EFFECTIVE POWER TRADING MANAGEMENT IN TURKISH ELECTRICITY MARKET: HEDGING WITH OPTIONS

(TÜRKİYE ELEKTRİK PİYASASINDA ETKİN TİCARET YÖNETİMİ: FİNANSAL OPSİYONLAR YÖNTEMİ)

by

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LIST OF SYMBOLS

BS **:** Black-Scholes Methodology
BOTAS **:** Turkish Petroleum Pipeline Company
CAGR : Compounded Annual Growth Rate
CRR **:** Cox-Ross-Rubinstein Methodolody
EEX : European Energy Exchange
EMRA **:** Energy Market Authority
EPIAS **:** Energy Market Operation Company
EUAS **:** Energy Generation Company
MCP **:** Market Clearing Price
PMUM **:** Market Financial Settlement Center
OTC **:** Over the Counter Market
TEAS **:** Turkish Electricity Generation and Transmission Corporation
TEIAS **:** Turkish Electricity Transmission Company
TEDAS **:** Turkish Electricity Distribution Corporation
TEK **:** Turkish Electricity Corporation
TETAS **:** Turkish Electricity Trading and Contracting Company

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ABSTRACT

Today with the support of deregulations, a liberal market structure has been started in the energy markets. At the same time, new liberal market structures possess many uncertainties and risk factors. It became very difficult to adapt to changing dynamics and to maintain profitability by keeping the risk under control. Continuously changing factors such as technological development, ever-growing demand for energy consumption, meteorological realizations, and state politics are creating an uncertain environment. Internal and external risk factors are triggering many unexpected outcomes. To survive in this fluctuating environment, risk strategies should be established and continuously developed.

Turkey has a significant part in the global energy sector. With its young population, the ever-growing needs for consumption, the diversity of renewable resources and the closeness to the natural gas producer countries come among Turkey's the most important advantages. On the other hand Turkey's natural fossil resources cannot form a reliable basis to cover the demand for consumption. Turkey has very limited natural gas resources and local-coal is not sufficient by quality and by quantity. These cause foreign-dependency as the biggest disadvantage of Turkey. At the end, all these pros and cons increase the trade volume of Turkey and pave the way for conversion into an energy hub.

In this study, electricity power trading market is focused. The electricity energy trade market has a liberal structure and participants can trade on spot day-ahead market. In addition, to these intraday and over-the-counter (OTC) markets are available and market participants perform transactions at these markets to increase the financial performance of their portfolio and to prevent their risks. The transactions carried out in OTC markets are derivative instruments and the leverage and also the risk ratio are high. Turkish OTC markets are under development. Consequently traders in OTC markets are mostly trading

forward contracts. Option contracts are rather infrequent and are not preferred due to lack of knowledge of pricing methodology and components.

The strategy proposed in the study is the use of option contracts to increase the trading firms' financial performance and to manage its risks effectively.

A financial option contract is a contract between two parties that gives the buyer the right to buy or sell a product up to a predetermined amount for a certain amount of payment (option premium). For the seller that provides the obligation to sell or to buy the property, asset or the financial indicator that constitutes the basis of the contract. Option contracts cannot provide as much revenue as forward contracts, but they provide flexibility to their buyers. When a possible financial loss occurs with very dramatic results in forward contracts, however the option buyers' financial loss is always limited to a predetermined option premium.

In developed markets it is possible to find many studies with options, but there is a limited number of studies on financial options in Turkish energy sector. This study presents a sophisticated forecasting model that takes into account the country and sector's dynamics as well as a financial performance evaluation with derivative products.

Initially a fundamental price forecast model for the second half of the year 2017 is introduced. The forecast model starts with a multiple regression. The calculation is performed to estimate Turkey's natural energy consumption.

Later on, renewable energy production and state owned production forecasts obtained with stochastic methods were subtracted from the estimated consumption value. The result will be the amount of electric energy to be obtained from the spot market. By this residual amount, the merit order structure is simulated and the cost based weighted estimated price is calculated.

At the next step of the application, the forecast result is compared with the forward contract prices existing in the OTC market. Then the corresponding option contracts for the same period have been worked out. European call options, American call options,

Asian-type geometric call options, lookback call options and barrier options were priced using the Black-Scholes model and binomial tree model.

All results are compared with realized spot market prices. According to the results, the success of the forecasting model is satisfyingly high, and naturally the highest performing derivative is the forward contract. As stated before options created lower profit. Also another important outcome is that exotic options resulted better financial performance comparing to plain–vanilla options and the best performing option in this study is the lookback call option.

The financial loss of the seller is another eye catcher of the study. The use of buying and selling option contracts allows the businesses to see their fronts in an uncertain environment, with reducing risk and potential losses.

Finally, the results of this approach have been discussed and future work has been mentioned for the improvement and development of the present study.

RÉSUMÉ

Aujourd'hui, avec le soutien des dérégulations, une structure de marché libérale a été lancée sur les marchés de l'énergie. Dans le même temps, les nouvelles structures de marché libérales possèdent de nombreuses incertitudes et facteurs de risque. Il est devenu très difficile de s'adapter à une dynamique changeante et de maintenir la rentabilité en maîtrisant les risques. Des facteurs en constante évolution tels que le développement technologique, la demande toujours croissante de consommation d'énergie, les réalisations météorologiques et politiques de l'État créent un environnement incertain. Les facteurs de risque internes et externes déclenchent de nombreux résultats inattendus. Pour survivre dans cet environnement fluctuant, des stratégies de risque doivent être établies et continuellement développées.

La Turquie joue un rôle important dans le secteur énergétique mondial. Avec sa population jeune, les besoins croissants de consommation, la diversité des ressources renouvelables et la proximité des pays producteurs de gaz naturel sont parmi les avantages les plus importants de la Turquie. D'autre part, les ressources fossiles naturelles de la Turquie ne peuvent constituer une base fiable pour couvrir la demande de consommation. La Turquie a des ressources en gaz naturel très limitées et le charbon local n'est pas suffisant par qualité et par quantité. Ceux-ci causent la dépendance à l'étranger comme le plus grand désavantage de la Turquie. À la fin, tous ces avantages et inconvénients augmentent le volume commercial de la Turquie et ouvrent la voie à la conversion en un centre énergétique.

Dans cette étude, le marché de l'échange d'électricité est concentré. Le marché du commerce de l'énergie électrique a une structure libérale et les participants peuvent négocier sur le marché spot-ahead day-ahead. De plus, ces marchés intraday et over-the-counter (OTC) sont disponibles et les participants au marché effectuent des transactions

sur ces marchés afin d'augmenter la performance financière de leur portefeuille et de prévenir leurs risques. Les transactions effectuées sur les marchés de gré à gré sont des instruments dérivés et l'effet de levier ainsi que le ratio de risque sont élevés. Les marches turcs de gré à gré sont en cours de développement. Par conséquent, les traders sur les marchés de gré à gré négocient principalement des contrats à terme. Les contrats d'option sont plutôt rares et ne sont pas préférés en raison du manque de connaissance de la méthodologie et des composants de la tarification.

Un contrat d'option financière est un contrat entre deux parties qui donne à l'acheteur le droit d'acheter ou de vendre un produit jusqu'à un montant prédéterminé pour un certain montant de paiement (prime d'option). Pour le vendeur qui prévoit l'obligation de vendre ou d'acheter la propriété, l'actif ou l'indicateur financier qui constitue la base du contrat. Les contrats d'option ne peuvent pas fournir autant de revenus que les contrats à terme, mais ils offrent une certaine flexibilité à leurs acheteurs. Lorsqu'une perte financière possible survient avec des résultats très spectaculaires dans les contrats à terme, la perte financière des acheteurs d'option est toujours limitée à une prime d'option prédéterminée.

Dans les marchés développés, il est possible de trouver de nombreuses études avec des options, mais il existe un nombre limité d'études sur les options financières dans le secteur énergétique turc. Cette étude présente un modèle de prévision sophistiqué qui prend en compte la dynamique du pays et du secteur ainsi qu'une évaluation de la performance financière avec les produits dérivés.

La stratégie proposée dans l'étude est l'utilisation de contrats d'option pour augmenter la performance financière des sociétés de négoce et gérer efficacement ses risques. Initialement, un modèle fondamental de prévision des prix pour la seconde moitié de l'année 2017 est introduit. Le modèle de prévision commence par une régression multiple. Le calcul est effectué pour estimer la consommation d'énergie naturelle de la Turquie.

Plus tard, la production d'énergie renouvelable et les prévisions de production détenues par l'État obtenues avec des méthodes stochastiques ont été soustraites de la valeur de consommation estimée. Le résultat sera la quantité d'énergie électrique à obtenir sur le marché au comptant. Par ce montant résiduel, la structure de l'ordre de mérite est simulée et le prix estimé pondéré basé sur le coût est calculé. À la prochaine étape de la demande, le résultat prévisionnel est comparé aux prix contractuels à terme existant sur le marché de gré à gré. Ensuite, les contrats d'option correspondants pour la même période ont été élaborés. Les options d'achat européennes, les options d'achat américaines, les options d'appel géométriques de type asiatique, les options d'achat rétrospectif et les options de barrière ont été évaluées à l'aide du modèle Black-Scholes et du modèle d'arbre binomial.

Tous les résultats sont comparés aux prix réalisés sur le marché au comptant. Selon les résultats, le succès du modèle de prévision est satisfaisant et, naturellement, le dérivé le plus performant est le contrat à terme. Comme indiqué avant que les options ont créé un bénéfice inférieur. Un autre résultat important est que les options exotiques ont abouti à une meilleure performance financière par rapport aux options simples et l'option la plus performante dans cette étude est l'option d'appel rétrospectif.

La perte financière du vendeur est un autre accroche-regard de l'étude. L'utilisation de contrats d'option d'achat et de vente permet aux entreprises de voir leurs fronts dans un environnement incertain, avec une réduction des risques et des pertes potentielles.

Finalement, les résultats de cette approche ont été discutés et des travaux futurs ont été mentionnés pour l'amélioration et le développement de la présente étude.

ÖZET

Günümüzde enerji sektöründeki, deregülasyonlarla birlikte serbest bir piyasa yapısının önü açılmıştır. Değişen dinamiklere uyum sağlayabilmek ve aynı zamanda karlılığı, riski kontrol altında tutarak sürdürebilmek çok zor hale gelmştir. Teknolojik gelişim, sürekli büyüyen enerji tüketimi talebi, meteorolojik olayların sadece kısa vadeli olarak doğru tahmin edilmesi, devlet politikaları gibi sürekli değişen faktörler belirsiz bir ortam oluşturmaktadır. Tüm bu, iç ve dış risk faktörleri beklenmeyen sonuçların oluşmasını tetiklemektedir. Enerji sektöründe var olabilmek için paydaşlar riskten korunmak için proaktif stratejiler oluşturulup, sürekli geliştirilmelidir.

Türkiye dünya enerji sektöründe önemli bir paya sahiptir. Genç nüfus, sürekli artan tüketim ihtiyacı, yenilenebilir enerji kaynakların çeşitliliği ve doğal gaz üreten ülkelere yakınlık bunun en önemli avantajları arasında gelmektedir. Türkiye enerji üretiminde sabit ve güvenilir bir temel oluşturacak doğal gaz ve kömür kaynaklarının ihtiyaca göre çok az bir paya sahip olması nedeniyle dışa bağımlı bir yapıya sahiptir. Tüm bu avantajlar ve dezavantajlar Türkiye'nin ticaret hacmini artırmakta ve dünyada bir enerji serbest pazarına dönüşümünün önünü açmaktadır.

Bu çalışmada enerji sektörü içerisinde yer alan elektrik enerjisi ticaret piyasasına odaklanılmıştır. Borsa İstanbul bünyesinde bulunan EPIAS tarafından işletilen, elektrik enerjisi ticaret piyasası liberal bir yapıya sahip olup katılımcılar spot gün öncesi piyasası üzerinden işlemlerini gerçekleştirebilmektedirler. Bunun yanı sıra, herhangi bir otorite tarafından işletilmeyen, tezgahüstü (OTC) piyasaları da mevcut olup, piyasa katılımcıları portföylerinin finansal performanslarını artırmak, risklerini koruma altına almak amacıyla bu piyasalarda da işlemler gerçekleştirmektedir. OTC piyasalarda gerçekleştirilen işlemler türev işlemler olup, kaldıraç ve risk oranı yüksektir. OTC

piyasalarda çoğunlukla forward kontratları işlem görmektedir. Opsiyon kontratları ise, oldukça seyrek olup fiyatlama ve bileşenleri hakkındaki bilgisizlik nedeniyle çok tercih edilmemektedir.

Çalışmada önerilen strateji, firmanın finansal performansının artırılması ve risklerinin etkin bir şekilde yönetilmesi amacıyla opsiyon kontratlarının kullanılmasıdır. Opsiyon kontratları, iki taraf arasında yapılan alıcıya, üzerinde mutabakat sağlanmış bir vadede opsiyon primine istinaden söz konusu ürünü, alım veya satım hakkı sağlayan, ürünü satan tarafa da alıcı tarafın hakkını kullanması halinde, sözleşmede belirlenmiş malı veya göstergeyi alım veya satım zorunluluğu tebliğ eden sözleşmelerdir. Opsiyon kontratları, forward kontratları kadar gelir sağlayamazlar fakat alıcısına esneklik ve önünü görebilme imkanı sağlamaktadır. Olası bir finansal kayıp forward kontratlarda oldukça dramatik sonuçlar ile gerçekleşirken, opsiyon kontratlarında belirlenen opsiyon primi kadar bir kayıp gerçekleşmektedir. Literatürde Türkiye elektrik enerjisi sektöründe türev ürünler ile sınırlı sayıda çalışma mevcuttur. Bu çalışma hem ülke hem de sektör dinamiklerini göz önüne alan sofistike bir tahmin modeli hem de türev ürünlerle oluşturulan finansal performans değerlendirmesi sunulmuştur.

İlk olarak, 2017 senesi ikinci yarı yıllık dönemi için oluşturulan fiyat tahmin modeli tanıtılmıştır. Tahmin modelinde çoklu regresyon yöntemi kullanılarak Türkiye ulusal tahmini elektrik tüketimi hesaplanmıştır. Daha sonra yenilenebilir enerji üretimi ve stokastik yöntemlerle elde edilen devlete ait üretim beklentisi, tahmin edilen tüketim değerinden çıkarılarak spot piyasada elde edilecek elektrik enerjisi miktarına ulaşılmıştır. Bu elde kalan miktar ile merit order yapısı benzitelerek, maliyet bazlı ağırlıklı tahmini fiyat hesaplanmıştır.

Uygulamanın bir sonraki adımında tahmin edilen fiyata göre forward kontratın fiyatı gösterildikten sonra, aynı dönem için ilgili opsiyon kontratları çalışılmıştır. Avrupa tipi alım opsiyonları, Amerikan tipi alım opsiyonları, Asya tipi geometric alım opsiyonları, geriye dönük alım opsiyonları ve bariyer opsiyonları Black-Scholes modeli ve binom ağacı kullanılarak fiyatlandırılmıştır.

Elde edilen sonuçlar gerçekleşen spot piyasa fiyatları ile karşılaştırılmıştır. Çıkan sonuçlara göre tahmin modelinin başarısı oldukça yüksek olup, en yüksek getiriyi ilgili döneme ait forward kontratı sağlamıştır. Hesapladığımız opsiyon fiyatları üzerinden bakıldığında en iyi sonucu veren opsiyon tipi ise egzotik opsiyonlardan geriye dönük alım opsiyonudur.

Finansal sonuçlarda dikkat edilmesi gereken nokta satıcının uğradığı zarardır.Uzun vadeli alım ve satım işlemlerinde opsiyon kontratlarının kullanılması, riski ve kaybı azaltacağı gibi işletmelerin belirsiz ortamda önlerini görebilmesi için imkan yaratacaktır.

Son olarak bu sofistike yaklaşımın sonuçları tartışılmış ve yapılan çalışmanın iyileştirilmesi ve geliştirilmesi için yapılabilecek gelecek çalışmalardan bahsedilmiştir.

1. INTRODUCTION

As in the past, also in today energy sector is one of the most important sectors in the world. Energy effectuates the basis of life having profound social, economic and political effects on humanity. Energy sector plays a significant role in the progress of the world and it is the main pillar of all industries. This is why energy is measured and governed by every country, aiming for a better effective development.

The study focusses on electricity energy. Supply and demand are two main entities of electricity system which has no stable course, creating risks and uncertainty. It is a burden for countries and the very best way to cope is the deregulated market structure. During last decades' countries passed far beyond form their monopolistic markets. Starting from US and EU electricity markets, deregulation diffused nearly all over the world. Physical electricity trade, derived from matching of demand and supply, is now possible in spot markets however, despite on-going deregulation processes, such as most financial markets, electricity market is also volatile and bringing on more need to hedge risks.

Before Turkish electricity had a monopolistic structure, and it was operated by Turkish Electricity Corporation (TEK). Years after American and European countries, in 2001 Turkish electricity market law passed into law having objective to build a solid, transpicuous and competing electricity market found on bilateral contracts (Kurucak, 2013).

Firstly, balancing and settlement system is launched with the objective of minimizing system deficits. In this mechanism market participants, which have a consumption over a predetermined limit, were reporting their consumption forecats to prevail penalty fees, which deteoriates system balance. A couple years after, a spot market with day ahead price mechanism, market clearing price (MCP) took into account.

Additionally of the spot market, deregulated over the counter markets took off. Financial derivatives are started to exercise. Forward contracts are the most commonly used ones. Forward prices are very speculatively and they are open to risks. This study focusses on applying and pricing financial options, in electricity trading markets. In this study, also a sophisticated price forecasting model will be studied. The model will be formed with latest sector dynamics for a better understanding of Turkish electricity market. Selling and purchasing electricity options is an alternative to existing derivatives, provided to market participants.

An option is a financial settlement that provides the option holder the right (flexibility) to buy or sell specified amount until an expiration date (Pineda & Conejo, 2012). Option holder pays a specified fee to option writer. On the other hand, a forward contract is costless but has no flexibility.

The organization of the thesis is as follows: In Chapter 2, brief information regarding of the Turkey's electricity power market is provided and by literature reviews risk faced by market participants are investigated. In the next chapter, an extensive literature review is conducted on, derivatives, forward and option contracts that utilized in the power markets. In chapter 4, background information on option valuation methods is given. Black-Scholes and Cox Ross Rubinstein's binomial models are explained in detail.

Black – Scholes model is considered as the most famous and extensively applied method for pricing financial options. It's used to calculate the theoretical value of regular European options adopting actual stock prices, dividend pay-offs, settlement price, interest rates, time to expiration and historical volatility (Black & Scholes, 1973). The Cox-Ross-Rubinstein (CRR) option pricing model is derived from Black-Scholes methodology. The model had a great impact because it approaches the underlying instrument over a time period, rather than a single point in time (Cox et al., 1973).

In the application section a fundamental price forecasting method is presented for Turkish electricity power market and a numerical example for the second half of the year 2017 is provided. According to the literature survey, these options are widely used in Scandinavian and European markets however there no studies in Turkish electricity sector. Next, as a contribution to the conventional trading on forwards, same example will be performed by sets of plain-vanilla and exotic option contracts. To present plain-vanilla options European and American call options are studied and for exotic options geometric Asian, lookback, barrier call options for exotic options are designated in detail. Then convenient option valuation for these type of options are determined and these options are priced. American option is priced by using binomial tree and the others priced by using Black-Scholes equation.

Finally, in Chapter 7, the conclusions drawn from this study, a financial performance comparison of derivatives and the possible future work are emphasized.

2. TURKISH ELECTRICITY TRADING MARKET

The purpose of this chapter is to explain the reason behind selecting energy sector electricity trading market by presenting the importance and the position of the sector. First of all, general information on the Turkish energy sector is provided with relevant industry data. In this chapter a review on the energy sector of the world and Turkey will take in account. In the second part of this chapter, Turkish electricity trading sectors dynamics and risk factors are presented using examples from the literature survey.

2.1.REVIEW ON THE SECTOR IN THE WORLD AND TURKEY

Energy derived from the Greek word "energon"; is expressed as the ability to do business in an object or system (Aruoba & Alpar, 1992). In other words, energy is the main building block formed within any system. Energy, which is a measurable physical quantity and it is one of the basic concepts of the physical sciences and at the same time, energy is an indispensable element of economic activities and therefore of production.

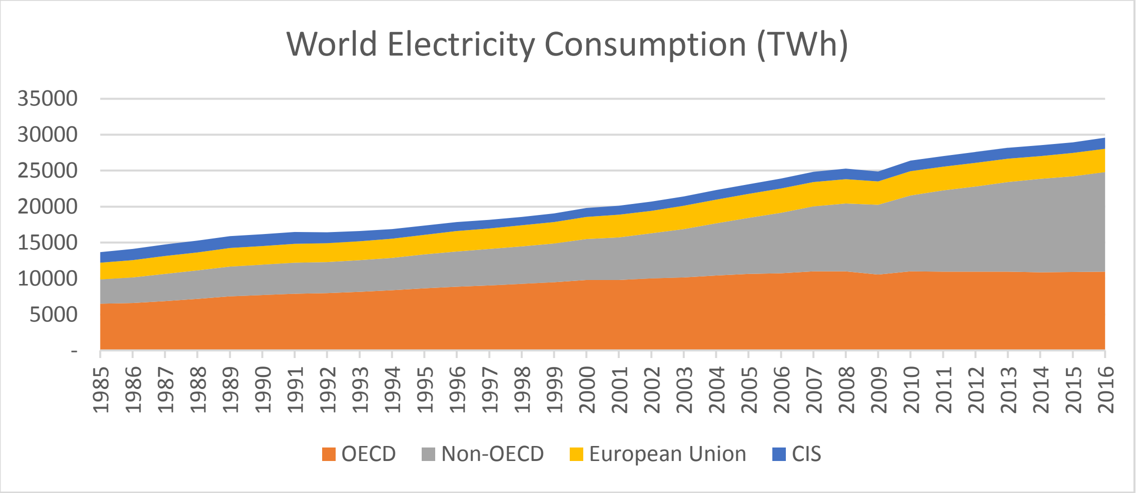

Figure 2.1: Graph of the World Electricity Consumption

Electric power began to be used in daily life in 1878 and the first power plant was constructed in 1882 in London. In 1902, electric power was generated in Turkey using a 2 kW hydroelectric turbine. The first power plant with a capacity of 15 MW was built in Istanbul in 1913. After then Turkish installed capacity is developed by investments and with the aid of technological progress.

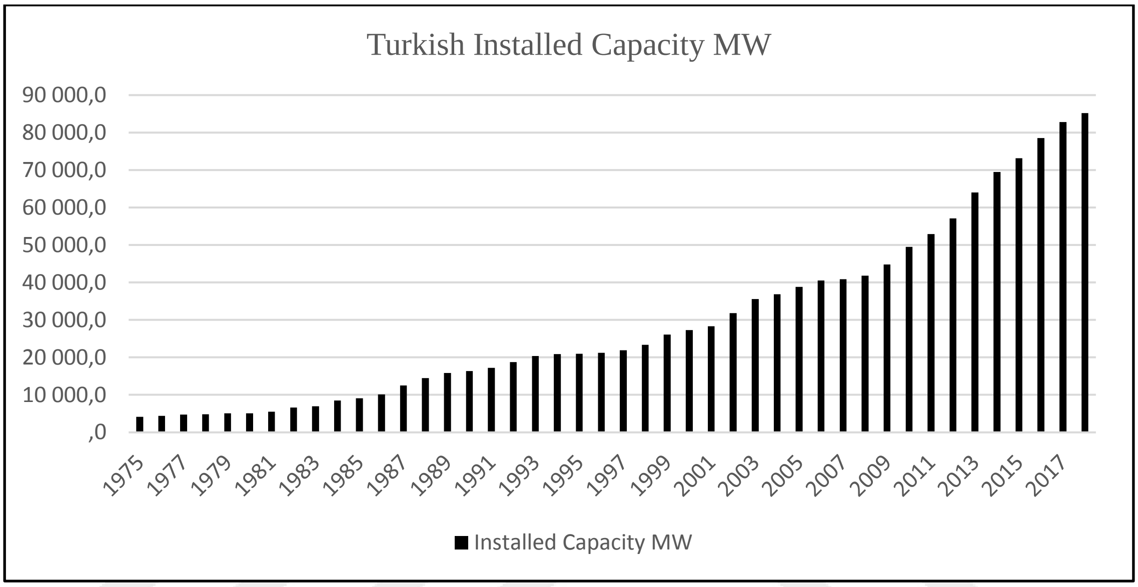

Figure 2.2: Graph of the Turkish Installed Capacity

In the world, the cheapest electricity is obtained by countries having natural gas, oil resources and nuclear power plants. The electricity produced by fossil fuels is still the most reliable. Energy prices in foreign-dependent countries are always higher than producer countries.

Although fossil fuel based production is still leading with technological development renewables' share in electricity production is increasing. Especially in European Union countries are pioneering the change. According 2017 BP annual report %21 of worlds electricity is generated by renewables, but in European Union countries this ratio is realized as %30,5.

Table 2.1: World Electricity Generation TWh

	2010	2011	2012	2013	2014	2015	2016
Total North America	5266	5284	5236	5279	5315	5311	5329
Total S. & Cent. America	1150	1184	1234	1268	1277	1304	1312
Total Europe & Eurasia	5356	5326	5380	5335	5269	5318	5373
Total Middle East	871	903	963	977	1047	1092	1116
Total Africa	669	682	719	743	765	775	782
Total Asia Pacific	8249	8863	9265	9801	10170	10414	10905
Total World	**21562**	**22242**	**22797**	**23403**	**23844**	**24216**	**24816**

2.2. TURKISH ELECTRICITY SECTOR AND DYNAMICS

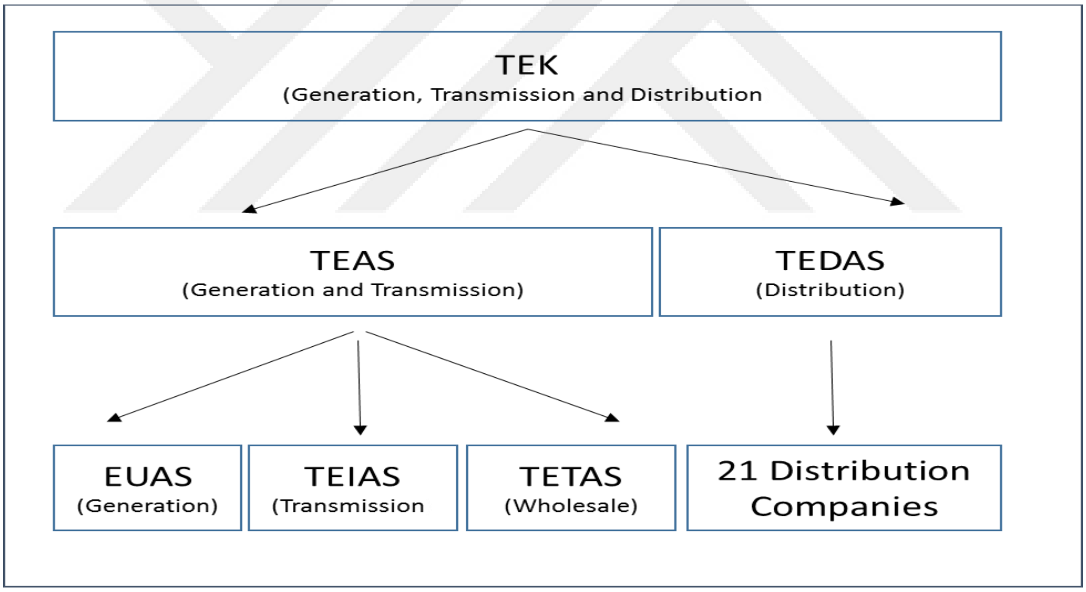

Figure 2.3: Changes in the structure of TEK

Before 2001, all electricity operations were regulated by Turkish Electricity Corporation (TEK). In line with the law TEK divided into two, Turkish Electricity Generation and Transmission Corporation (TEAS) and Turkish Electricity Distribution Corporation (TEDAS). There were 3 companies under TEAS, which are Turkish Electricity Trading and Contracting Company (TETAS), Energy Generation Company (EUAS) and Turkish Electricity Transmission Company (TEIAS). All these four companies are regulated by an autonomous board Energy Market Regulatory Authority (EMRA) (Cetin & Oguz, 2007),(Bagdadioglu & Odyakmaz, 2009).

In 2005 PMUM (Market Financial Settlement Center) was established under TEIAS. PMUM was having the role of system operator, balancing the electricity in the system (Kurucak, 2013). In 2009 a spot market started to operate. In 2013 new Electricity Market Law of Turkey was substantively enacted by repealing EML of 2001. The law also dictates the establishment of the EPIAS (Energy Market Operation Company) as the market operator. EPIAS is charged of establishing energy exchange along with the exchange operator Borsa ˙Istanbul A.S. to furnish market participants with new risk management tools.

Besides in last years, in Turkey, demand for energy consumption is higher than the growth of GDP. In Figure 2.2, it is shown that between year 2013 and 2018 compounded annual growth rate of electricity consumption demand is 4% and the USD based GDP growth is -2,4%.

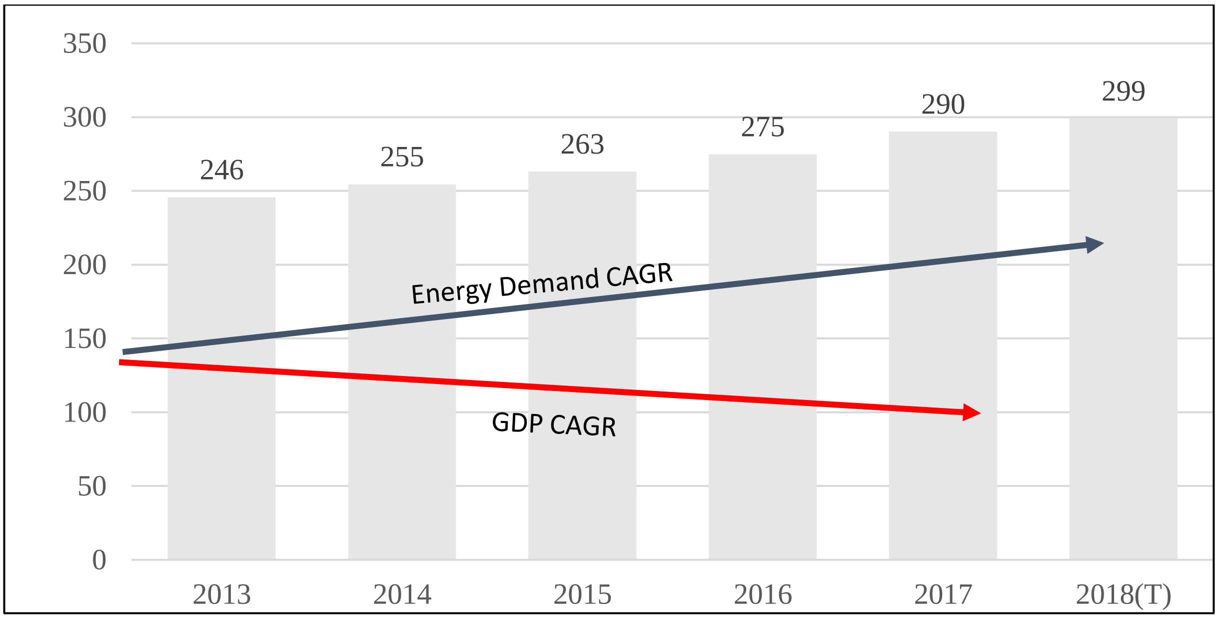

Figure 2.4: Growth of electricity demand vs GDP

Installed power generation capacity of Turkey is 85.200 MW by the end of 2017. Electricity can be generated by EUAS, by Build Operate and Transfer power plants

(BOT), by Build and Operate power plants (BO), by Transferring of Operation Rights power plants (TOOR) and by private producers.

Generated electricity, which reached up to 300 TWh by the end of 2017 is sold to TETAS or private suppliers. TETAS has a private tariff determined by EMRA and its customers are identified by the law. Finally TETAS's electricity is transferred to non-eligible customers, transmission losses, enlightenment and agricultural irrigation customers. Private suppliers are also called as wholesale trading firms, can sell the electricity to eligible customers or can trade it in financial markets.

In this study it will be focused on spot day ahead market prices which are previously mentioned as MCP in Turkey. In the day-ahead market prices are determined by a uniform price auction mechanism. Market participants' bids and offers are collected and the price at the intersection is called MCP. Electricity generators who proposed an offer under or equal to MCP are paid by MCP and all buyers who proposed a bid equal or above to MCP, pay MCP for their demand. Bids and offers that doesn't have a match are obliged to o the prices of balancing and settlement system (Erdogdu, 2010).

In Turkish electricity trading market, MCP is considered as the reference price. Accurate MCP forecasting is vital for decision-making and strategy development of energy companies. Based on demand evolution and supply capacity and production costs market participants create MCP forecast models.

Energy markets are known to support extreme price volatility by their nature. The main reason behind is that, electricity storage is very rare and expensive. In literature many denoted that electricity is non storable (Bassembinder & Lemmon, 2002), (Oum et al., 2003). This non-storability prompts the electricity market to be distinctive from other financial markets.

Electricity spot prices can dramatically change even in case of fluctuation in power generation or load. There exist four main aspects of electricity, which are seasonality, volatility, mean reversion, spikes (Brierbauer, 2003). Also electricity market is up to many internal and external risks. Such as breakdowns, maintenances, fossil fuel supply reliability, commodity prices, weather conditions, water inflow, currency risk, credit risk and political etc. Also considering physical delivery, there is no chance for arbitrage. To hedge risks of trading portfolio, derivatives are commonly used.

In Turkey 50% of annual market volume consists of bilateral contracts, 39% consists of Day Ahead Market, 10% consists of Balancing Power Market and 1,2% consists of Intraday Market transactions. Market Clearing Price (MCP) derived from day-a-head market is determined by merit order mechanism and it is called as the spot market price. Bilateral contracts has the highest shares because of two main reasons. Firstly many companies have two or more legal entities and they transfer the physical electricity by bilateral contracts from their production entity to trading entities. Secondly, a physical electricity can be traded more than one time. Although if we compare number of transactions with European and American markets, their transaction average is 6,5 per contract, however in Turkey the average is 2,3. The difference indicates that Turkish trading market is a developing market.

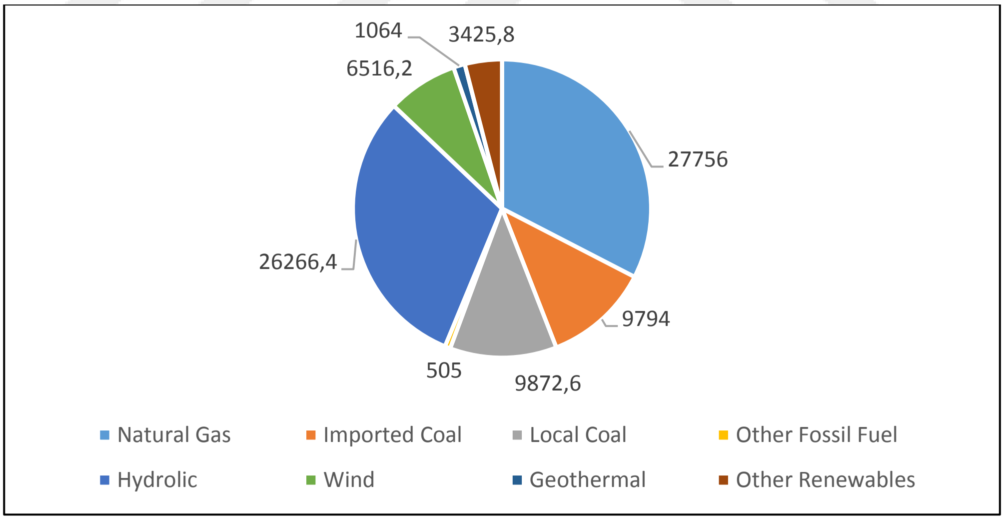

Figure 2.5: Installed Capacity of Turkey

Turkey has long term purchasing contracts relied on foreign currency and commodity stock prices. Moreover, the other half is composed by hydroelectric power plants and wind farms, which are unreliable resources due to weather conditions. Also local coal supply is insufficient to meet ever-growing demand. There are several studies on Turkish spot market in literature focused on the dynamics of day ahead electricity prices applying parametric approaches and taking in account external risk factors and strategic bidding (Surucu et al., 2016). Also portfolio optimization problems of Turkish day-ahead electricity market by using mean-variance, downside and semi-variance techniques for electricity prices are studied (Gokgoz & Atmaca, 2012a, 2012b).

According to Turkish state officials and sector experts, foreign-dependency is the most important risk factor of Turkish power market. Natural gas and imported coal powered plants constitute nearly half (%45) of the installed capacity. There are studies as outlook to Turkish power sector and supply structure, especially during gas shortages in winter (Dastan & Selcuk, 2016).

3. LITERATURE SURVEY

In this section of the thesis, the reason behind of selecting the topic will be explained by giving examples from existing studies in the literature and the importance of the contribution is underlined by showing what is missing in the existing.

As it is told in the Chapter 2, deregulations in Turkish energy sector have a long way ahead to reach developed European and American markets. Studies on other countries' and Turkey's market structure and methodologies that researchers utilized to increase efficiency will be briefly presented. It is seen that most studies are focused on price forecasting and risk hedging. In the second part of this chapter, it will be focused on financial options topic. Studies on financial option types and their valuation is given.

3.1. RISKS FACTORS IN ELECTRICITY MARKETS

In literature there are many studies on internal and external risk factors in electricity trading market.

Bessembinder and Lemmon (2002) presented an equilibrium model that the forward contracts are a downwars biased indicator of the future spot price. They conducted an empirical study resulting, when the variance in the demand increases, the forward premium is greater. Ventosa and River (2005) focused on electricity generation market. Their paper introduced a classification according to most relevant attributes, aiming to help identify, classify and characterize the approaches in the literature. They diversified approaches under three groups; optimization, equilibrium and simulation. Dyner et al. (2009) provided a study for oligopolistic markets with insufficient market participants. They created a parametric learning tool having features using game theory techniques for risk hedging.

Sorwar and Dowd (2010) studied on estimating risk measures for options, in their paper they created a simulation tool to estimate risk factors for electricity option positions.

Jones (2012), in his book guided to assess and manage energy prices. He studied on geopolitical strategies, changes in regulations, OPEC decisions, speculative reports, transportation issues, and supply and demand fluctuations as crucial risk factors.

Pineda et al. (2012, 2013) studied on managing risks by using options. Both studies are presented from the perspective of power producers. They mainly focused price volatility and unit breakdowns. They proposed a stochastic model that determine the optimal involvement to the available forwards and financial option contracts.

Oum et al. (2016) focused hedging portfolio risks in competitive electricity wholesale market. They addressed quantity risk in the electricity market and the paper also points on risk hedging problem of a distribution company, which provides electricity to its' customers at a regulated price having price and quantity risks.

Dagoumas et al. (2017) focused on unit commitment risks using artificial neural network. The risks investigated risks are breakdowns, strategic bidding, demand peaks, ramp-up incapacity and imprecise capacity reserved to ancillary services. With artificial neural network methodology, they modeled the unit commitment in Greek electricity market and found accurate results according to relevant data.

Aliabadi et al. (2017) worked on risk aversion in oligopolistic markets. Within the study a flexible agent-based simulation is proposed. Their model is a learning model, as more data processed, models' accuracy success is increasing.

Bahrami and Amini (2018) conducted a study on a quite new topic in energy sector, system operators demand forecast risk of a decentralized grid structure. Renewable producers and load aggregators offers are tired to optimize the network.

Hain et al. (2018) offered a risk hedging methodology taking into account rising energy demand, price fluctuations, supply disruptions and environmental impact. They have studied with hedging natural gas, coal and crude oil contracts to reduce such as equity and commodity market returns or exchange rate risk.

3.2. SPOT MARKET PRICE FORECASTING

As stated many risk factors are present in electricity markets, which makes it even more difficult to make price forecasts. Price forecasting is one of the most important work done by analysts, traders, investors and researchers. In literature it is possible to find various studies on MCP forecasts in other markets, however it is very difficult to find studies on Turkish MCP forecast.

Weron (2014) composed a literature review article having goal to demonstrate the intricacy of available studies. They performed swot analysis to interprete all existing forecast models.

Boravkova and Schmeck (2017) focused on price forecast modeling using EEX (European Energy Exchange) data with stochastic time change. They proposed a technique which allows integrating distinctive aspects of spot market prices such as seasonality, mean-reversion and spikes in their model. Lago et al. (2018) studied measuring the importance of these interdependent factors. They proposed a feature evaluation model which, using Bayesian optimization and functional analysis of variance, assesses the impact of the features on the outcomes.

Others studied with Nord-Pool data on nonlinear empirical pricing in electricity markets using parametric weather changing factors (Torbaghan, 2010; Lopez et al., 2017). Also there are backwards examples in the Spanish electricity market, on price forecast validation using forecasts as input data (Ortiz et al., 2016).

Nikkinen and Rothovus (2018) studied on electricity option contracts in NASDAQ. They are focused on bidding strategies and market strategic behavior in seasonal trading.

In the literature commonly using historical data spot prices are modeled by production cost models, equilibrium models, statistical models and with quantitative models. Briefly production cost models are based on marginal costs of electricity generators. These models take essential that at command supply capacity effectuate prices. For example, from historical MCP data it is possible to see that in springs due to eminent hydro-electric power plant production prices are lower. Controversially, in winters due to high consumption, lack of renewable resources and fossil fuel based production prices scales up. Turkey has very limited natural gas reserves and procure natural gas from other countries by long term take or pay contracts. The contracts are related with commodity prices and currency rates. For example, in February 2017 because of the high consumption and severe winter conditions a serious gas crisis took part and caused a great spike in MCP.

However, production cost based models are vulnerable to strategic bidding. Hortacsu and Puller (2005) conducted a study on strategic bidding in restructured electricity markets. They analyzed bidding strategies of firms with large stakes and smaller firms. Wolfram (1997) studied on strategies of firms supplying electricity of England and Wales. The price mechanism, it is also very similar MCP mechanism in Turkey, proposes that bidders selling more than one electricity product have an incentive to increase the prices as they bid at high quantities.

Equilibrium models can be considered as extensions of production based models, using game theory traders give strategic bids. These models have low accuracy and risky. Quantitative models use historical data, using statistical properties of historical prices as price derivatives.

3.3. FINANCIAL OPTIONS

In finance terminology, two types of financial positions are available, they are called as long position and short position. When the amount of bought products are bigger than amount of sold, it is called long position. Oppositely, when amount of sold products are bigger than amount of bought, it is called short position.

In the case of financial options, the buyer the financial option contract is at long position and the seller, also called writer, of the option is at short position.

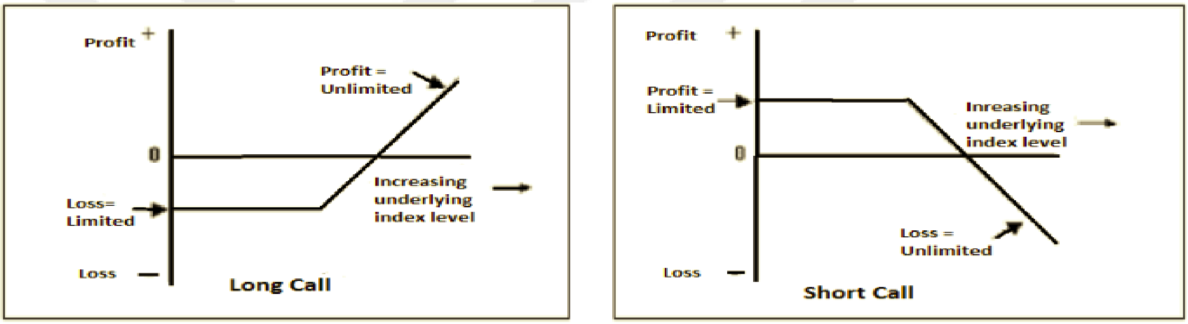

Figure 3.1: Long and short regular call option payoffs

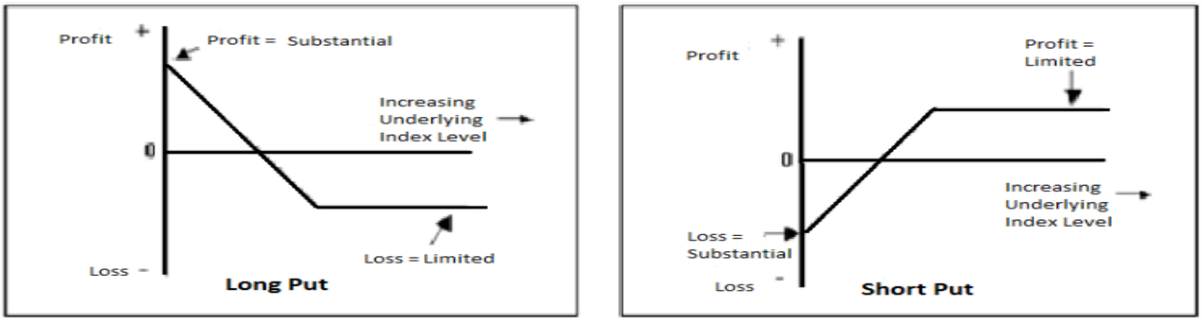

Figure 3.2: Long and short regular put option payoffs

An investor who purchases a call option has substantially purchased a standard right to have a specific amount of an asset at to a determined exercise price, whereas a put option gives the holder the opportunity to sell the asset at the strike price. On the other hand for the option sellers there are not such flexibility. Seller receives an option premium and is obliged to follow the contract terms.

Option contracts have the ancient Greek roots. Aristotle's famous work Politics, talks about Thales' successful execution of a primitive speculative option. Thales has done meteorological investigations, and predicts that the olive harvest would be higher in the next summer. He rents all the olive presses in Milet and Chios at a low cost because the demand is not too high at the beginning of the year. When the summer season arrives, the olive harvest and simultaneous demands for presses increase. As a result, Thales hires the presses at a high price, and has a substantial amount of money (Andersen, 2002).

Another process that carries option features in antiquity is; in the Bible (Genesis 29), Laban offers an option to Jacob to marry her little daughter in return seven years in the service of Laban. This story at the same time such as the possibility of non-delivery is also an example of an important difficulty with regard to operations. Because, after completing the seven-year compulsory service, Laban gave Jacob permission to marry Leah, who is older than her daughter Rachel. Contracts based on the delivery of goods carried by vessels during Phoenician and Roman times are similar to option transactions. In addition to this, wheat-based option transactions were made in England during the middle ages.

Except for the primitive contracts that are similar to the above-mentioned option transactions, option transactions that can be regarded as the first version of today's option contracts were made in the 1600s by Dutch users on the tulips. Tulip bulbs have been traded by many Dutch as a speculative commodity with prices reaching a thousand times their real value. On top of that, tulip producers began to sell option contracts that would be paid by buyers in case of falling prices. However, due to falling prices, tulip producers failed to fulfill the requirements of the options they sold by bankruptcy and caused the termination of option contracts. In the 1900s, oversea traders re-invented options but manipulated their prices. In the 1930s and from World War II until 1956, options were banned in the United Kingdom. In America, options were illegally traded in Chicago streets. Even though the Options Dealers Association was established in 1934, and the option costs were realized by 30% less than the fair value.

An alternative to spot market trade and to forward contracts is provided to the market participants by selling or buying via financial options. A financial option is a contract that gives the buyer the right to buy (call option) or right to sell specified amount of electricity energy until an expiration date at a fixed price (strike price). Buyer pays a fee to have those right (option price). Other derivatives such as forwards are costless. According to market conditions option holder (buyer) decides whether to use this option or not. On the other hand, the option writer (seller) doesn't have such flexibility (Blanco & Wehrheim, 2017).

With many risk factors in an uncertain environment options hedge risks, and aid strategic management of companies. As a result of development of the options market, actors started to have extended intelligence about products and accordingly their demands and needs have increased.

In literature many studied financial options in energy markets. Aid et al. (2010) focused on pricing and hedging electricity derivatives. To price and hedge derivatives a risk minimization approach is followed. Others focused on forward premium values of futures, using a four dimensional value at risk model, to distinguish elementary and behavioral aspects of price creation in both the daily and monthly forward premium (Stoft, 1999 ; Bunn & Chen, 2013).

Ghosh and Ramesh (1997) created an options model for electric markets, investigating the development of derivatives market in a market setup. In so doing model considers the market based financial derivative instruments and they concluded with proposing a tool called optimal power flow.

Also there are studies using power options to hedge volume risk in Colombian market. Their framework was compared with the historical data of the Colombian power market. They found out that by two put and three call options on a monthly basis a better management of risk hedging might be achieved (Sanchez et al, 2011).

It is possible to have many studies with exotic options especially swing options. Others studied on hedging swing options in complete markets, the option' price without arbitrage is determined by hedging on forwards. The study is presented both from the perspective of the holder and the writer of the option (Vayanos et al., 2011). In other studies; arbitrage-free option pricing is evaluated against three hypotheses based on mental accounting (Rockenbach, 2004). The pricing of options without arbitrage is evaluated. The data shows that, even with considerable experience, untapped arbitrage opportunities persist.

In this study a fundamental model will be prosed, by using evolution of production costs and other parameters such as weather conditions, water inflow, currency futures and commodity futures at supply side. Also seasonality, fluctuations in demand will take part.

3.3.1. FINANCIAL OPTIONS TYPES

Financial options are separated into two, they are called as regular options and exotic options. Regular options are also known as plain- vanilla options. Plain-vanilla options distinct in to two because of their maturity structure and called as European and American options. European options can only be exercised at the end of their maturity, on the other hand American options can be exercised any time until their maturity. European options seems to be traded at a discounted fee according to American options because American options provide holder more flexibility to exercise (Wang and Qian, 2011).

Exotic options can be considered as new generation, nonstandard options, which have additional conditions in order to be customized for individuals and traded frequently in OTC markets. Exotic options possess some features, which make them more flexible and appropriate for the needs of market participants.

Exotic options have many types such as; swing options, rainbow options, barrier options, look back options, Asian type options, compound options, etc.

An exotic option is an option that differs in structure from plain-vanilla options in terms of the underlying asset or the calculation of the payoff. Exotic options are generally much more sophisticated than plain vanilla options, they are customized options to meet functional requirements of options' parties.

These options are old as regular options however they are first defined as exotic options in 1990s (Rubinstein, 1991; Zhang,1997). Exotic options divide in to two as path-independent and path-dependent options. In path dependent options, option premium is affected by the behavior of underlying asset.

Asian options are grouped under path-dependent options having a strike price which is the arithmetic or geometric average of a period. A period's average is naturally is less volatile than the stock price, which makes Asian options cheaper than plain-vanilla options (Clark et al., 1999).

Jeon et al. (2016) obtained partial parabolic differential equations with time-dependent coefficients on the path-dependent Asian options and derived a closed-form formula of the price of the path-dependent geometric Asians option using the pricing formula of the European options with time dependent coefficients. Wang et al. (2018) studied on pricing the products of Asian rainbow options under mean-reversion.

For lookback options, the payment of some options can withstand the lowest and highest bid received by the option on which it is placed. When the option is exercised, the exercise price would be close to spot price, within time as the spot prices change the strike price changes too. Kim and Jeon (2018) studied on closed form solutions to value partial lookback options. They compared their results with the outcomes of the Monte-Carlo simulation.

A barrier option is a type of option whose payment depends on even if the underlying asset has reached or not a predetermined barrier. A barrier option can be classified as knockout, which means that it can expire as worthless if the underlying exceeds a certain price, which limits the profits for the holder and the losses for the option writer. It can also be a knock-in, which means it has no value until the underlying exceeds a certain price. Sousa et al. (2018) investigated the pricing of financial options under the stochastic volatility model. It is an analytical model that reproduces the curve for volatility and the asymmetry effects observed in empirical market data.

4. OPTION VALUATION METHODOLOGIES AND BACKGROUND

In this section of thesis, a brief summary of the factors having effect on option premium and option valuation methodologies is presented. As mentioned in the previous section, to hedge and control their risks traders often use option contracts. Plain-vanilla and exotic options are frequently traded in financial markets. One of the most important decisions is about pricing the option contract. In literature there are many studies regarding how option contracts are traded and how to evaluate them. However, there are more than one pricing methodologies, all do not meet requirements to price every kind of financial options.

The objective of this section is to present selected Black-Scholes and Binomial tree algorithms for this study.

4.1. FACTORS THAT INFLUENCE OPTION PREMIUM

In option contracts rights and responsibilities of sides are not symmetrical. To purchase flexibility, the option owner is obliged to pay a premium to the option seller. An investor needs to determine the right and fair price for a contract. There are several reasons that affect option price such as; spot market price, strike price, type of option, time to expiration, risk-free interest rate and volatility.

Spot market price of the underlying asset influences directly on option premium. In call options, if the spot market price is higher than the strike price higher option premium occurs. Controversially, in put options, if the spot market is higher than the strike price, there will be a lower option price (Black & Scholes, 1973).

Options start in profit or in loss due to difference between spot market price and strike price, so strike price is also a remarkable factor (Oum et al., 2016). Risk-free interest rate indirectly reduce the present value of the strike price so in call options higher interest rates cause higher premium value, in contrast for put options cause lower premium value. Financial options contracts take in action in uncertain environments. Time to expiration is another dimension of uncertainty and both in put and call options, premium decreases as approaching to expiration (Brierbauer et al., 2003). Finally volatility is always derived from uncertainty, higher volatility increases the option premium (Hoffmann, 2001 ; Poon & Granger,2003).

Table 4.1: Factors influencing option price

Factor	Call Option Price	Put Option Price
Spot market price ↑	↑	↓
Strike price ↑	↓	↑
Time to expiration ↑	↑	↑
Risk-free interest rate ↑	↑	↓
Volatility ↑	↑	↑

4.2. OPTION VALUATION METHODOLOGIES

As mentioned in previous chapters, options are being trading for centuries. Before breakthrough of Black-Scholes in 1973, many different methodologies are utilized. In this section of thesis to ensure a basic understanding the reasons about why we choose our methodologies, post Black-Scholes models will be briefly presented.

4.2.1. BLACK-SCHOLES METHODOLOGY

Option valuation methodologies contain probabilistic approach and future price estimation. First known approach is created by two mathematicians Blaise Pascal and Pierre De Fermat. They set up a probability theory, which became background theory for modern researchers (Ore, 2006).

However solely option pricing methodologies starts with Louis Bachelier in 1900 that studied in his PhD dissertation (Bachelier, 1900).
He built his theory on arithmetic Browninan motion which has assumptions on normally distributed returns according to Bachelier without dividend yield paying and zero interest rate, the price of European call should have calculated by:

$$(S,T) = SN\left(\frac{S-K}{\sigma\sqrt{T}}\right) - KN\left(\frac{S-K}{\sigma\sqrt{T}}\right) - \sigma\sqrt{T}n\left(\frac{S-K}{\sigma\sqrt{T}}\right) \tag{4.1}$$

Where S is the stock price, K is the strike price, σ is the normal distribution of the stock prices, T is time to expiration, $N(x)$ is the the cumulative normal distribution function and $n(x)$ is the probability density function. His remarkable work stayed as the unique option valuation model for almost 60 years. Then Merton and Smith discovered that Bachelier method can outcome negative stock prices and ignores price discounts (Merton, 1969 ; Smith, 1976). Sprenkle in 1964 applied geometric Brownian motion by lognormal returns, however his formula had too many quite implicit estimations, and couldn’t achieve the popularity of Black-Scholes (Sprenkle, 1964). Later Boness contributed Sprenkle’s model by adding time value of money and Samuelson and Merton let the option to have a different risk from the stock price (Boness, 1973), (Merton, 1973).

The post studies were great contributions to the literature and guided Black and Scholes for their breakthrough. Black-Scholes found out that the return of the option price should have risk-free rate and certain amount of stock could entirely have hedged. It is easy to say that Black-Scholes formula has tree great advantages; firstly, it was explicit using volatility of stock price, risk free interest rate, time to expiration, strike and spot prices. Secondly, it ignores the option buyers risk adverse because it only depends volatility and risk free interest rate. Thirdly, there is no need to estimate parameters except volatility (Benhamou, 2011).

Their methodology is derived from the volatility; the defaults of long and short positions and underlying stocks. This model allows the premium value of the option to be calculated using the underlying asset price, usage price, interest rate, volatility, and time remaining in the transaction. The same principle constitutes the substructure of almost all option pricing formulas used today in financial markets.

$$c = S \times N(d_1) - K \times e^{-rT} \times N(d_2) \tag{4.2}$$

$$p = K \times e^{-rT} \times N(-d_2) - SN(-d_1)\,N(d_1) \tag{4.3}$$

$$d_1 = \frac{\ln\left({}^{S}/_{K}\right) + (\,r + {}^{\sigma^2}/_{2}) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} \tag{4.4}$$

$$d_2 = \frac{\ln\left({}^{S}/_{K}\right) + (r - \,{}^{\sigma^2}/_{2}) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} = d_1 - \sigma\sqrt{T} \tag{4.5}$$

where:

S = spot price
K = exercise price
r = risk free interest rate
T = time to expiration date (years)
σ = volatility
$N(d_1)$, $N(d_2)$ = normal distribution
c = call option price
p = put option price

In 1973 Robert Cox Merton (Merton, 1973) added on Black-Scholes model to price continuous dividend paying stocks. Having the dividend yields as a continuously compounded rate (q), you may find below pricing of a European call option.

$$c = S \times e^{-qT} \times N\,(d_1) - K \times e^{-rT} \times N(d_2) \tag{4.6}$$

$$d_1 = \frac{\ln\left({}^{S}/_{K}\right) + (r - q + {}^{\sigma^2}/_{2}) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} \tag{4.7}$$

$$d_2 = \frac{\ln\left(S/_K\right) + (r - q - \sigma^2/_2) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} = d_1 - \sigma\sqrt{\mathrm{T}} \tag{4.8}$$

4.2.2. BINOMIAL TREES (CRR METHODOLOGY)

Cox, Ross and Rubinstein (1979) proposed their methodology. Their model is a derivation of the Black-Scholes formula. The model became very famous because it allows considering underlying asset over a period of time instead at one specific point. It takes in account the possible changes of the various parameters with in time. So binomial trees have very successful results with American options which can be exercised any time until specified expiration (Bally etl., 2005 ; Cescato & Lemgruber, 2011). However the model doesn't have sense for European options which can be exercised only at expiration.

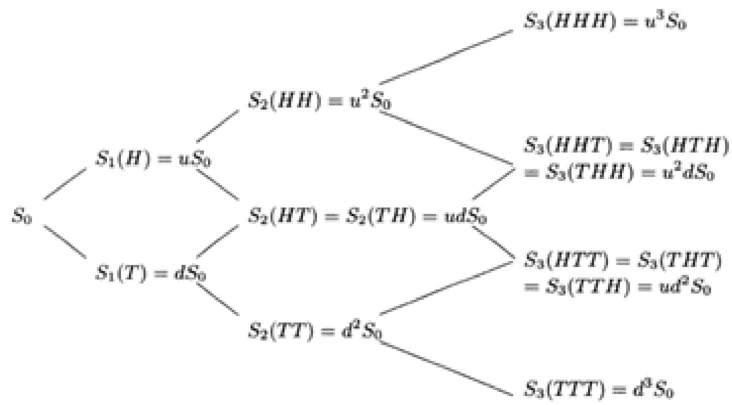

Figure 4.1: Three period binomial tree

where:

S = Stock price

H = up function

T = down function

u = size or magnitude of up step

d = size or magnitude of down step

Such as Black-Scholes, CRR has assumptions, such as in risk neutrality, no-possible arbitrage and at a node price can take only an up or a down. Another advantage CRR is that it has less complicated math rather than Black-Scholes. In literature it is possible to see studies focused on pricing options via CRR methodologies. Moon et al. (2016) studied a method for pricing for pricing asian options via binomial tree which can be used independently to construct a new tree method, or it can be combined with other existing tree methods. Braouezec (2017) conducted a research offering a new and simple methodology to determine the range of prices of standard European call (or put) options using a one-period trinomial model. Building on the flexibility of this trinomial model, it is shown that the pricing bounds may be lower than the classical ones.

Ghaffari and Venkatesh (2015) created a network constrained model for option based ancillary energy procurement from wind power plants using binomial trees. Jackwerth (1999) proposed an implied binomial tree which model stochastic process of the underlying asset prices. In his study he found risk-neutral probability distribution of the prices. Kim et al. (2016) launched a binomial tree model suits all dimensions of geometric Brownian motion. Their model combine the classical Cox–Ross–Rubinstein, the Jarrow–Rudd, and the Tian binomial tree models. The new binomial model is utilized a partial hedge of by option valuation. Rambaud and Perez (2017) used binomial tree approach also in real options project assessment.

4.3.PRICING PLAIN-VANILLA OPTIONS

As mentioned in previous sections, there are two types of plain-vanilla options. They are European and American options. The crucial difference between them is although a European option can be exercised if and only at its’ maturity date, American option can be exercised any time. In Black-Scholes the strike price has set before so it doesn’t work for American options. To price American options, in literature CRR models (binomial-trinomial trees), Monte-Carlo simulation models are widely used.

4.4.PRICING EXOTIC OPTIONS

In this thesis, Asian options, lookback options, swing options and barrier options compound options has been presented. These types are widely utilized in developed energy markets. In this part pricing of these exotic options will be explained in detail.
As declared in previous sections, exotic options are like regular options, except that they have unique specifications that make them sophisticated. With these adaptive specifications all-or-nothing style hedge is possible (Taleb, 1997) and also situations where an investor faces exchange-rate and price risk, as well as many other situations, can be solved with these tidy packages.

4.4.1. PRICING ASIAN OPTIONS

Asian options are also called average options and used very commonly in electricity markets. These can be a yearly, half of year, quarterly, monthly, or even daily products. Features of the probability distribution of the stochastic process of the stock price make it possible to obtain an analytical closed form formula, derived from the Black Scholes formula. These properties also make it possible to achieve a closed form formula for the price of a Geometric Asian option due to the features of a geometric mean (Wiklund, 2012).

Arithmetic means do not have the same key features with geometric means and Arithmetic Asian option prices are hence, apparently, impossible to express in an analytical Black-Scholes formula. As will be presented in the application section, it is possible to approximate an arithmetic Asian option prices using the geometric mean prices (Michael, 2004). For pricing arithmetic Asian options with high accuracy numerical methods has to be used, and one such is Monte Carlo Simulation. Also as stated there are studies on arithmetic Asian options pricing via binomial trees.

In literature it is easy to find studies on pricing Asian options. Moon et al. (2016) studied a method for pricing for pricing Asian options via binomial tree which can be used independently to construct a new tree method, or it can be combined with other existing tree methods. Fanelli et al. (2016) also had interest in arithmetic Asian options pricing in the day ahead market, underlying that the market participants to predict the future demand contributing to market efficiency by letting lower option premiums.

You may find below the Black- Scholes geometric Asian options pricing formulas where n is the number of observations to form the average, h is the observation frequency and j is the number of observations past in the averaging periods (Lakhani, 2013).

$$c = S \times A_j \times N\left(d_{n-j} + \sigma\sqrt{T_{2,n-j}}\right) - K \times e^{-rT} \times N\left(d_{n-j}\right) \tag{4.9}$$

$$p = K \times e^{-rT} \times N\left(-d_{n-j}\right) - S \times A_j \times N\left(-d_{n-j} - \sigma\sqrt{T_{2,n-j}}\right) \tag{4.10}$$

$$d_{n-j} = \frac{\ln\left({}^{S}/_{K}\right) + \left(r + {}^{\sigma^2}/_{2}\right) \times T_{1,n-j} + \ln(B_j)}{\sigma\sqrt{T_{2,n-j}}} \tag{4.11}$$

$$A_j = e^{-r\left(T - T_{1,n-j}\right) - \frac{1}{2}\sigma^2\left(T_{2,n-j} - T_{1,n-j}\right)} \tag{4.12}$$

$$T_{1,n-j} = \frac{n-j}{n}\left(T - \frac{(n-j-1) \times h}{2}\right) \tag{4.13}$$

$$T_{2,n-j} = \left(\frac{n-j}{n}\right)^2 \times \left(T - \frac{(n-j) \times (n-j-1) \times (4n-4j+1) \times h}{6n^2}\right) \tag{4.14}$$

$$B_j = \left(\prod_{j=1}^{n} \frac{S \times T - (n-j) \times h}{S}\right)^{1/n}, B_0 = 1 \tag{4.15}$$

Hence the formulation above is too complex, after by work of many the formula is simplified as:

$$c = S \times N(d_1) - K \times e^{-rT} \times N(d_2) \tag{4.16}$$

$$p = K \times e^{-rT} \times N(-\, d_2) - \ S \times N(-d_1) \tag{4.17}$$

$$b_{avg} = \frac{1}{2}\ (\mathrm{b} - \frac{\sigma^2}{6}) \tag{4.18}$$

$$\sigma_{avg} = \frac{\sigma}{\sqrt{3}} \tag{4.19}$$

$$d_1 = \frac{1}{\sigma_{avg}\sqrt{\mathrm{T}}}\left(\left(\ln\left(\frac{S}{K}\right) + (b_{avg} + \frac{1}{2}\ \sigma_{avg}^2\right) \times T\ \right) \tag{4.20}$$

$$d_2 = \ d_{1-}\ \sigma_{avg}\sqrt{\mathrm{T}} \tag{4.21}$$

As stated above Black Scholes formula works for only geometric average options, however Wiklund (2012) had an important work on applying Black Scholes on non – dividend paying arithmetic Asian options. Another well-known methodology for Asian options is CRR. CRR methodology is suitable for both geometric and arithmetic average where the following path-dependent variable denoted by A is introduced below (Chalasani et al., 1999).

$$A_n = \begin{Bmatrix} \frac{1}{n}\sum_{i=1}^{n} S_i \ \ , Asian\ arithmetic \\ (\prod_{i=1}^{n} S_i)^{1/n}, Asian\ geometric \end{Bmatrix} \tag{4.22}$$

With pay-offs:

$$\Lambda\ (S_n, A_n) = \begin{Bmatrix} (A_n - K)\ , Asian\ call \\ (\mathrm{K} - A_n), Asian\ put \end{Bmatrix} \tag{4.23}$$

For up (u) and for down (d) movements:

$$A^{u,d} = \begin{Bmatrix} \dfrac{(t - \Delta t)\ A + S_{u,d}\ \times \Delta t}{t} \\ A^{\frac{t-\Delta t}{t}}\ (\ S_{u,d})^{\frac{\Delta t}{t}} \end{Bmatrix} \tag{4.24}$$

4.4.2. PRICING LOOKBACK OPTIONS

In this study fixed lookback options are studied. Lookback options are separated into two; floating strike and fixed strike options. Floating strike lookback put options give right to sell the option, to the highest price realized in options lifetime. Regarding this, payoff of the option is equal to the difference between the max or min value and the option value at the expiration (Yu et al., 2001). Conze and Viswanathan's (1991) formula is commonly used.

Fixed strike lookback options, have a fixed strike price defined at the beginning and the option pay-offs is the difference between max or min value and the strike price *X*.

For lookback call options:

$$c = S\ \times e^{(b-r)T} \times N(d_1) - K\ \times\ e^{-rT} \times N(d_2) + S\ \times\ e^{-rT} \times \frac{\sigma^2}{2b}\left[-\left(\frac{S}{K}\right)^{-\frac{2b}{\sigma^2}} \times\ N\left(d_1 - \frac{2b}{\sigma}\sqrt{T}\right) +\ e^{bT} \times N(d_1)\right] \tag{4.25}$$

Where

$$d_1 = \frac{\ln(S/_K) + (b + \sigma^2/_2) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} \qquad d_2 =\ d_1 -\ \sigma\sqrt{\mathrm{T}} \tag{4.26}$$

For lookback put options

$$c = -S \times e^{(b-r)T} \times N(d_1) + K \times e^{-rT} \times N(d_2) + S \times e^{-rT} \times \frac{\sigma^2}{2b}\left[-\left(\frac{S}{K}\right)^{-\frac{2b}{\sigma^2}} \times N\left(-d_1 + \frac{2b}{\sigma}\sqrt{T}\right) - e^{bT} \times N(d_1)\right] \quad (4.27)$$

Where

$$d_1 = \frac{\ln(S/K) + (b + \sigma^2/2) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} \qquad d_2 = d_1 - \sigma\sqrt{\mathrm{T}} \quad (4.28)$$

In literature there are many studies on pricing lookback options, using various techniques. Most commonly used ones are Black-Scholes, CRR model. Conze and Viswanathan (1991) used Black-Scholes methodology on European lookback options and by using probabilistic tools compared their results with American options. Studies with other methodologies are also present. Jeon et al. and Babbs used binomial trees for pricing American lookback options (Babbs, 2000), (Jeon et al., 2017).

4.4.3. PRICING SWING OPTIONS

As defined in previous sections, swing options permits the option holder to purchase a predetermined quantity of a market product at a settled price with having flexibility in the amount purchased and on the strike price. Vayanos et al. (2011) studied both from the perspective of the holder and the writer of the option, on hedging swing options in complete markets, the option's no arbitrage price interval is determined by hedging with forwards. Kovacevic and Pflug (2014) used swing option pricing by stochastic bilevel optimization.

4.4.4. PRICING BARRIER OPTIONS

Barrier options are very similar to regular options, but they are triggered by one or two values. They are also called as knock-in options or knock-out options, if they reach a trigger value. (Up and in) and (down and in) options are knock-in. (Up and out) and (down and out) options are knock-out.

- Up and in options ; the option is exercised when stock price reaches above a barrier value.
- Up and out options ; the option is abolished when stock price reaches above a barrier value.
- Down and in options ; the option is exercised when stock price reaches under a barrier value.
- Down and out options ; the option is abolished when stock price reaches under a barrier value.

Barrier options are priced by Black-Scholes analytical solution model, Monte-Carlo simulations, finite difference method and binomial trees. In this thesis analytical solution model will be studied. Merton (1973), Reiner and Rubinstein (1991) have developed formulas for barrier options.

$$A = \phi \times S \times e^{(b-r)T} \times N(\phi x_1) - \phi \times K \times e^{-rT} \times N\left(\phi x_1 - \phi\sigma\sqrt{T}\right) \tag{4.29}$$

$$B = \phi \times S \times e^{(b-r)T} \times N(\phi x_2) - \phi \times K \times e^{-rT} \times N\left(\phi x_2 - \phi\sigma\sqrt{T}\right) \tag{4.30}$$

$$C = \phi \times S \times e^{(b-r)T} \times (H-S)^{2(\mu+1)} N(\eta y_1) - \phi \times K \times e^{-rT} \times (H-S)^{2(\mu+1)}\left(\eta y_1 - \eta\sigma\sqrt{T}\right) \tag{4.31}$$

$$D = \phi \times S \times e^{(b-r)T} \times (H-S)^{2(\mu+1)} N(\eta y_2) - \phi \times K \times e^{-rT} \times (H-S)^{2(\mu+1)} N\left(\eta y_2 - \eta\sigma\sqrt{T}\right) \tag{4.32}$$

$$E = K \times e^{-rT} \times N\left(\eta x_2 - \eta \sigma \sqrt{T}\right) - (H - S)^{2\mu} \times N\left(\eta y_2 - \eta \sigma \sqrt{T}\right) \qquad (4.33)$$

$$F = K \times \left[(\frac{H}{S})^{\mu+\lambda} N(\eta z) + (\frac{H}{S})^{\mu-\lambda} N\left(\eta z - 2\eta\lambda\sigma\sqrt{T}\right) \right] \qquad (4.34)$$

The formulas presented above are predetermined formulas to find barrier call and put option payoffs. Different combinations are possible for different knock-in and knock-out options.

where

$$x_1 = \frac{\ln\left(\frac{S}{X}\right)}{\sigma\sqrt{T}} + (\mu + 1) \times \sigma\sqrt{T} \qquad x_2 = \frac{\ln\left(\frac{S}{H}\right)}{\sigma\sqrt{T}} + (\mu + 1) \times \sigma\sqrt{T} \qquad (4.35)$$

$$y_1 = \frac{\ln\left(\frac{H^2}{SX}\right)}{\sigma\sqrt{T}} + (\mu + 1) \times \sigma\sqrt{T} \qquad y_2 = \frac{\ln\left(\frac{H}{S}\right)}{\sigma\sqrt{T}} + (\mu + 1) \times \sigma\sqrt{T} \qquad (4.36)$$

$$z = \frac{\ln\left(\frac{H}{S}\right)}{\sigma\sqrt{T}} + \lambda\sigma\sqrt{T} \qquad \mu = \frac{b - \frac{\sigma^2}{2}}{\sigma^2} \qquad \lambda = \sqrt{\mu^2 + \frac{2r}{\sigma^2}} \qquad (4.37)$$

In the numerical example knock-in call option is studied, so in this section only payoffs for this type is denoted. For up and in barrier (knock –in) call options (S < H), the pay-off is calculated by $\max(S - K;\ 0)$; if S $\geq$ H before T and K at expiration:

$$c\,(X > H) = A + E \quad \eta = -1, \quad \phi = 1 \qquad (4.38)$$

$$c\,(X < H) = B + C - D - E \quad \eta = -1, \quad \phi = 1 \qquad (4.39)$$

5. APPLICATION OF DERIVATIVES IN TURKISH ELECTRICTY TRADING MARKET

As stated in the previous chapters, electricity sector has a significant role in Turkish economy. Although Turkey possesses many geographical advantages such as proximity to countries producing oil and natural gas and high renewables capacity, due to increasing consumption demand, to ensure reliable electricity supply electricity market participants work on building procurement and trading strategies. One of the tools to provide reliable electricity is the electricity spot market.

While electricity production holds a structure, which is very variable and ambiguous, external factor are less predictable, such as currency risk, commodity prices, political relations etc. As in the other financial markets, the market uncertainties created need for derivatives. Forwards are most commonly used derivatives in by Turkish electricity sector participants. In the recent years due to high price volatility financial option contracts started to exercise. The purpose of this study is to find out best trading strategy to ensure a better financial performance by using derivatives. For this aim, financial option pricing is proposed as a solution. It is considered that correct option pricing boost trading portfolio performance by hedging risks.

At the initiation step, to provide a better understanding to Turkish electricity sector, using historical data a fundamental price forecasting model will be presented. Major elements of the model are; consumption demand, commodity prices, at command capacity, renewable production and foreign currency rate. Spot price will be estimated by the fundamental model for a determined period.

Forward prices for the relevant period in the over the counter market (OTC) will be shared. Then financial options for electricity products will be presented. Subsequently financial options will be priced by aforecited valuation techniques. Such as in Pineda's (2013) and Vehvialnen's (2002) works a derivative product portfolio will be formed and its financial performance to be calculated and the advantages of using financial options will be discussed.

5.1. A FUNDAMENTAL SPOT PRICE FORECAST MODEL WITH THE DYNAMICS OF TURKISH ELECTRICITY POWER SECTOR

This section complies a fundamental spot price forecast model by using dynamics of the Turkish power sector. In the day-ahead spot market prices are determined by a uniform price auction mechanism. Intersection of demand and supply determine spot prices. Market participants notify their bids and offers to EPIAS system for day ahead mechanism.

Table 5. 1: Monthly MCP Averages

Period	Monthly MCP Average
2017 / 01	181,32
2017 / 02	172,55
2017 / 03	145,29
2017 / 04	145,13
2017 / 05	152,36
2017 / 06	148,54
2017 / 07	175,06
2017 / 08	173,33
2017 / 09	178,51
2017 / 10	164,13
2017 / 11	174,65
2017 / 12	155,82

Starting from the demand side, there are two types of consumers in the electricity system; eligible and non-eligible customers. Non-eligible customers are obliged from buy electricity from national tariff prices. On the other hand, eligible customers who have monthly electricity consumption higher than a specified limit that is determined by EMRA, have right to choose their electricity supplier via bilateral contracts. If they don't use their right, their electricity supply is provided from national tariff. Non-eligible customers' consumption is procured by electricity distribution companies. Electricity distribution companies are also charged for system leaks, agricultural irrigation and electrical enlightenment supply. The needed amount of electricity distribution companies is provided by bilateral contracts from TETAS. This amount doesn't take role in price mechanism.

Eligible customers' electricity supply, if not provided from suppliers' private generation units, is procured from the day ahead spot market. Besides day ahead market, market participants can trade in OTC market. If a bilateral agreement realized by a physical contract, delivery must have notified to EPIAS system. In this case if seller of the contract doesn't provide the agreed amount by its own electricity generation capacity, the amount must be gathered from the day ahead market.

For example, from MCP historical data it is possible to see that in springs due to eminent hydro-electric power plant production prices are lower. In contrast in winter due to high consumption, renewable resources cannot cover the demand and fossil fuel based production scales up the prices. Turkey has no natural gas reserves and procure natural gas from other countries by long term take or pay contracts. They are related with commodity prices and currency rates. As its' shown in Figure 3. 1, caused to high consumption and severe winter conditions, in February 2017 a serious gas crisis took part and caused spikes in MCP.

Regarding historical data spot prices are modeled by production cost models, equilibrium models, statistical models and with quantitative models. Briefly production costs models are based on marginal costs of electricity generators.

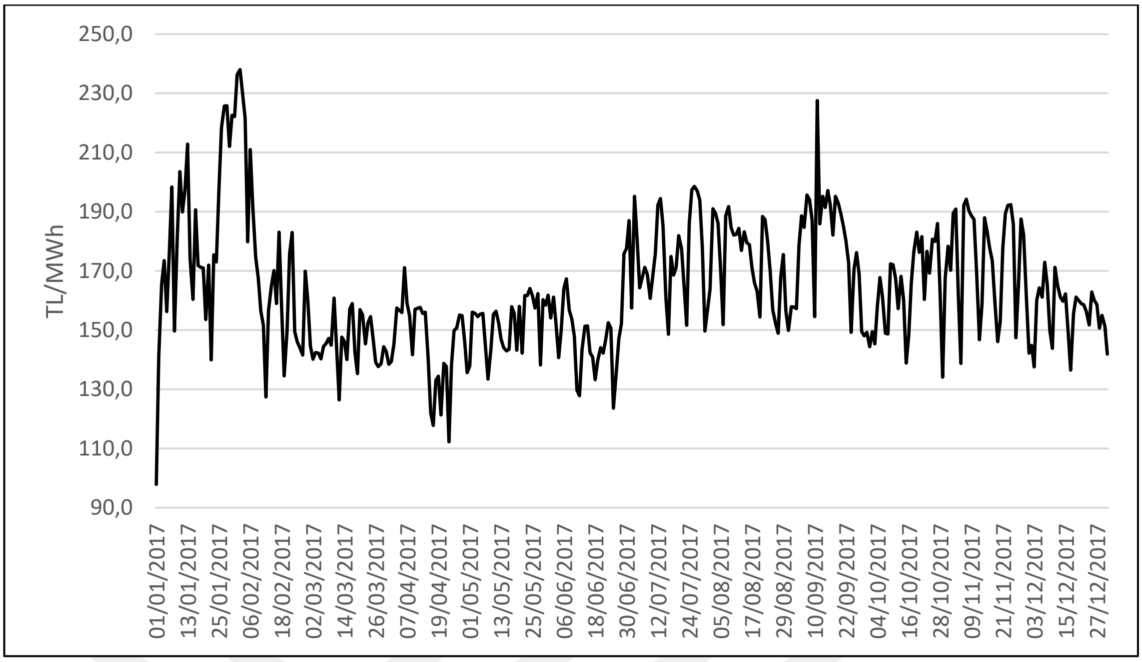

Figure: 5.1: Daily MCP average prices

Equilibrium models can be considered as extensions of production based models, using game theory traders give strategic bids and offers. These models have low accuracy and they are risky. If their price dependent model output doesn't match in the spot market mechanism, there is a high risk to trade from balancing and settlement price which is very high than MCP. Quantitative models use historical data, by statistical properties of historical prices derivatives products. These methodologies take essential that at command supply capacity effectuate prices. Also, production cost based models are vulnerable to strategic bidding. One of the essentials is that in Turkish electricity spot market, before implementing a model, it is compulsory to sort out the demand and supply capacity, which affects the pricing.

Because of the non-storability of electricity, the relation between the current spot market price and forwards is fragile. Traded electricity at any given future is a separate asset. As any other financial products in derivative markets, electricity prices converge to the underlying asset stock price at the maturity. The underlying asset is the spot price, electricity forward trading ends before the delivery period.

In this study assuming the current date is 31.03.2017, for the second half of the year 2017 (H2'17) a fundamental price forecast model is going to be proposed by using evolution of production costs and other parameters such as weather conditions, water inflow, currency futures and commodity futures at supply side. Also seasonality, fluctuations in demand will take part.

First taking account the ever-growing demand for eligible customers in the Turkish grid is to be estimated. Than the at-demand supply capacity is going to be formulated and production costs will be implemented. Due to risk factors and changing parameters an estimated price will be found.

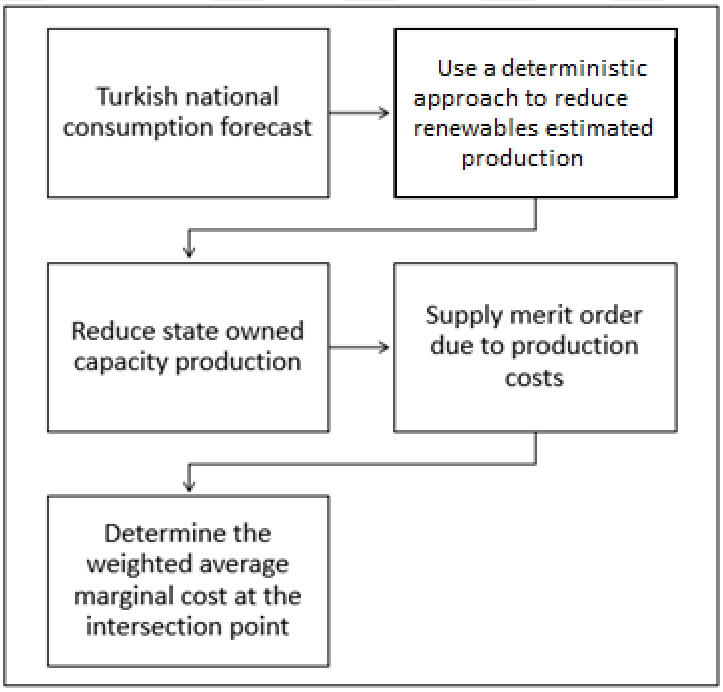

Figure: 5.2: MCP Price Forecast Model

Turkish electricity consumption depends on temperature, population, industrial production, country GDP, technological advance etc. In literature it is easy to find studies modeled by artificial neural network algorithms, autoregressive moving average and regression models etc. In this study for electricity consumption forecast multiple regression method is used. Industrial production index and GDP are strongly correlated with electricity consumption.

However weather temperature has a quite different regime lowest electricity consumption occurs when temperature is between 15-20 °C. Also it reaches yearly maximum at temperatures lower than 5°C and higher than 25 °C.

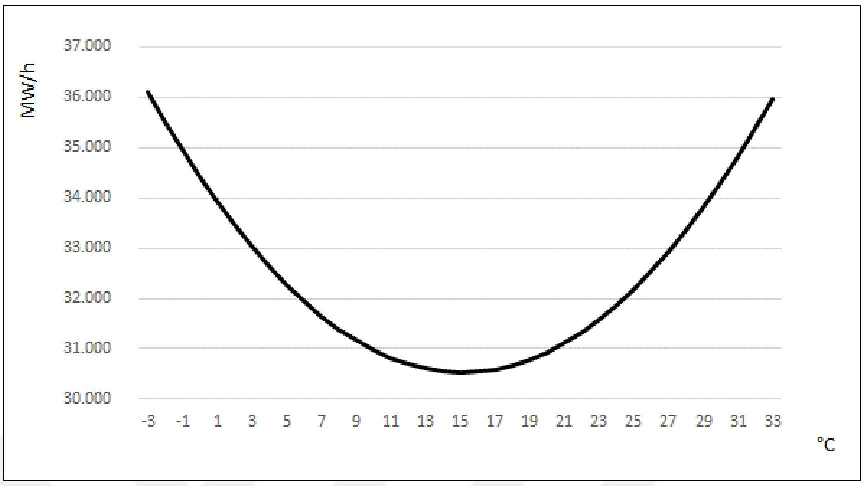

Figure 5.3: Electricity demand and temperature change

Hence using multiple regression formula for the Turkey's electricity consumption forecast:

$$y = a_0 + \sum_{i=1}^{3} a_i \times X_i \tag{5.1}$$

Where
X_1 = monthly average weather temperature index
X_2 = industrial production index
X_3 = work day count

These three factors are selected among a set of eight which have a strong correlation with Turkish national consumption. The correlation of temperature is 0,87, industrial production is 0,55 and workday count index have a correlation of 0,40. These coefficients will be a_i values. This methodology is performed on previously year data and resulted a standard deviation of 523 MWh per hour, which has an accuracy ratio of %98. In literature there are several studies modeled by artificial neural network algorithms, autoregressive moving average and regression models etc. In this study for electricity consumption forecast multiple regression method is used. Temperature index has to highest variation and correlation so, three scenarios will be studied high temperature, low temperature and average temperature.

Table 5.2: Turkish National Power Consumption Indexes

	Temperature index	Industrial Production index	Workday index	Turkish National Consumption MW/h
2016 / 01	1,04	0,94	0,93	31890
2016 / 02	0,96	0,75	0,98	30391
2016 / 03	0,95	0,92	1,07	29786
2016 / 04	0,94	1,16	0,98	29586
2016 / 05	0,95	1,10	0,98	29436
2016 / 06	0,99	1,00	1,07	32016
2016 / 07	1,02	1,09	0,93	32755
2016 / 08	1,02	1,11	1,07	35307
2016 / 09	0,98	0,91	0,93	29491
2016 / 10	0,95	1,00	0,98	29368
2016 / 11	0,95	1,06	0,98	31360
2016 / 12	1,05	1,26	1,02	33818
2017 / 01	1,03	1,43	1,07	33739
2017 / 02	1,02	1,29	0,98	33408
2017 / 03	0,96	1,31	1,12	31701
2017 / 04	0,95	1,41	0,98	30570
2017 / 05	0,95	1,49	1,02	31424
2017 / 06	0,99	1,06	0,98	32091

Table 5.3: Turkish National Power Consumption Indexes (high scenario)

	Temperature index (high scenario)	Industrial Production index	Workday index	Turkish National Consumption MW/h
2017 / 07	1,06	1,3	1,02	**35874**
2017 / 08	1,06	1,15	0,98	**35257**
2017 / 09	0,98	1,09	0,93	**31476**
2017 / 10	0,97	1,03	1,07	**32444**
2017 / 11	0,97	0,99	1,07	**32390**
2017 / 12	1,03	1,06	1,02	**34355**
Average	1,01	1,10	1,02	**33633**

Table 5.4: Turkish National Power Consumption Indexes (low scenario)

	Temperature index (low scenario)	Industrial Production index	Workday index	Turkish National Consumption MW/h
2017 / 07	1,03	1,3	1,02	**33977**
2017 / 08	1,04	1,15	0,98	**33753**
2017 / 09	1	1,09	0,93	**31612**
2017 / 10	0,99	1,03	1,07	**32594**
2017 / 11	0,99	0,99	1,07	**32541**
2017 / 12	1,06	1,06	1,02	**34820**
Average	1,02	1,10	1,02	**33216**

Table 5.5: Turkish National Power Consumption Indexes (average scenario)

	Temperature index (average scenario)	Industrial Production index	Workday index	Turkish National Consumption MW/h
2017 / 07	1,044	1,34	1,024	**35023**
2017 / 08	1,05	1,15	0,98	**35623**
2017 / 09	0,99	1,09	0,93	**31315**
2017 / 10	0,95	1,03	1,07	**32200**
2017 / 11	0,95	0,99	1,07	**32122**
2017 / 12	1,04	1,06	1,02	**35006**
Average	1,00	1,11	1,02	**33548**

As seen in Table 5.3, Table 5.4 and Table 5.5 by April 2017 estimated electricity demand consumption values are in bold. Hourly consumption for H2'17 is found as 33.548 MW/h for average scenario, 33.216 for low scenario and 33.633 for high scenario.

Secondly as focusing on renewables it is a must to state that although renewable energy supply has a high investment cost, their production costs are very low. As they don't use fossil fuel, production cost covers only the maintenance cost and operational expense costs. In literature there are many studies on renewable production forecast using statistical data and stochastic approach. As mentioned in the previous sections renewables consist of wind power plants, hydroelectric power plants, solar energy and biofuel. In this study by evolution of installed power capacity and using statistical capacity utilization ratio a deterministic forecast is performed. Meteorological realizations can create significant deviations, especially for wind and hydro-electric power plants. In this study three scenarios are studied which are low, high and average renewables production.

Table 5.6: Renewables Production Forecast (high scenario)

	Wind		Hydro		Solar		Other		Forecast
	MW	%	MW	%	MW	%	MW	%	MW
2017/7	5882	44%	11463	32%	800	33%	1142	62%	**7228**
2017/8	5910	48%	11568	14%	840	32%	1149	59%	**5403**
2017/9	5910	36%	12464	15%	867	33%	1149	62%	**4996**
2017/10	5960	30%	14423	16%	902	33%	1149	64%	**5129**
2017/11	6000	31%	10467	15%	954	28%	1209	66%	**4495**
2017/12	6050	47%	11896	20%	999	21%	1209	69%	**6267**
Average	5952	39%	12047	19%	894	30%	1168	64%	**5601**

Table 5.7: Renewables Production Forecast (low scenario)

	Wind		Hydro		Solar		Other		Forecast
	MW	%	MW	%	MW	%	MW	%	MW
2017/7	5882	38%	11463	26%	800	33%	1142	62%	**6188**
2017/8	5910	45%	11568	13%	840	32%	1149	59%	**5110**
2017/9	5910	33%	12464	10%	867	33%	1149	62%	**4195**
2017/10	5960	25%	14423	11%	902	33%	1149	64%	**4110**
2017/11	6000	24%	10467	12%	954	28%	1209	66%	**3761**
2017/12	6050	43%	11896	15%	999	21%	1209	69%	**5430**
Average	5952	35%	12047	15%	894	30%	1168	64%	**4822**

Table 5.8: Renewables Production Forecast (average scenario)

	Wind		Hydro		Solar		Other		Forecast
	MW	%	MW	%	MW	%	MW	%	MW
2017/7	5882	41%	11463	30%	800	33%	1142	62%	**6780**
2017/8	5910	46%	11568	13%	840	32%	1149	59%	**5200**
2017/9	5910	35%	12464	13%	867	33%	1149	62%	**4651**
2017/10	5960	28%	14423	15%	902	33%	1149	64%	**4847**
2017/11	6000	29%	10467	13%	954	28%	1209	66%	**4169**
2017/12	6050	45%	11896	19%	999	21%	1209	69%	**6023**
Average	5952	37%	12047	17%	894	30%	1168	64%	**5278**

State owned production is traded by TETAS, which has a separate tariff that changes on a quarterly basis. TETAS collects weekly consumption forecasts from in charge distribution companies and manages the production portfolio of EUAS, BO, BOT and TOOR plants and local coal incentive portfolio. Although it is a liberal market state controls a remarkable portion of the installed capacity. As a very big actor in the market, state always has ability to influence prices.

In the example of winter 2017, Turkey had very severe winter conditions and imported natural gas was mostly reserved for domestic heating. Then the national gas distributor BOTAS limited the electricity production of gas-fired power plants. To provide missing electricity, state decided to use its hydroelectric dam power plant portfolio, consequently an important portion of the water reserve was used and spikes in MCP prices were observed.

Table 5.9: State Owned Electricity Production

	State Controlled Power Production	**Loca Coal (Incentive) Production**	**State Portfolio**
2017/7	13.443	2330	15.773
2017/8	13.321	2330	15.651
2017/9	11.358	2330	13.688
2017/10	10.069	2330	12.399
2017/11	10.014	2330	12.344
2017/12	10.815	2330	13.145
Average	**12.007**	**2330**	**14.337**

As shown in Table 5.9 Turkey’s state controlled production can be calculated as follows. After reduced renewables and state controlled production from the national consumption, the remaining demand is procured from the day-ahead market which will be covered by spark spread and dark-spread power plants. For the case presented, 9 scenarios have been demonstrated in Table 5.10.

Table 5.10: Day Ahead Market Trading Volume

Temperature / Renewables	**Low**	**Average**	**High**
Low	14057	13601	13278
Average	14389	13933	13610
High	14474	14017	13694

Using commodity future prices average marginal production cost based, price estimation will be calculated. In Table 5.11 coal and natural gas production costs are denoted. Coal prices are correlated with commodity prices and currency. On the other hand, 90% of the natural gas is procured from BOTAS and BOTAS applies subvention on prices. BOTAS cost is %20 above from its sale price and according to commodity futures it supposed to rise in December 2017. Market participants expect a raise in BOTAS sale price.

Table 5.11: Spark Spread and Dark Spread Production Costs

TL/MWh	Coal	Natural Gas
2017/7	147	169
2017/8	154	169
2017/9	155	169
2017/10	166	169
2017/11	172	169
2017/12	174	181

Another important issue is to take in account that due to volatility of the consumption, the prices led the producers to work in the hours that the sale price is higher than the production marginal costs. However in natural gas fired power plants 2750 MW of electricity is produced as a side-product while producing process steam. These power plants are co-generation type and they are mostly located in organized industrial zones or in big factories. They are obliged to work to generate process steam and give offers independent from the MCP prices. So 2750 should be subtracted from the values in Table 5.10.

As seen in Table 5.11 dark spread (coal-fired) production cost is always lower than the spark spread (natural gas –fired) production. These power plants work most efficiently with full load and so they can minimize the unit-breakdowns. Also to prolong turbine life they work in consecutive hours. To determine MCP for a natural gas fired from the dark spread production which is about 7500 MW from the remaining. Finally in Table 5.12 demand procured from price dependent natural gas power plants are denoted.

Table 5.12: Demand Procured from Price Dependent Spark Spread

Consumption /Renewables	Low	Average	High
Low	3807	3351	3028
Average	4139	3683	3360
High	4224	3767	3444

Daily average spark spread dominant hour count is calculated as follows values in Table 5.12 are multiplied by 24 to determine daily total production and divided to remaining installed capacity which is about 6200 MW. Results are demonstrated in Table 5.13.

Table 5.13: Daily Average Spark Spread Dominant Hours for H2’ 17

Consumption /Renewables	Low	Average	High
Low	15	13	12
Average	17	15	14
High	18	15	14

Hourly analysis is performed and seen that only 15 hours natural gas fired power plants work at maximum capacity so the weighted average price is calculated as 167 TL/MWh for the scenario with average temperature and average renewables production. For all scenarios H2’17 MCP forecasts are places in Table 5.14.

Table 5.14: MCP Forecast for H2’17 by Scenarios

Consumption /Renewables	Low	Average	High
Low	167	167	166
Average	168	167	167
High	169	167	167

5.2.APPLICATION WITH DERIVATIVES

As stated in previous chapters, electricity power market participants use derivative products to hedge their portfolio and prevent risks. Day ahead market is open to risks, spot prices can dramatically change even in case of fluctuation in power generation or load. There exist four main characteristics of electricity, which are seasonality, volatility, mean reversion, spikes (Brierbauer et al., 2003). Also electricity market is up to many internal and external risks. Such as breakdowns, maintenances, fossil fuel supply reliability, commodity prices, weather conditions, water inflow, currency risk, credit risk and political etc. The purpose of this study to boost financial performance and to provide a quick solution to deal with the uncertainties and the risks that participants' face. For this aim, using derivatives is proposed as a solution. It is considered that by constructing a rigid trading portfolio by derivatives it is possible to minimize risk.

In the previous section using historical data and deterministic parameters a price estimation model is proposed. In this section, using derivatives, a better performing strategy will be presented. Derivative products that will take part in this section are forwards and financial options.

Table 5.15: Electricity derivative instruments that are used

Instrument	**Available model**
Day ahead spot market	N/A
Electricity forward	Fundamental Model
European option	Black-Scholes
American option	Binomial Tree, Monte-Carlo
Geometric Asian option	Black-Scholes
Lookback option	Black-Scholes, Monte-Carlo
Barrier option	Black-Scholes, Monte-Carlo

The relevant data is from the Turkish electricity market, all prices are in Turkish Lira per Megawatt Hour (TL/MWh) and for the yearly risk free interest rate, it is assumed that it will be constant and equal to r = 15%. The historical volatility is calculated by lognormalized returns assuming that relevant product is in line with geometric Brownian motion. $\sigma = 7{,}09\ \%$

As of 30.03.2017, forward contracts for H2'17 period is traded to 157,5 TL/MWh. Table 5.7 summarize the details of the electricity forward contract.

Table 5.16: Details of the forward contract for H2'17

Contract	Maturity forward	Delivery period	Market clearing price
Second half of year 2017	30/06/2017	01/07/2017 – 31/12/2017	157,5

5.2.1. PRICING EUROPEAN OPTIONS

In the OTC markets historical data at 30/12/2017 at the same date there is a European call option contract traded. The strike price is at 159 and the option premium 2 TL/MWh. In this section, using Black-Scholes methodology we will consider investing on this contract.

$$c = S \times N(d_1) - K \times e^{-rT} \times N(d_2) \tag{5.2}$$

$$d_1 = \frac{\ln(S/K) + (r + \sigma^2/2) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} \tag{5.3}$$

$$d_2 = \frac{\ln(S/K) + (r - \sigma^2/2) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} = d_1 - \sigma\sqrt{T} \tag{5.4}$$

First d_1 is found,

$$d_1 = \frac{\ln\left(157{,}5/159\right) + (0{,}15 + 0{,}0709^2/2) \times (\frac{3}{12})}{0{,}0709\sqrt{\frac{3}{12}}} = 0{,}8135 \tag{5.5}$$

Then d_2,

$$d_2 = 0{,}8135 - \ 0{,}0709\sqrt{\frac{3}{12}} = 0{,}779 \tag{5.6}$$

Finally the value of the call option is found:

$$c = 157{,}5 \times N(0{,}8135) - 159 \times e^{-0{,}25*0{,}15} \times N(0{,}779) = 5{,}07 \tag{5.7}$$

As it seen it was traded with a low option premium, however with Black-Scholes model a higher option price is found. This contract is a profiting one, so a possible investment can be considered.

5.2.2. PRICING AMERICAN OPTIONS USING BINOMIAL TREE

In this section same properties are valid for pricing American call options. With the Cox, Ross, Rubinstein (1973) model is run for 6 stages and the option value is as found 3,447.

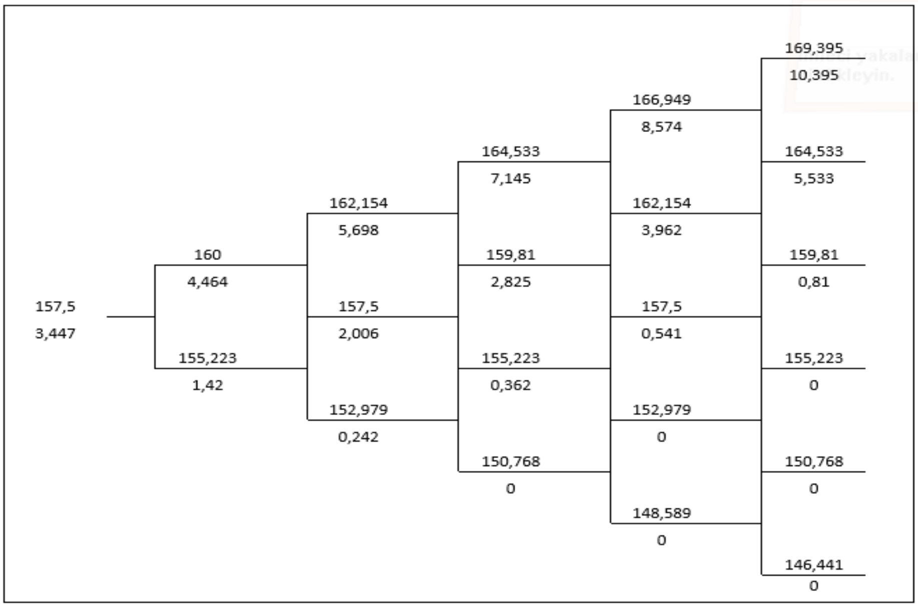

Figure 5.4: American Call Option Binomial Tree Valuation

5.2.3. PRICING GEOMETRIC ASIAN OPTION USING BLACK-SCHOLES

It is a discrete geometric options using yearly data of one year period time having 12 observations. Wiklund (2012) formulas are used to determine prices. If there would be more than 250 observations, it would converge to continuous geometric options.

$$c = V \times N(d_1) - K \times e^{-rT} \times N(d_2) = 2{,}32 \tag{5.8}$$

$$V = e^{-rT} \times S \times e^{\left(\frac{((N+1)\times\mu)}{2} + \frac{a \times T \times \sigma^2}{2N^3}\right)} \tag{5.9}$$

$$\mu = r - q + \frac{1}{2}\sigma^2 = 0{,}153 \tag{5.10}$$

$$a = \frac{N \times (N+1) \times (2N+1)}{6} = 55 \tag{5.11}$$

$$\sigma_{avg} = \sigma \sqrt{\frac{2N+1}{6(N+1)}} = 0{,}039 \tag{5.12}$$

$$d_1 = \frac{1}{\sigma_{avg}\sqrt{\mathrm{T}}} \left(\left(\ln\left(\frac{V}{K}\right) + (r - \delta + \frac{1}{2}\sigma_{avg}^2 \right) \times T \right) = 0{,}48 \tag{5.13}$$

$$d_2 = d_{1-} \sigma_{avg}\sqrt{\mathrm{T}} = 0{,}45 \tag{5.14}$$

5.2.4. PRICING LOOKBACK OPTIONS

In OTC market there are products for lookback options. It is studied to price lookback options and a better result is found.

$$d_1 = \frac{\ln(S/K) + (b + \sigma^2/2) \times \mathrm{T}}{\sigma\sqrt{\mathrm{T}}} = 0{,}8135 \tag{5.15}$$

$$\begin{aligned} c = 157{,}5 \times N(0{,}8135) - 159 \times e^{-0{,}15*0{,}25} \times N(0{,}779) + 157{,}5 \\ \times e^{-0{,}15*0{,}25} \\ \times \frac{0{,}0709^2}{0{,}3} \left[- \left(\frac{157{,}5}{159}\right)^{-\frac{2r}{\sigma^2}} \times N\left(0{,}8135 - \frac{0{,}3}{0{,}0709}\sqrt{0{,}25}\right) \right. \\ \left. + e^{0{,}15*0{,}25} \times N(0{,}8135) \right] = 2{,}1 \end{aligned} \tag{5.16}$$

5.2.5. PRICING BARRIER OPTIONS

Same example is studied for barrier call options. For up and in barrier (knock –in) call options at t = 0 ($S < H$ | 157,5 < 170), the pay-off is calculated by $\max(157{,}5 - 159\,;\ 0)$;
if ($S > H$ | $157{,}5 \geq 170$) before expiration or S = K at expiration, (H =170):

$$c\ (\mathrm{K} < \mathrm{H} \mid 159 < 170) = \mathrm{B} + \mathrm{C} - \mathrm{D} - \mathrm{E} = 2{,}35 \qquad \eta = -1\,, \quad \phi = 1 \tag{5.17}$$

$$B = S \times e^{-rT} \times N(x_2) - 1 \times K \times e^{-rT} \times N(x_2 - \sigma\sqrt{\mathrm{T}}) = 4{,}89 \tag{5.18}$$

$$C = S \times (H-S)^{2(\mu+1)}\, N\,(-y_1) - 1 \times K \times e^{-rT} \times (H-S)^{2(\mu+1)}\left(-y_1 + \sigma\sqrt{T}\right) \quad (5.19)$$
$$= 2{,}12$$

$$D = S \times (H-S)^{2(\mu+1)}\, N\,(-y_2) - 1 \times K \times e^{-rT} \times (H-S)^{2(\mu+1)} N\left(-y_2 + \sigma\sqrt{T}\right) \quad (5.20)$$
=2,01

$$E = K \times e^{-rT} \times N\left(x_2 + \sigma\sqrt{T}\right) - (H-S)^{2\mu} \times N\left(-y_2 + \sigma\sqrt{T}\right) = 1{,}3 \quad (5.21)$$

Where

$$x_1 = \frac{\ln\left(\frac{S}{X}\right)}{\sigma\sqrt{T}} + (\mu+1) \times \sigma\sqrt{T} = 0{,}73 \qquad x_2 = \frac{\ln\left(\frac{S}{H}\right)}{\sigma\sqrt{T}} + (\mu+1) \times \sigma\sqrt{T} \quad (5.22)$$
$$= 0{,}59$$

$$y_1 = \frac{\ln\left(\frac{H^2}{SX}\right)}{\sigma\sqrt{T}} + (\mu+1) \times \sigma\sqrt{T} = 1{,}03 \qquad y_2 = \frac{\ln\left(\frac{H}{S}\right)}{\sigma\sqrt{T}} + (\mu+1) \times \sigma\sqrt{T} \quad (5.23)$$
$$= 0{,}9$$

$$z = \frac{\ln\left(\frac{H}{S}\right)}{\sigma\sqrt{T}} + \lambda\,\sigma\sqrt{T} = 2{,}4 \qquad \mu = \frac{r - \frac{\sigma^2}{2}}{\sigma^2} = 0{,}5 \qquad \lambda = \sqrt{\mu^2 + \frac{2r}{\sigma^2}} = 7{,}7 \quad (5.24)$$

5.3. NUMERICAL RESULTS

Table 5.17: Numerical results

Instrument	Strike Price	Calculated Option Value
Day ahead spot market	170	N/A
Fundamental forecast model	(166 – 169)	N/A
Electricity forward	157,5	N/A
European call option	159	5,07
American call option	159	3,44
Geometric Asian call option	159	2,65
Lookback call option	159	2,10
Barrier option (up and in)	159	2,35

Until the expiration date, regarding the water deficit of the hydro-electric power plants, increasing coal and natural gas prices rose forward prices, and reached it maximum at 30.06.2017 with 166 TL/MWh. As seen in Table 5.17 at the exercise date 30. 03. 2017 fundamental forecast model resulted quite close to realized prices with a deviation of maximum 4 TL/MWh. The success ratio of the forecast model is above %98. One of the reasons behind this results is that the coal prices and natural gas tariff realized as expected. In addition to this, for all 9 scenarios presented in Section 5.1, it is found that the forecast range is between 166 TL/MWh and 169 TL/MWh and with this result buying a forward contract to 157, 5 TL/MWh is always the most logical among all possible derivatives. Besides in OTC market at the time derivative products have been traded to lower prices. If the purchasing contract was settled for 1 MW/h, it would bring a profit of $(170 - 157{,}5) \text{ x } 4380 \;=\; 54.750$ TL.

If the trading company had bought an option contract to strike price 159, best performing option would be the lookback option with the option premium 2,1 TL/MWh. The payoff of the lookback call option would be $(170 - 159 - 2{,}1) \text{ x } 4380 \;=\; 38.982$ TL. As seen in the Table 5.8, best performing options were all exotic options, which are very common in electricity market due to non-storability of the electricity and assuring more flexibility than the plain-vanilla options. Second best option choice would be the barrier option in the case presented barrier is set up for 170 TL/MWh, if the barrier value was set for a lower value for the up and in barrier option, option premium would resulted higher. Also geometric Asian options would came up with a better result than plain-vanilla options. For plain-vanilla options American option which calculated 6 staged Binomial tree, resulted a lower option premium than the European option. Which is inconvenient with the expectations of the model and it must be tested with a more gradual Binomial tree algorithm.

6. DISCUSSION

This study mainly focusses on pricing derivatives to minimize risks and effective financial management. The contribution in this study consists of designing a sophisticated forecast model in order to assure a better financial performance and then to boost efficiency derivative products such as forwards and options are priced. In literature there is no such a hybrid-study. Additionally, in literature there is limited range of studies on Turkish electricity power sector, especially option valuation examples are very rare.

As stated in previous chapters that there is a high volatility in electricity market and options facilitates flexible portfolio management as effective risk hedging instruments. Key risk factors having effect on realizations and also on derivative prices are; the sudden strategic decisions in an oligopolistic market structure, the interest rate risk, and the changes in commodity prices, the difference between meteorological realizations and expectations, and the elements of strategic bidding.

The studies in the literature are generally on decision making, for a better financial gain derivative prices between existing option contracts' premium prices and the results of several methodologies such as Black-Scholes, CRR and Monte-Carlo simulation and stochastic optimization.

In the case presented, it is found that for the relevant period, a buyer's most profitable choice is a forward derivative contract. On the other hand, from the perspective of the seller a forward would have caused great financial loss. To prevent such big losses and risks, seller would have preferred put option contract, in order to minimize loss to affordable amounts. Results were found as expected. Only for the plain-vanilla American call option value with six stage binomial tree was quite lower than expected. To justify our result same example is performed by a VBA code for a hundred stages and found an option premium higher than the European option. Results also emphasized that exotic options suit better to power markets in order boost efficiency of the trading portfolio.

Better financial results could be obtained assessing MCP prices on a daily or hourly basis. Naturally, volatility will be minimal as well as internal and external risks and realizations can be better predicted. Also in addition running a sensitivity analysis would ease decision making for future operations and studies.

7. CONCLUSION

In conclusion, it can be stated that today electricity power trading markets are in severe competition and one cannot survive on the market unless responding to changing dynamics quickly. As the business conditions are volatile, the trading firms are less predictable in their forecasts. These companies and other market participants work for creating solid financial gain in their operations. In order to survive in the market, they started to use derivative contracts just after the market liberalization. Electricity power trading sector is always good example for a financial market in perspective of risk hedging with derivatives. It is the one of the fastest growing sectors in Turkey and the energy sector has a very important part in Turkish economy creating %50 Turkey's imports. For the reasons stated above, derivative contracts application for a specified period is investigated.

For the methodology of the study, a hybrid model is created. A fundamental forecast model is developed and its' performance aimed to boost using plain-vanilla and exotic options. To price options Black-Scholes and CRR methodologies are used. The application is presented for the average spot market price of second half of the year 2017 and its purpose is to denote best performing trading strategy with derivatives and hedging risks occur due to sector dynamics. First of all, the fundamental production cost based forecast model is implemented. Using multiple regression analysis and correlation coefficients Turkish national consumption demand for the relevant period is estimated. The demand consumption is very important in the electricity sector because it directly affects pricing.

Secondly using historical data for the seasonal capacity utilization of renewable sources and the installed capacity, renewable production is forecasted. Renewable production

%85 varies due to meteorological realizations. Subsequently state owned production is estimated by using stochastic approach regarding water reserves and domestic electricity consumption. From Turkey's total consumption renewables production and state controlled production are reduced. Remaining amount will be covered by day ahead merit order mechanism. Producers give offers to system operator regarding their marginal production cost. Highest production cost belongs to natural gas fired power plants which means they are at top of the list. According to merit order lowest price matches first, from this point of view it is found that natural gas power plants can determine prices average 15 hours daily, and a weighted average production cost of merit order is found. There were lower forward contracts' prices in the OTC market.

Forward contracts are the most commonly used derivatives in Turkish electricity market. Market participants' work on accurate price forecast making to have financial gain in their operations. However forward contracts based fundamental forecast models are open to strategic bidding risk. To increase efficiency, we focused on financial options. In financial markets option contracts are useful instruments to hedge risks, especially to cope exogenous risks.

Then in the second stage, predetermined plain- vanilla options and exotic options are presented. European and American call options are presented for plain-vanilla and geometric Asian, lookback, barrier call options for exotic options are designated in detail. According to the literature survey, these options are widely used in Scandinavian and European markets however there no studies in Turkish electricity sector. Then convenient option valuation for these type of options is determined and these options are priced. American option is priced by using binomial tree and the others priced by using Black-Scholes equation.

Outcomes of the application denoted that proposed fundamental model resulted successfully. In the example presented for a buyer most profitable choice would be a forward contract. Controversially, for a seller a forward would have concluded severe financial loss. To prevent such risks, seller would have preferred put option contract, in order to minimize loss to affordable amounts.

If an option contract was purchased, best performing options would be exotic options. Among them best financial performance would had by a lookback option. Plain-vanilla options are less effective because of the non-storability of electricity and the relevant product is formed by average MCP prices of a predetermined period.

In this work, there are certain aspects which should be developed by further studies. Turkey has interconnection electricity lines with its neighbors Greece, Bulgaria and Georgia, which will expand the trading environment and possibility for arbitrage will occur.

In future work, the derivative pricing will be used for a trading portfolio formed by multiple products. To facilitate decision making under uncertain environment, “Option Greeks” sensitivity analysis called can be performed. Also it is possible to work with fuzzy Binomial tree and fuzzy Black-Scholes and game theory to prevail risks created by strategic bidders.

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APPENDIX – VBA Code For Pricing American Call Options with Binomial Tree Model

```
Dim r, u, d, s, K, price, T As Double
Dim prob_up, T_help, delta, min_up, price_help, disc As Double
Dim help_matrix(0 To 100, 0 To 100) As Double
Dim i, j, n, flag, positive As Integer
Dim continue, exercise As Double

Sub price_put()
Worksheets("Binomial_American").Activate
u = Range("Binomial_American!b4").Value
d = Range("Binomial_American!b5").Value
r = Range("Binomial_American!b6").Value
n = Range("Binomial_American!b7").Value
flag = Range("Binomial_American!b9").Value
K = Range("Binomial_American!b10").Value
s = Range("Binomial_American!b11").Value
T = Range("Binomial_American!b12").Value
delta = T / n
prob_up = 1 / 2
disc = 1

If flag = 1 Then
   price_help = s * Exp(n * Log(u))
   Else
   price_help = s * Exp(n * Log(d))
End If
For i = 0 To n + 1
```

```
 For j = 0 To n + 1
   help_matrix(i, j) = 0
 Next j
Next i

If flag = 1 And price_help > K Then
   positive = 1
End If
If flag = 2 And price_help < K Then
   positive = 1
End
   If flag = 1 And positive = 1 Then
  i = n + 1
  While price_help > K And i > 0
    help_matrix(i, n) = price_help - K
    price_help = price_help * d / u
    i = i - 1
  Wend
End If
'Starting the backward computation in case of a call

If flag = 2 And positive = 1 Then
  i = 1
  While price_help < K And i < n + 2
    help_matrix(i, n) = K - price_help
    price_help = price_help * u / d
    i = i + 1
  Wend
End If
'Starting the backward computation in case of a put

If flag = 1 Then
```

```
For j = 1 To n
  price_help = s * Exp((n - j) * Log(d))
  For i = 1 To (n + 1 - j)
    continue = (prob_up * help_matrix(i + 1, n - j + 1) + (1 - prob_up) * help_matrix(i, n - j +
1)) / (1 + r * delta)
    exercise = price_help - K
    If continue > exercise Then
    help_matrix(i, n - j) = continue
    Else
    help_matrix(i, n - j) = exercise
    End If
    price_help = price_help * u / d
  Next i
Next j
End If
'backward computation in case of call

If flag = 2 Then
For j = 1 To n
  price_help = s * Exp((n - j) * Log(d))
  For i = 1 To (n + 1 - j)

continue = (prob_up * help_matrix(i + 1, n - j + 1) + (1 - prob_up) * help_matrix(i, n - j + 1)) /
(1 + r * delta)
    exercise = K - price_help
    If continue > exercise Then
    help_matrix(i, n - j) = continue
    Else
    help_matrix(i, n - j) = exercise
    End If
    price_help = price_help * u / d
  Next i
Next j
```

```
End If
'backward computation in case of put

price = help_matrix(1, 0)

 Worksheets("Binomial_American").Activate
    Cells(14, 2).Value = price

End Sub
```

BIOGRAPHICAL SKETCH

The author of this thesis was born in 1988 in Istanbul, Turkey.

He has studied in Saint-Joseph French High School between 2002 and 2007, and started his undergraduate education in the Industrial Engineering Department of the Engineering and Technology Faculty of Galatasaray University in 2007-2008 term. Consequent the graduation from undergraduate degree in 2011 defending his thesis on "Application of Axiomatic Design Techniques for Sustainable Supply Chain Management, he has enrolled to the Industrial Engineering Master's Degree in the same university's Institute of Sciences.

The conference proceeding paper written under the supervision of Abdullah Çağrı Tolga, with the name of "Effective Trading in Turkish Electricity Market: Hedging with Options" was accepted by The World Congress on Engineering that will take place in London, U.K., 4-6 July, 2018.

He has a business work experience of 6 years. Since 2017, he has been working in energy sector as an energy trader.