responsible for operating the state-owned power generation facilities, TEIAS (Turkish Electricity Transmission Company) which is responsible for operating the national grid, and TETAS (Turkish Electricity Trading and Contracting Company) which has an authority to deal with purchasing the electricity from the producers and the sale of this electricity to the energy distribution companies.

Reforms in energy market were proceeded with “Electricity, Energy Market and Supply Security Strategy Paper” which was published by the Ministry of Energy and Natural Resources in May 2009. This paper aims to continue to create a competitive market as making a new demand driven electricity production structure with sustainable investments. Besides 21 distribution companies (2009-2013) and some state owned generations were privatized to provide more efficient distribution services, quality and consumer satisfaction.

Figure 1: Structure of Turkish Electricity Market

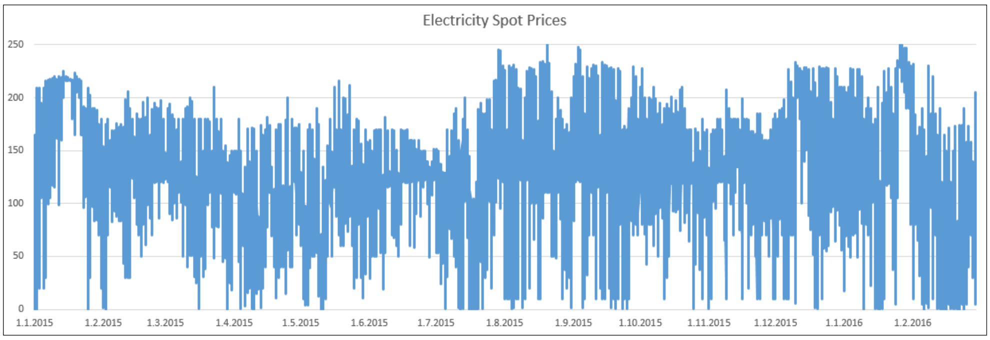


The new Electricity Market Law No. 6446, came into operation on 14 March 2013, was the second important step in order to specify the legal and institutional framework and further development of the sector. The aim of Law No. 6446 is to liberalize the electricity market in Turkey establishing a financially strong, stable, transparent and competitive electricity market. In line with the new law 6446, TEIAS was separated into two companies: EXIST (EPIAS) which is responsible for operating electricity market (market operator) and TEIAS which is responsible for operating the national grid as an owner of the all transmission grid assets (system operator).

Together with law 6446, organized electricity wholesale markets were introduced as an electrical energy market where electrical energy, capacity or retailing are traded and the day-ahead market, intra-day markets and standardized electricity contracts having the characteristics of capital market instruments. Derivative markets were also introduced and over the counter (OTC) opportunity has been improved. These are markets where electrical energy and/or capacity is purchased or sold for purposes of delivering cash settlement at a defined point in the future. Licensed legal entities are conducting market activities and financial transactions in the organized electricity wholesale markets which are operated by EXIST.

Turkish Electricity Market has developed and liberalized where a remarkable increase in electricity generating capacity and demand during last ten years. Besides installed capacity has increased with various power plant technologies as coal, natural gas, hydro and other renewables. Due to non-continuous electricity demand and supply, imbalances in the transmission system, daily, weekly, and yearly seasonal behaviour, weather and business activities, electricity prices are affected by various market uncertainties. (Hayfavi, Talasli, 2013)

Figure 2: Turkish Electricity Day-ahead market prices.



Volatility is a measure of differences in prices over a time interval. Daily, weekly or annual volatility is observed in electricity markets due to uncertainties as seasonal changes, uncertainty in fundamental market drivers, physical problems of electricity generation and transmission. Price fluctuation is extremely important for all market participants, especially for trading and generation companies that volatility evaluation is crucial for financial and trading risk management, in addition volatility is a part of some derivative instrument pricing. Energy companies take risk with their energy position that volatility in electricity prices strongly effect trading and sales policies. Hence all trading and hedging decisions are affected by electricity price volatility that reliable knowledge of volatility modelling is extremely important for each market participant for financial and risk management. In this study, which is a new approach at this area, stochastic volatility modelling of Turkish Electricity Market day-ahead hourly prices were researched with using maximum likelihood and efficient importance sampling methods to develop a new approach to volatility modelling which is substantially important to electricity trading and risk management.

In this paper, it is structured as follows. In section 2 contains literature review of electricity prices volatility methods. In section 3, data interval and variables are introduced and multi factor regression model demonstrated. In section 4, methodology of stochastic volatility modelling was introduced. In section 5, results of volatility modelling are demonstrated and interpreted. Section 6 concludes the study.

2 Review of the Literature

Price volatility modelling has been an area of extensive research in economy and finance disciplines. Even if volatility modelling of electricity market researches has been issued in developed markets, Turkish Electricity Market spot price volatility modelling issue is a shallow area of reference. Thus, global papers and researches are focused to lead the way this study. The first three reviews below approaches to price volatility via GARCH and variance of GARCH models, besides the study of electricity market fundamentals are discussed. The last three studies include stochastic modelling to determine electricity price volatility.

The volatility of U.K. electricity spot prices were studied to understand fundamental and behavioural drivers by Karakatsani and Bunn (2010). Three modelling approaches are developed in order to find fundamental drivers over time period. Systematic components of electricity market spot prices are related to economic fundamentals and the effect of market design, besides Karakatsani and Bunn (2010) has introduced residual volatility is attributed to agent reactions of market fundamentals, adoption of price formation due to agent learning and temporary extreme pricing in periods of scarcity. GARCH modelling has been developed to understand volatility specifications and GARCH effects decrease with accounting volatility with source used in the study and fundamentals can yield more certain volatility than an explicit GARCH specification with allowed time varying responses of price.

Bennini, Marracci, Pelacchi and Venturini (2002) has focused analysis of the day ahead spot price volatility in Spanish, California, UK and PJM markets. Market fundamentals and uncertainties have analysed to identify price volatility changes as fuel prices, availability of plants, hydro generation production, demand elasticity.

Sotiriadis, Tsotsos, Kosmidou (2016) published price and volatility relationships in five European day-ahead, wholesale spot electricity markets. CCC-MGARCH and DCC-MGARCH model used to define volatility, including VAR model with dummy variables. Results show market integration as calculated by cross-mean spillovers and conditional correlation besides physical interconnection capacity is not enough for the electricity markets to be fully integrated.

Duffie, Gray, Hoang (1998) had discussed constant volatility and stochastic volatility in energy prices. Markovian models of stochastic volatility and different classes of Markovian stochastic volatility models are focused including auto-regressive volatility, implied and forecasted volatility, Garch volatility, Egarch volatility, multivariate Garch volatility, and stochastic volatility. The performance of electricity, heating oil, light oil, natural gas stochastic volatility models as applied and compared.

Hayfavi and Talasli (2013) has focused on stochastic multifactor modelling of Turkish daily spot electricity prices. Stochastic modelling has been designed as multistep algorithm constructed on GARCH which estimates volatility with iterative threshold function in separation of price jumps. Price series pattern and empirical moments are observed with capturing different mean reversion rates.

Benth (2013) published the analysis of a model which includes stochastic volatility effects. Mean reverting stochastic spot price dynamics with a stochastic mean level modelled as an Ornstein-Uhlenbeck process. Barndoff-Niellsen and Shephard type stochastic volatility modelling has also included to study besides properties of dynamics are discussed in relations to energy markets. Margrabe formula which is for options on the spread is used to analyse dependency risk under an Esscher measure transform that this measure shows that this methodology may increase the tail dependency in the bivariate jump of the energy spot model.

3 Data

The reorganization of TEK started in 1994, generation, transmission, distribution and trading activities were separated to state-owned companies to have more sustainable energy market. In 2009 the government submitted Electricity Energy Market and Supply Security Strategy Paper to constitute more efficient, competitive, sustainable, strong, transparent energy market.

Some of state-owned generation plants and all distribution companies were privatized in the way of this policy. Responsibility of operating electricity market was given to Energy Exchange Istanbul (EXIST) in this liberalization period. Main of objective of EXIST is to “Plan, establish, develop and manage energy market within the market operation license in an effective, transparent, reliable manner that fulfills the requirements of energy market and to be an energy market management that procures reliable reference price without discriminating equivalent parties and maximizes the liquidity with increasing number of market participants, product range and trading volume as well as allowing to merchandise by means of market merger.”(Electricity Market Law 6446, www.epias.com.tr)

The objective component of this study is an electricity spot day ahead prices which are determined in EXIST Day-Ahead Market. Turkish Day-Ahead Market prices are specified for every hour for a related day. Prices and matched volumes for 24 hours of next day are announced at 12:00 pm by market operator EXIST. Day ahead prices are derived from supply demand curve with optimization model calculation. Uncertainties in supply and demand side dominates the price levels.

The data sets consist of hourly values of EXIST day ahead spot prices and explanatory variables. 14 months of data are collected from 1 January 2015 to 29 February 2016. During this period 424 days exist and each day has 24 hours trading period. Besides, this data set interval starts at feed-in tariff capacity increases in 2015 and this capacity increment has significant effect on hourly prices. (www.rapor.epias.com.tr)

Economic fundamentals, plant constraints, risk sensation, market inefficiencies, market design are non-trivial factors to define hourly electricity prices. The structure of price and volatility has fundamental variables such as demand, fuel prices, weather conditions which are used in electricity price models (Vehvilainen and Pyykkonen ,2004; Ohashi and Kanamura,2004). The main objective of this study is increasing base factors to understand price and volatility behaviours.

The approach to modelling electricity prices includes formulation of the regression model. Substantial variables collected from public databases which are defined below, available to Turkish electricity market participants (rapor.epias.com.tr, seffaflik.epias.com.tr). The important aspect of this modelling, electricity price structure is based on hourly data therefore substantial variables also determined in this way.

a) Demand

Demand variable is a fundamentally driver of electricity prices which has powerful influence on price variation moreover it has determinant role in short term analysis and long term analysis models. The data are daily published by system operator.

b) Demand Forecast

Demand Forecast is published by system operator that gives the explanatory relation between price and demand.

c) Demand.Lin and Demand.Quad

The polynomial formula of demand gives us the non-linear demand effect that represent convexity and concavity at price shape. The formula decoupled into two orthonormal functions, linear component Demand.Lin and quadratic component Demand.Quad.

d) Demand Slope and Demand Curve

Demand differences shows an aspect of dynamic changes in the market. The rate of change in demand data represents data periods that reveal consumption patterns, weather and other market indicator. Demand Slope is the first difference of demand; Demand Curve is the second.

e) Spot Daily

Average of daily Day-ahead market price.

f) PT1, PT7, MPT1

These values are considered in the same period in the data. PT1 is price at the same hour and on the previous day. PT7 is the price at the same hour 7 days before. MT1 is the average daily price of the previous day.

g) Spot Volatility and Demand Volatility

Spot and Demand volatility show the price instability and risk. Coefficient of variation (standard deviation / mean) of these variables for each hour in a 7 days moving period.

h) Margin, Margin1 and Scarcity

Margin is the hourly total possible output of all generators mines the demand of a day. This variable shows us the excess generation capacity besides margin is kind of negative effect meter on prices. Thenceforward if the margin is decreased, that means unscheduled outages or structural constraints exist, more expensive generation units compensate energy supply. Margin1 variable is the previous hour margin value at the same period. Scarcity shows us the effect of margin on prices. Scarcity is calculated from max (Lower Quartile of Ratio- Ratio,0) where Ratio=Margin/Demand.

i) Trend and Seasonality

Trend demonstrates a linear time trend on stabilization effect in the developing market. Seasonality gives the weight of monthly average price of the data set.

j) Natural Gas

Total Gas Fired Power Plants production amount for relevant hour at the same period.

k) Water Flow, River and Dam

River variable contains a total production of run of river type renewable plants, Dam variable is total production of dam type power plants which have a reservoir. Water Flow is the total rain approach to plants.

l) Wind, Wind2, Yekdem

Wind demonstrates the total production of wind generated power plants which are in RITM database (Monitoring and Forecasting System Development for Wind Generated Electrical Power in Turkey, www.ritm.gov.tr). Wind2 contains total production of wind generated power plants in Turkey. Yekdem data show us total production which plants are in feed-in tariff mechanism.

m) Free Supply

Total production of power plants which sell power to day-ahead market with price independent right.

Variable data separated into 4 periods which are Monday, Weekdays (Tuesday, Wednesday, Thursday, Friday), Saturday and Sunday (Karakatsani, Bunn, 2010). Demand variable is fundamentally driver of electricity prices and demand behaviour significantly differs at these periods. Thus the aim of the separation is to get more accurate regression results. Linear regression model is estimated for each 24 hours for each day type. For a given day type, j, this price model is specified as:

$$P_{jt} = X'_{jt} * \beta_j + \varepsilon_{jt} \quad , \quad \varepsilon_{jt} \sim N(0,\sigma_j^2)$$

Where P_{jt} denotes price on a day t and day type j.

t= (1, 2, …, T), T is the sample size (T=424).

j=1, 2, …, 24, Hours of a day.

β_j , 26 x 1 vector of coefficients.

X_{jt} = (1, $Demand_j$, $DemandForecast_j$, $Demand.Lin_j$, $Demand.Quad_j$, $DemandSlope_j$, $SpotDaily_j$, $DemandCurve_j$, $Margin_j$, $Margin1_j$, $Scarcity_j$, $DemandVol_j$, $SpotVol_j$, $PT1_j$, $PT7_j$, $MPT1_j$, $Trend_j$, $Seasonality_j$, $Wind_j$, $Wind2_j$, $WaterFlow_j$, $River_j$, Dam_j, $NaturalGas_j$, $Yekdem_j$, $FreeSupply_j$)

This multi factor model demonstrates a significant price variation of the structural effects on daily, hourly prices (Karakatsani and Bunn 2004). Herewith significant models are specified for each period and each hour (4 periods x 24 Hours = 96 models) so stochastic volatility model follows these models. Stepwise regression model used for optimal significant variable selection to find out significant explanatory variables of stochastic volatility modelling.

4 Methodology

In the previous part influential variables were detailed specifically. Points to be considered, data separated into day types that Monday, Saturday and Sunday group has single day per week however weekday group contains four days as Tuesday, Wednesday, Thursday and Friday. Due to weekday group's data range is quadrupled so linear regression analysis and stochastic volatility model runs have been practiced separately.

As it mentioned, explanatory variables of hourly electricity periods and related data has determined to solve out stochastic volatility modelling in this study which was introduced by Taylor (1982, 1994). Embraced attitude is Univariate volatility model which model tries to capture persistence.

The univariate volatility model is specified as follows:

$p_t = \alpha'_t x_t + \exp(\lambda_t/2)\varepsilon_t$ (1)

$\lambda_t = \gamma + \delta\, \lambda_{t-1} + \upsilon\eta_t$ (2)

where,

p_t, denotes observed hourly day-ahead electricity prices

λ_t, observed volatility

$\alpha = j * 1$

$x = j * 1$

j denotes number of significant variables in the least squared results for each hour at 96 different runs.

(ε_t, η_t), independent N (0,1) random variables. Furthermore $|\delta|<1$.

Gaussian nonlinear dynamic state-space model is characterized by Equations 1 and 2 for the univariate volatility model. The Kalman Filter Application is prevented by the nonlinear dependence of pt on the latent factor λt in equation 1. Evaluation of the likelihood function of the model is applied by Efficient Importance Sampling (EIS) which was published by Richard and Zhang (2007). Besides test-statistics for the null hypotheses of interest is applied by likelihood Ratio (LR). EIS approach is one of the wide range of stochastic volatility models which produces highly accurate Monte Carlo estimates of likelihood functions, Liesenfeld and Richard (2003, 2006).

Equations (1) and (2) define a measurement density $f(p_t|\lambda_t)$ and a state transition density $f(\lambda_t|\lambda_{t-1}, x_{t-1})$ respectively to show the standard characterization of state-space models.

Let $\Lambda_t = \{\lambda_s\}_{s=0}^{t}$ and $P_t = \{p_s\}_{s=1}^{t}$. High-dimensional monte carlo numerical integration with respect to ΛT is required that Λt is not shown estimation of the likelihood function:

$$f(P_t|x_0) = \int f(\lambda_0)\prod_{t=1}^{T}[f(p_t|\lambda_t)f(\lambda_t|\lambda_{t-1}, x_{t-1})]d\Lambda_t \tag{4}$$

In this equation the stationary density of λ_0 is denoted by $f(\lambda_0)$.

Constructing a numerically efficient parametric sequential importance sampling process is aimed by Efficient Importance with $\{m(\lambda_t|\lambda_{t-1}; a_t); a_t \in A\}_{t=1}^{T}$.

Particularly, the process is started by pre-selection of a parametric class of auxiliary density kernels $K = \{k(\lambda_t, \lambda_{t-1}; a_t); at \in A\}$. Densities in that they ignore normalizing factors are differed by Kernels. The relationship between densities and kernels is shown by

$$m(\lambda_t|\lambda_{t-1}, a_t) = \frac{k(\lambda_t, \lambda_{t-1}; a_t)}{\chi(\lambda_{t-1}; a_t)} \tag{5}$$

$$\chi(\lambda_{t-1}, a_t) = \int k(\lambda_t, \lambda_{t-1}; a_t)\, d\lambda_t \tag{6}$$

For any given set $\{a_t\}_{t-1}^{T}$ the likelihood integral in (4) is then approximated by

$$\widehat{f_N}(P_T|x_0) = \frac{1}{N}\sum_{d=i}^{N}\omega\left(\breve{\lambda}_t^j, \breve{\lambda}_{t-1}^j, a_t\right) \quad (7)$$

Where

$$\omega(\lambda_t, \lambda_{t-1}; a_t) = \frac{f(p_t|\lambda_t)f(\lambda_t|\lambda_{t-1}, x_{t-1})}{m(\lambda_t|\lambda_{t-1}, a_t)} \quad (8)$$

and $\left\{\left\{\breve{\lambda}_t^j\right\}_{t=0}^{T}\right\}_{j=1}^{N}$ N i.i.d. trajectories drawn from the sequential IS sampler are denoted

$$(f(\lambda_0)\{m(\lambda_t|\lambda_{t-1}; a_t); a_t \in A\}_{t=1}^{T}).$$

Selecting the auxiliary IS parameters $\{a_t\}_{t=1}^{T}$ is aimed by EIS in a way hence the Monte Carlo sampling variance of the likelihood is approximately minimized by EIS estimate in (7).

While accounting for the Markovian dynamics of the state transitions, minimizing the variance requires EIS to transform the IS ratios in (8). EIS transforms IS ratios by interchanging the IS normalizing factor χ (λ_t; a_{t+1}) back by one period to regrouping in the period −t numerator all factors depending on λ_t. The transformed IS ratios are represented by

$$\omega_*(\lambda_t, \lambda_{t-1}; a_t, a_{t+1}) = \frac{\varphi_t(\lambda_t, \lambda_{t-1}; a_{t+1})}{k(\lambda_t, \lambda_{t-1}; a_t)} \quad (9)$$

where the IS target kernel is denoted by φi(.)

$$\varphi t\,(\lambda_t, \lambda_{t-1}; a_{t+1}) = [f(p_t|\lambda_t)\, f\,(\lambda_t|\lambda_{t-1}, x_{t-1})]\, \chi\,(\lambda_t; a_{t+1}) \tag{10}$$

Solving the following backward recursive sequence of auxiliary least square (LS) problems obtain approximate optimal values for $\{a_t\}_{t=1}^{T}$.

$$(\hat{a}_t, \hat{c}_t) = ArgMin_{a\in A, c\in P} \sum_{j=1}^{S} \left[ln\varphi_t\left(\breve{\lambda}_t^j, \breve{\lambda}_{t-1}^j; \hat{a}_{t+1}\right) - c - lnk\left(\breve{\lambda}_t^j, \breve{\lambda}_{t-1}^j; a\right)\right]^2 \tag{11}$$

where S i.i.d. trajectories $\left\{\left\{\breve{\lambda}_t^j\right\}_{t=1}^{T}\right\}_{j=1}^{S}$ should best be drawn from the Efficient Importance Sampling sampler itself.

In practice, embedding the sequential Least Squares minimization problem can achieve this in (11), inside a fixed-point search for $\{\hat{a}_t\}_{t=1}^{T}$ under favour of step-l solutions to (11) are based upon draws from the sequential IS sampler which is obtained in step-l. Richard and Zhang (2007) discussed additional implementation details which are usually fast (4–5 steps) for well-behaved applications such as stochastic volatility models with convergence to a fixed-point solution approach. For further, efficient likelihood estimation for state-space models and, specifically, EIS (global) approximations are discussed by DeJong et al. (2011) instead of local Taylor Series approximations for Extended Kalman Filters.

5 Results

Turkish Electricity Market hourly day-head prices and expected potential driver of electricity price volatility data was collected from Turkish market which was available for public information. As it described in Data chapter, 14 months of data were selected from January 2015 to February 2016 and separated into day type and 24 hours of a day as Monday, Weekday, Saturday and Sunday. Thus 96 different data set was prepared to uncover stochastic volatility dynamics effects of selected market drivers and volatility behaviour on day-ahead market hourly spot prices.

Specific factors of price and volatility are non-trivial issue to model that market drivers and participants of market change due to economical, technical and strategic evolvements. Therefore, the closest actualized data used in this study and expected market driver inputs were used to define influential variables of day-ahead spot prices with the linear regression approach. Due to 26 different influential variables, stepwise regression model approach was estimated for each 24 hours of day types in 5% confidence interval. This method helps to eliminate insignificant variables easier and reliable.

Table1: Regression Estimation Results for Monday.

MONDAY EXP.VAR/HOURS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
SpotDaily	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
NaturalGas			1	1	1							1		1				1		1	1				8
Freesupply						1			1	1	1				1		1								6
Pt1		1	1				1						1			1	1								6
DemandQuad							1						1			1	1					1			5
SpotVol	1				1																	1	1	1	5
Seosanality													1			1		1	1						4
River					1				1	1															3
DemandLin					1			1																1	3
DemandSlope					1													1					1		3
DemandVol						1						1										1			3
Trend					1													1	1						3
Pt7	1		1																						2
DemFore											1				1										2
DemMW					1																				1
Wind																		1							1
WaterFlow											1														1
Dam		1																							1
MPt1							1																		1
Margin1		1																							1
Scarcity			1																						1
YEKDEM												1													1
Wind2												1													1
Ones																									0
DemandCurve																									0
Margin																									0
# of VARIABLES	3	4	5	2	8	3	4	2	3	3	4	5	4	2	3	4	4	6	3	2	2	4	3	3	

Monday electricity prices are mainly influenced by SpotDaily, Natural Gas, FreeSupply and Pt1 explanatory variables. It is seen that seasonality and past data has more weight on Monday prices in addition price and demand fluctuations. Monday differs from other week days with market electricity demand characteristic. This distinctness is also observed from fewer significant results than weekend data.

Table2: Regression Estimation Results for Weekday.

Weekdays EXP.VAR/HOURS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
SpotDaily	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1		1	1	1	22
Pt1	1		1	1	1	1	1	1	1					1	1		1	1	1	1	1	1	1		17
NaturalGas		1	1	1	1	1	1					1	1	1	1	1	1					1	1	1	15
DemandQuad			1	1		1				1	1	1		1	1	1	1	1	1			1		1	14
Freesupply		1	1	1	1	1				1	1			1	1	1	1	1							12
MPt1	1			1	1		1	1			1			1	1	1	1		1		1				12
Trend	1			1						1	1							1	1	1		1	1	1	10
YEKDEM					1	1			1			1	1						1	1		1	1	1	10
DemandVol						1						1	1	1	1	1							1		7
Scarcity			1					1	1				1	1		1								1	7
Seosanality				1					1			1					1	1	1	1					7
DemandLin		1		1								1		1	1	1									6
Pt7										1		1				1				1	1	1			6
SpotVol			1			1	1			1				1								1			6
Margin1		1												1		1				1				1	5
WaterFlow		1								1	1	1						1							5
DemandCurve					1	1						1												1	4
DemMW														1	1	1							1		4
DemandSlope		1	1													1									3
Margin											1						1	1							3
Dam													1								1				2
River									1															1	2
DemFore										1															1
Wind									1																1
Wind2						1																			1
Ones																									0
# of VARIABLES	4	7	8	9	7	10	5	4	7	8	7	10	5	12	9	12	8	8	7	7	4	8	7	9	

In specific, weekday electricity demand amount is bigger than other day types. Therefore, prices are formed with more various explanatory variables. Peak hours (08:00 – 20:00) are shined out with demand variated factors and historical trend of price. Besides it is seen that natural gas plant production which produces electricity without price concern (FreeSupply) shapes the price almost for every hour on weekday.

In Turkish Electricity Market, like other markets, weekend demand behaviour differs from weekday. Public and industry consumption behaviour shapes the distinctness that the regression model estimates lower explanatory variables than other days. Natural gas plant productions have substantial influence on hourly prices in addition to seasonality especially on Saturday.

Demand variated explanatory variables draw attention on Sunday in any case the lowest demand observed in this day.

Table3: Regression Estimation Results for Saturday and Sunday.

SATURDAY EXP.VAR/HOURS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
SpotDaily	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
NaturalGas				1	1	1	1					1	1	1	1	1		1							10
Seosanality				1	1							1					1	1	1						6
Pt1		1									1									1		1	1		5
Trend	1			1					1										1	1					5
WaterFlow		1		1					1	1														1	5
Freesupply				1	1	1		1																	4
Wind2		1									1						1			1					4
DemandVol																		1	1						2
Scarcity															1	1									2
DemandLin										1		1													2
Dam						1												1							2
Ones			1	1																					2
DemandQuad																	1								1
MPt1																					1				1
YEKDEM				1																					1
Pt7																		1							1
SpotVol																								1	1
DemMW											1														1
Margin																1									1
River				1																					1
DemFore			1																						1
Margin1																									0
DemandCurve																									0
DemandSlope																									0
Wind																									0
# of VARIABLES	2	4	3	9	4	4	2	2	3	3	4	4	2	2	3	4	4	6	4	4	2	2	2	3	

SUNDAY EXP.VAR/HOURS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
SpotDaily	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
Seosanality			1		1			1	1									1	1	1	1				8
Pt1								1							1	1		1	1			1	1		7
Freesupply						1	1		1										1		1				5
DemandQuad		1	1				1										1					1			5
DemandVol		1	1									1	1	1											5
MPt1					1			1							1			1							4
DemandCurve		1					1				1						1								4
Margin		1	1	1								1													4
SpotVol						1	1		1																3
Trend	1										1									1					3
Pt7							1	1										1							3
DemFore																					1		1	1	3
Scarcity								1		1								1							3
Wind							1					1													2
WaterFlow						1	1																		2
YEKDEM										1															1
Wind2						1																			1
Ones											1														1
NaturalGas																									0
River																									0
DemandLin																									0
DemandSlope																									0
DemMW																									0
Dam																									0
Margin1																									0
# of VARIABLES	2	5	5	2	3	5	8	6	4	3	4	4	2	2	3	2	3	6	4	3	4	3	3	2	

Table4: Regression Estimation Results for All Day Types.

EXP.VAR / HOURS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL
SpotDaily	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	3	4	4	4	94
Pt1	1	2	2	1	1	1	2	2	1		1		1	1	2	2	2	2	2	2	1	3	3		35
NaturalGas		1	2	3	3	2	2					3	2	3	2	2	1	2		1	1	1	1	1	33
Freesupply		1	1	2	2	4	1	1	2	2	2			1	2	1	2	1	1		1				27
DemandQuad		1	2	1		1	2			1	1	1	1	1	1	2	4	1	1			3		1	25
Seosanality			1	2	2			1	2			2	1			1	2	4	4	2	1				25
Trend	3			2	1				1	1	2							2	3	3		1	1	1	21
MPt1	1			1	2		2	2			1			1	2	1	1	1	1		2				18
DemandVol		1	1			2						3	2	2	1	1		1	1			1	1		17
SpotVol	1		1		1	2	2		1	1				1								2	1	2	15
WaterFlow		2		1		1	1		1	2	2	1						1						1	13
Scarcity			2					2	1	1			1	1	1	2		1						1	13
YEKDEM				1	1	1			1	1		2	1						1	1		1	1	1	13
Pt7	1		1				1	1		1		1				1		2		1	1	1			12
DemandLin		1		1	1			1		1		2		1	1	1								1	11
DemandCurve		1			1	1	1				1	1					1							1	8
Margin		1	1	1							1	1				1	1	1							8
DemFore			1							1	1				1						1		1	1	7
Wind2		1				2					1	1					1			1					7
River				1	1				2	1														1	6
DemandSlope		1	1		1											1		1					1		6
DemMW					1						1			1	1	1							1		6
Margin1		2												1		1				1				1	6
Dam		1				1							1					1			1				5
Wind							1		1			1						1							4
Ones			1	1							1														3

In case of ignoring day types, aggregated results show that SpotDaily, Pt1, NaturalGas, FreeSupply, Demand.Quad, Seasonality variables has a substantial effect on market prices. Particularly historical price trend is more influential on the hourly day-ahead market prices.

Stochastic volatility model which was mentioned in Method chapter was used to determine significant explanatory variables and parameters of volatility for 4 different day types. The results can be shown below where significant variables are written in bold. In following tables, two hours of each day time periods are selected and demonstrated because of many results, peak for 08:00 – 20:00 and offpeak for other hours of a day. Delta and Nu parameters are key findings to evaluate volatility that Delta demonstrates persistence of volatility that it is more volatile when delta value is closer to 1 and Nu variable is the standard deviation of volatility.

Table5: Estimation results for stochastic volatility for Monday

EXP.VAR / HOURS	OFFPEAK		PEAK	
	4	21	9	13
SpotDaily	- 0.13	- 0.04	- 0.69	- 0.04
Pt1				**0.88**
NaturalGas	**1.31**			
Freesupply			**- 3.28**	
Demand.Quad		**- 383.73**		
Trend	- 4.56			
DemandVol		**0.92**		
SpotVol	**1.37**	**- 37,063.98**		
WaterFlow	**53.20**			
Demand.Lin	**- 0.97**			
River	**311.81**		0.17	
DemandSlope	**9.33**			
DemMW	**0.34**			
Gama	**12.09**	**32.19**	**0.01**	**3.12**
Delta	**0.79**	**0.92**	**0.40**	**0.86**
Nu	**0.71**	0.25	**1.79**	**0.64**
Log Likelihood	78.33	83.53	69.88	81.31

Key findings on Monday can be summarized that some of the explanatory variables are significant especially demand related ones. NaturalGas, PT1, Demand.Quad, Demand.Lin, DemandVol, SpotVol, FreeSupply, WaterFlow, River, DemandSlope, DemMW variables have significant volatility effect on related hours. Even if SpotDaily variable is significant at regression results almost for all hours, it has insignificant effect on volatile for hours 4,9,13 and 21. Delta parameters show that these hours significantly volatile, particularly hours 4, 21 and 13 are more persistence where parameter value is closer to 1. However, hours 4, 9 and 13 standard deviations of volatility are high. That means volatility persistency can be seen changeable, even price shocks can be occurred at these hours derived by other effects of market apart from explanatory variables listed in Table5.

Table6: Estimation results for stochastic volatility for Weekday

EXP.VAR / HOURS	OFFPEAK		PEAK	
	5	20	9	16
SpotDaily	0.00	- 0.12	- 0.03	- 0.03
Pt1	**20,344.31**	- 0.12		**0.66**
NaturalGas	**1.40**			**1.90**
Freesupply	**- 2.93**		**121.30**	
Demand.Quad	**- 185.73**		**0.59**	**1.00**
Trend			**32.61**	**26,166.53**
MPt1		**1.38**		
DemandVol	**98.95**			
SpotVol	**14.55**		**0.15**	**13.99**
WaterFlow			**26,761.94**	
YEKDEM	**- 1.88**			**- 0.29**
Pt7		**0.92**		**0.36**
DemandCurve	**- 2.86**			
DemFore			**- 0.30**	
Wind2	**- 20.61**			
Gama	**0.17**	**- 1.25**	**- 0.23**	**35.21**
Delta	**0.97**	**0.64**	**0.92**	**0.92**
Nu	**0.45**	**0.65**	**0.51**	**0.35**
Log Likelihood	288.83	329.57	287	324

Results for weekday can be summarized that almost all explanatory variables like Pt1, NaturalGas, FreeSupply, Demand.Quad, Trend, MPt1, DemandVol, SpotVol, WaterFlow, YEKDEM, Pt7, DemandCurve, DemFore, Wind2 are significant at volatility. Demand related and plant production variables have a remarkable effect on volatility. As it is seen that SpotDaily variable has insignificant effect on volatility at these hours because volatility is ignored at ordinary least squares method. Hours 5, 9, 16 and 20 seems to have more persistent volatility on the other hand hours 9 and 20 standard deviations are high which uncertainty is also effective in the volatility at these hours.

Table7: Estimation results for stochastic volatility for Saturday

EXP.VAR / HOURS	**OFFPEAK**		**PEAK**	
	6	**20**	**11**	**16**
SpotDaily	- 0.04	**- 0.82**	**- 1.36**	- 0.01
Pt1				
NaturalGas	**1.61**		0.32	
Demand.Quad				**0.64**
Seosanality			- 7.43	**1.17**
MPt1		5.74		
Demand.Lin			**- 0.01**	
Wind2				**60,470.76**
Gama	0.00	- 6.28	**18.97**	**21.32**
Delta	**0.92**	0.17	**0.91**	0.57
Nu	**0.30**	**1.59**	**0.46**	0.19
Log Likelihood	82.26	75.92	80.48	86.05

Saturday results show that hours 6 and 11 have persistent volatility and their standard deviations are low. This result shows us volatility is high at these hours but also the price shocks which are captured by standard deviation of parameter also have significant effect on volatility. Besides hour 20 volatility is not persistent and its standard deviation is high which shows that volatility process is dominated by unobserved effects. Either Hour 16 volatility and standard deviation are insignificant.

Table8: Estimation results for stochastic volatility for Sunday

EXP.VAR / HOURS	OFFPEAK		PEAK	
	0	6	13	19
SpotDaily	**- 0.78**	- 0.03	- 0.03	- 0.49
Freesupply		**- 0.42**		
Demand.Quad		**1.39**		
Seosanality				**0.95**
Trend	**0.79**			11.87
DemandVol			**0.84**	
SpotVol		**111.48**		
WaterFlow		**7,603.91**		
Pt7		**- 0.78**		
DemandCurve		**0.22**		
Wind		**- 41.74**		
Gama	**0.57**	**39.97**	**36.48**	**0.55**
Delta	- 0.57	**0.90**	**0.96**	- 0.05
Nu	0.73	**0.27**	**0.34**	**0.99**
Log Likelihood	79.25	84.83	77.95	82.75

Sunday results can be summarized that almost all explanatory variables are significant. Volatility seems persistence at hours 6 and 13 and standard deviation are low. Thus hours 6 and 13 are highly volatile Demand related and renewable plant variables seem remarkable for volatility process. However, hour 0 delta and nu parameters are insignificant. Hour 19 volatility persistency is insignificant and volatility process is mostly affected by unobserved factors of Turkish Electricity Market.

6 Conclusions

Electricity market prices show that volatility is higher than financial assets and commodities (Karakatsani, Bunn, 2004). Electricity price volatility is so important for all energy market participants, particularly for trading and generation companies that volatility evaluation is crucial for trading and financial risk management. This study models stochastic volatility behaviour of electricity prices that helps to reduce short term trading and financial risks. To understand the dynamics of stochastic volatility Taylor (1982, 1994) model used and efficient importance sampling method (Richard and Zhang, 2007).

On the inspiration of results, volatility magnitude is variable at each hour of a day for each day types (Monday, Weekday, Saturday, Sunday). Especially weekday stochastic volatility modelling results show volatility is more persistence and estimated explanatory variables have significant effect on the volatility process where hourly electricity demand of the market is higher than other day types. Even if explanatory variables are statistically significant at price levels, some results demonstrate that other market irregularities have an influence on price fluctuation due to demand, plant operating constraints changes and other structural components. Due to lower electricity demand on Monday, Saturday and Sunday there are less number of significant explanatory variables and volatility behaviour is more complex. Results suggest that market fundamentals should be pursued at hours which have high fluctuation at volatility to manage better trading and financial risks.

References

Bennini, Marracci, Pelacchi and Venturini, 2002, Power Engineering Society Summer Meeting, IEEE

DeJong, D.N., Liesenfeld, R., Moura, G.V., Richard, J.F., 2011. Efficient Likelihood Evaluation of State-Space Representations. University of Pittsburgh, Mimeo.

Duffie, D., Gray, S., and Hoang, P., (1998) "Volatility in Energy Prices" Managing Energy Price Risk. Risk Publications.

EXIST, Energy Exchange Istanbul, www.epias.com.tr

EXIST Transparency Platform, www.seffaflik.epias.com.tr

EXIT Report Platform, www.rapor.epias.com.tr

F.E. Benth, Paris-Princeton Lectures on Mathematical Finance 2013, Lecture Notes in Mathematics, 2081

Hayfavi, A; Talasli, 2013, I. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS; 259; p434-p442

Karakatsani, N.V., Bunn, D., 2004, Modelling The Volatility of Spot Electricity Prices, EMG Working Paper, London Business School

Karakatsani, N.V., Bunn, D., 2010. Fundamental and Behavioural Drivers of Electricity Price Volatility. Stud. Nonlinear Dynamics Econom., 14 (2010), pp. 1–40

Liesenfeld, Roman, Richard, Jean-Francois, 2003. Univariate and multivariate stochastic volatility models: estimation and diagnostics. J. Empirical Finan. 10, 505–531.

Liesenfeld, Roman, Richard, Jean-Francois, 2006. Classical and Bayesian analysis of univariate and multivariate stochastic volatility models. Econ. Rev. 25, 335–360.

Michail S. Sotiriadis, Radamanthis Tsotsos, Kyriaki Kosmidou, 2016, Price and volatility interrelationships in the wholesale spot electricity markets of the Central-Western European and Nordic region: a multivariate GARCH approach, Energy Systems, Volume 7, Issue 1, pp 5-32

Ohashi, K., and Kanamura, T. (2004) "On Transition Probabilities of RegimeSwitching in Electricity Prices", Working Paper, Hitotsubashi University.

Resmi Gazete, www.resmigazete.gov.tr

Republic of Turkish Ministry of Energy and Natural Resources, www.enerji.gov.tr

Richard, Jean-Francois, Zhang, Wei, 2007. Efficient high dimensional Monte Carlo importance sampling. J. Econom. 141, 1385–1411.

Taylor, Stephen J., 1982. Financial returns modelled by the product of two stochastic processes – a study of daily sugar prices. In: Anderson, O.D. (Ed.), Time Series Analysis: Theory and Practice 1. North Holland, Amsterdam, pp. 203–226.

Taylor, Stephen J., 1994. Modelling stochastic volatility: a review and comparative study. Math. Finan. 4, 183–204.

Vehvilainen, I., and Pyykkonen, T. (2004) "Stochastic Factor Model for Electricity Spot Price - The Case of the Nordic Market", Energy Economics, Forthcoming