ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

IMPACT OF RENEWABLE ENERGY ON THE POWER MARKET

M.Sc. THESIS

Burak GÖKÇE

Energy Science and Technology Division

Energy Science and Technology Programme

JUNE 2018

ISTANBUL TECHNICAL UNIVERSITY ★ ENERGY INSTITUTE

IMPACT OF RENEWABLE ENERGY ON THE POWER MARKET

M.Sc. THESIS

Burak GÖKÇE
(301121038)

Energy Science and Technology Division

Energy Science and Technology Programme

Thesis Advisor: Prof. Dr. M. Özgür KAYALICA

JUNE 2018

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ ENERJİ ENSTİTÜSÜ

YENİLENEBİLİR ENERJİNİN ELEKTRİK PİYASASI ÜZERİNDEKİ ETKİSİ

YÜKSEK LİSANS TEZİ

Burak GÖKÇE
(301121038)

Enerji Bilim ve Teknoloji Anabilim Dalı

Enerji Bilim ve Teknoloji Programı

Tez Danışmanı: Prof. Dr. M. Özgür KAYALICA

HAZİRAN 2018

Burak GÖKÇE, a M.Sc. student of ITU Institute of Energy student ID 301121038, successfully defended the thesis/dissertation entitled "IMPACT OF RENEWABLE ENERGY ON THE POWER MARKET", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. M. Özgür KAYALICA** İstanbul Technical University	....
Jury Members :	**Prof. Dr. Gülgün KAYAKUTLU** İstanbul Technical University	....
	Doç. Dr. Ahmet Deniz YÜCEKAYA Kadir Has University	....

Date of Submission : 4 May 2018
Date of Defense : 8 June 2018

I want to thank Prof. Dr. Gülgün Kayakutlu and my thesis supervisor Prof. Dr. M. Özgür Kayalıca for always being available to provide help on the thesis. Secondly, I want to thank ENGIE Turkey Head of Retail Paul Eduard Marie Van de Heijning, for giving me support to complete my thesis while working for the company. I would like to thank to my mentor Ergin Selim Gönen for always encouraging me to discover my potential. Last but not least, I would like to thank you Emrah Onat for his continuous motivation to complete this thesis.

FOREWORD

Following global renewables expansion, Turkish market has also experienced a significant increase in renewables capacity in the last decade with government renewable support mechanisms. Although renewables have many positive effects, the feed-in tariffs (FIT) have put a burden on retail electricity companies. Unpredictable and increasing FITs have become difficult to be managed by retail companies and caused serious losses. Indirectly, the end-consumers have been affected from the FITs. Consequently, to analyze the effects of renewables and quantify the burden on retail companies have become a necessity.

Thise thesis analyzes the renewable's effect on retail costs for the period in which FIT portfolio enlarged significantly. The thesis aims to guide policy makers to take into consideration the results of the study while designing new support policies for renewables. Moreover, the study aims to help market professionals to better understand the dynamics of renewables and use the study as a reference.

I would like to thank the market operator EXIST for the Transparency Platform they introduced in 2016. It has provided most of the data required for the empirical analysis used in the thesis. Futhermore, TEİAŞ and EMRA has published valuable data and information which was also useful for the thesis. Finally, I want to thank ENGIE Turkey company for its data contribution to this study.

May 2018

Burak GÖKÇE
(Electrical&Electronics Engineer)

TABLE OF CONTENTS

Page

ABBREVIATIONS

ADF	: Augmented Dickey-Fuller
AI	: Artificial Intelligence
AIC	: Akaike Information Criteria
ANN	: Artificial Neural Network
ARC	: Authorized Retail Company
ARDL	: Autoregressive Distributed Lag
ARMA	: Autoregressive Moving Average
ARMAX	: Autoregressive Moving Average Exogenous
BN	: Beveridge-Nelson
BO	: Build-Operate
BOT	: Build-Operate-Transfer
CCR	: Canonical Cointegration Regression
CES	: Conditional Expectation Sampling
DAM	: Day Ahead Market
EEX	: European Energy Exchange
EMRA	: Energy Market Regulatory Authority
EU	: European Union
EÜAŞ	: Türkiye Elektrik Üretim A.Ş
ERCOT	: Electric Reliability Council of Texas
FIT	: Feed-in Tariff
FX	: Foreign Exchange
FMOLS	: Fully Modified Ordinary Least Squares
GARCH	: Generalized Autoregressive Conditional Heteroskedasticity
GDP	: Gross Domestic Product
LDC	: Local Distribution Company
MCP	: Market Clearing Price
MILP	: Mixed-Integer Linear Programming
MLR	: Multiple Linear Regression
MOE	: Merit Order Effect
OLS	: Ordinary Least Squares
OTC	: Over-The-Counter
PMUM	: Piyasa Mali Uzlaşırma Merkezi Phillips-Perron
PP	: Phillips-Perron
PPA	: Power Purchasing Aggreement
PV	: Photovoltaics
RES	: Renewable Energy Sources
RLWR	: Robust Locally Weighted Regression
RTM	: Real Time Market
SCVAR	: Structural Cointegrating Vector Autoregression
SIRF	: Structural Impulse Response Functions
SMP	: System Marginal Price
SVAR	: Structural Vector Autoregression

TCMB	: Türkiye Cumhuriyet Merkez Bankası
TEİAŞ	: Türkiye Elektrik İletim Anonim Şirketi
TEDAŞ	: Türkiye Elektrik Dağıtım Anonim Şirketi
TETAŞ	: Türkiye Elektrik Ticaret ve Taahhüt Anonim Şirketi
TL	: Turkish Lira
TSO	: Transmission System Operator
USD	: United States Dollar
VIF	: Variation Inflation Factor
YEKA	: Yenilenebilir Enerji Kaynak Alanları
YEKDEM	: Yenilenebilir Enerji Kaynakları Destekleme Mekanizması

LIST OF TABLES

Page

LIST OF FIGURES

Page

IMPACT OF RENEWABLE ENERGY ON THE POWER MARKET

SUMMARY

Renewable energy sources have become mainstream sources of energy as the concerns for Global Warming grow. Motivated by ambitious international objectives and strong support policies, the installed capacities of renewable energy technologies has shown a large growth in recent years. This growth has raised important questions relating to their impacts on power markets and systems.

As part of State energy policies in Turkey, support for the renewable energy as a prime source has been increased. This has led a significant capacity increase in the last years, especially with wind and solar PV investments. Consequently, as in other countries, analyzing the economical impact of renewables and support schemes has become crucial.

The thesis aims to show the renewables effect on wholesale electricity prices and retail costs in Turkey. The prevalent and the oldest renewable support mechanism in Turkey is feed-in-tariff (FIT) mechanism. Renewable power plants are subsidized by FIT to cover their investments costs, which are higher than conventional power plants. The incentive cost is taken from electricity retailers in Turkish market.

Turkish day-ahead market (DAM) price formation method is merit-order curve which enables low marginal cost plants to produce electricity first instead of high marginal cost plants. Renewable plants with their almost zero marginal costs, enter merit-order curve from the lowest part. Thus, renewable generation replaces the conventional power plants with high marginal costs and decreases wholesale prices, which is called merit-order effect in literature.

In this thesis, Turkish electricity market hourly data which belongs to 2014-2017 period is analyzed using a multiple linear regression model. The ex-post analysis explains renewables under FIT mechanism and other main variables effect on historical spot prices. FIT portfolio in Turkey consists of wind, solar, hydropower, geothermal, and biofuel renewable sources. By using regression coefficients of renewables and demand, the model calculates merit-order effect of renewables which belong to FIT portfolio. Then, the merit-order effect is compared with historical FIT costs to find net cost effect of renewables. For the examined term, analysis shows that merit-order effect is less than FIT cost. That means, renewables step-down effect on wholesale prices are less than FIT cost so increases the total retail cost in the period. The calculations show that renewables increased total retail costs by 5.3 billion TL between 2014 and 2017.

The thesis calculates main cost components of retailing the power: commodity, FIT, profile and imbalance costs. To show the increasing FIT cost impact on retailers, retail costs in the investigated period are compared with national retail electricity tariff prices which determines an upper limit for retailer prices. It is found that, in 2017 the national

retail tariff prices are not high enough, which caused in diminishing retail sales gross margin.

Regulation of FIT and other renewable support mechanisms are also explained in the thesis. The regulation of FIT cost calculation method is applied with 2017 realized FIT cost input data such as generation of renewables, FX rates, spot prices. Recalculated monthly FIT costs are found similar to realize the FIT costs. The 2017 FIT calculation model is also used to show USD/TRY exchange rate and renewable generation technologies mix effect on the FIT costs.

FIT cost dependency on FX rates makes them unpredictable and volatile. Therefore, some electricity retailers, who work with limited sales margin, make loss because of volatile FIT costs. Thus, a significant part of eligible electricity customers switched to regulated authorized retail company portfolios. Consequently, the belief in private markets is reduced. Policy makers need new actions to rebuild the trust

YENİLENEBİLİR ENERJİNİNİN ELEKTRİK PİYASASI ÜZERİNDEKİ ETKİSİ

ÖZET

Yenilenebilir enerji, Dünya'da elektrik üretimi için en önemli kaynaklardan birisi haline gelmiştir. Henüz, üretilen elektriğin çoğu geleneksel kaynaklardan karşılansa da, son yıllarda yenilenebilir enerjiye dayalı kurulu güç artışı diğer kaynakların önüne geçmiştir. Bu artışın sebebi, ülkelerin güçlü hedefler belirleyerek, bu hedeflere ulaşmak için yenilenebilir destek mekanizmalarını politikaları haline getirmesidir. Böylelikle ülkeler, gelecek nesiller için daha temiz bir Dünya bırakabileceklerdir. Son yıllarda, yenilenebilir enerjinin yayılmasında öncü teknolojiler ise güneş ve rüzgar üretim tesisleri olmuştur.

Yenilenebilir enerji santrali kurulum maliyetleri özellikle Çin'in bu konudaki atılımıyla düşmeye devam etse de, hala geleneksel elektrik üretim teknolojilerinin üstündedir. Bu da yatırımcıların, maliyetlerini diğer elektrik santral tiplerine göre daha uzun sürede çıkarmasına sebep olmaktadır. Bu sebeple, hükümetler yatırımcıları yenilebilir enerjiye teşvik edebilmek için yenilenebilir enerji destekleme mekanizmalarını hayata geçirmiştir. Bu mekanizmalardan en yaygın olanı ve çoğu ülkede uygulananı şebekeye satış tarifesidir. Bu tarife ile yenilenebilir enerji üreticileri, ürettikleri elektriğin spot piyasalar yerine önceden belirlenmiş bir tarife fiyatı üzerinden belirli bir süre satışını gerçekleştirirler. Tarife fiyatları spot piyasa fiyat ortalamasından yüksek olduğundan, üreticiler yatırımlarının karşılığını daha kısa sürede alma şansına sahip olurlar. Tarife fiyatları, hükümetlerin yenilenebilir konusundaki agresifliğine bağlı olarak değişmektedir. Bir diğer yenilebilir enerji destekleme mekanizması da yenilenebilir enerji ihaleleridir. Bu ihaleler hükümetler tarafından geniş çaplı yenilenebilir enerji projeleri için yapılmaktadır. Bu ihaleler sonucu ortaya çıkan fiyatlar, şebekeye satış tarifesine göre düşüktür. Bu sebeple, hükümetler son yıllarda bu tarz ihalelelere ağırlık vermektedir.

Yenilenebilir enerji teşvik mekanizmaları, devletler için ekonomik bir yük doğurmaktadır. Kimi ülkelerde bu yük doğrudan son tüketiciye yüklenmekte kimilerinde ise perakende elektrik şirketleri veya başka taraflarca yüklenilmektedir. Yüklenen taraftan bağımsız olarak, bu maliyetler doğrudan ya da dolaylı olarak son tüketiciyi etkilemektedir. Bu durum, Dünya'da yenilenebilir enerji maliyetlerinin elektrik piyasalarına etkilerinin sorgulanmasına yol açmış ve konu birçok ülkede analiz edilmeye başlamıştır. Yenilenebilir enerji teşvik mekanizmalarının başlaması üzerine yeterince uzun zaman geçmesi ve bu süre zarfında biriken verinin enerji borsaları tarafından yayınlanmaya başlamasıyla, araştırmacılar bu analizler için daha fazla girdi bulabilmiştir.

Türkiye Dünya'daki yenilebilir enerji trendini takip etmektedir. Hükümetin yerli ve milli enerji politikası doğrultusunda Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına İlişkin Kanun 2005'te yasalaşmıştır. 2010'da ise bu kanunda değişiklik yapan yeni bir kanun ile Yenilenebilir Enerji Kaynakları

Destekleme Mekanizması (YEKDEM) hayata geçirilmiştir. YEKDEM kanunu ile birlikte 2011 yılından itibaren şebekeye satış tarifesi hayata geçirilmiştir. Bu tarifeye göre YEKDEM portföyüne dahil olan hidroelektrik, rüzgar, jeotermal, biyokütle ve güneş enerjisine dayalı elektrik üretim tesisleri belirli fiyatlar üzerinden ürettikleri elektriğin satışını on yıl süre ile gerçekleştirebileceklerdir. Tarife fiyatları, yenilenebilir enerji kaynağına göre 73 $/MWh ile 133 $/MWh arasında değişmektedir. Ayrıca, yenilebilir enerji santral yapımında, yerli ürün kullanılırsa tarife fiyatı artış göstermektedir.

YEKDEM mekanizması teşvik fiyatları Amerikan Dolarına bağlı olduğundan, son yıllarda kurda yaşanan artış mekanizmayı yenilenebilir enerji üreticileri için daha avantajlı hale getirmiştir. Bunun sonucunda, mevcut yenilenebilir enerji santralleri bu mekanizmaya dahil olmaya başlamıştır. Ayrıca, düşen yatırım maliyetleri ve YEKDEM teşvikiyle beraber, özellikle rüzgar ve güneş santralleri kurulumu yatırımcı için daha makul hale gelmiştir. 2014-2017 yılları arasında hem ciddi yenilenebilir enerji kurulu güç artışı yaşanmış hem de daha önce kurulmuş santrallerin önemli bir kısmı bu YEKDEM'e dahil olmuştur. Bunun sonucu, 2014-2017 arası YEKDEM maliyeti ciddi bir şekilde artmış ve Türkiye ekonomisine ciddi bir yük doğurmuştur. Bu maliyet doğrudan perakende elektrik şirketlerine yansımakta ancak dolaylı olarak son tüketiciyi etkilemektedir. Bu sebeple, diğer ülkelerde olduğu gibi, Türkiye elektrik piyasasında da bu teşvik mekanizmasının getirdiği maliyetlerin ekonomik olarak incelenmesi kaçınılmaz olmuştur. Bu amaçla, bu tezde, Türkiye'de yenilebilir enerjinin toptan satış fiyatlarına ve perakende maliyetlerine etkisinin gösterilmesi amaçlanmıştır.

Türkiye gün öncesi elektrik piyasasında fiyat oluşum metodu merit-order eğrisidir. Merit-order eğrisi marjinal (değişken) maliyetleme esasına dayanmaktadır. Burada marjinal maliyet, temelde bir üretim santralinin birim elektrik üretimi için kullandığı yakıt maliyetidir. Bu özelliklerinden dolayı merit-order eğrisi, düşük marjinal maliyetli santrallerin yüksek maliyetli santrallerden daha önce üretim yapmasına olanak sağlar. Böylelikle, toplam üretim maliyetleri en düşük seviyede tutulmuş olur. Yenilenebilir enerji santralleri, sıfıra yakın marjinal maliyetleri ile merit-order eğrisine en düşük noktadan girer. Böylelikle, daha yüksek maliyetli geleneksel santrallerin bir bölümü yerine üretim yapar. Bu da gün öncesi piyasasında oluşan spot fiyatların düşmesine sebep olur. Yenilebilir enerji kaynaklarının yarattığı bu etkiye literatürde merit-order etkisi denmektedir.

Tezde, Türkiye elektrik piyasasında 2014-2017 dönemine ait gerçekleşmiş saatlik veriler analiz edilmektedir. Saatlik zaman serisine uygulanan çoklu doğrusal regresyon modeli ile geçmiş veriye yönelik bir çalışma gerçekleştirilir. Bu modelle YEKDEM kapsamındaki yenilenebilir enerji santrallerinin üretimi ve bu üretimin merit-order etkisi incelenir. Ayrıca, model sonucunda piyasa spot fiyatlarına etki eden diğer önemli değişkenlerin etkisi de bulunur. Çoklu doğrusal regresyon modelinin doğru sonuç vermesi için, bu modelde kullanılacak verinin belirli özellikleri sağlaması gerekmektedir. Tezde, hem bu veri hem de model sonuçlarının doğruluğunun gösterilmesi amacıyla gerekli testler uygulanmıştır.

2014-2017 dönemindeki merit-order etkisi aylık olarak geçmiş YEKDEM birim maliyetleri ile kıyaslanır. Böylelikle, yenilenebilirlerin elektrik piyasasındaki net etkisi bulunur. Merit-order etkisi toptan satış maliyetlerindeki düşürücü etkisiyle perakende maliyetlerini düşürürken, YEKDEM birim maliyetleri ise perakende maliyetlerini yükseltmektedir. İncelenen dönem için yapılan analizde, YEKDEM birim maliyetlerinin merit-order etkisine göre daha fazla olduğu bulunmuştur. Analiz edilen 2014-2017 arası dönemde, yenilenebilir enerji kaynaklarının toplam perakende maliyetlerini 5,3 milyar TL artırdırdığı hesaplanmıştır.

Henüz özelleşme sürecini tamamlamayan Türkiye elektrik perakende piyasasında bulunan ulusal perekande elektrik tarifeleri, serbest olmayan ve serbest olma hakkını kullanmayan tüketicilerin elektrik kullanım fiyatlarını belirlemektedir. Bu tarife fiyatları, özel elektrik perakende şirketlerinin satış fiyatları için bir üst sınır oluşturmaktadır. Çünkü tüketiciler her zaman tarifeler üzerinden, kendi bölgelerinde yer alan görevli tedarik şirketi veya iletim şirketi aracılığıyla elektrik alma hakkına sahiptir. Tezde, yükselen YEKDEM birim maliyetlerinin perakende şirketleri üzerindeki etkilerini göstermek için, 2014-2017 arası perakendecilerin maliyetleri ulusal perekande elektrik tarifesi aktif enerji fiyatları ile karşılaştırılmıştır. Ortalama perakende elektrik maliyetleri, temel perakende elektrik maliyet kalemleri olan toptan elektrik, YEKDEM, profil ve dengesizlik birim maliyetleri kullanılarak bulunmuştur. Karşılaştırma sonucu 2017’de devlet tarafından belirlenen tarife fiyatlarının yeterince yüksek olmadığı sonucu ortaya çıkmıştır. Tarife fiyatları ile perakende maliyetleri arasındaki fark giderek düşmekte ve bu durum perakendici için daha sınırlı ve azalan bir satış marjı alanı bırakmaktadır. Bu marj, 2017 yılı için farklı tüketici gruplarında %1 ve %5 olarak gerçekleşmiştir. Bu marjın perakende elektrik şirketleri için yatırım, operasyonel giderleri karşılaması ve ayrıca kar marjı bırakması beklenmektedir. 2017 yılı marjlarına bakıldığında, bu pek mümkün görünmemektedir.

Tezde, YEKDEM ve son yıllarda yürürlüğe giren Yenilebilir Enerji Kaynak Alanları (YEKA) ve güneş çatı uygulamalarına dair regülasyonlar anlatılmıştır. Ayrıca, ilgili yönetmeliğe göre YEKDEM birim maliyet hesaplama metodu açıklanmıştır. Tez kapsamında, bu metod ve 2017’ye ait yenilenebilir kaynaklı üretimler, kur ve spot fiyatlar kullanılarak aylık YEKDEM birim maliyetleri hesaplanmıştır. Hesaplanan maliyetler ile gerçekleşen YEKDEM birim maliyetleri kıyaslanmıştır. Kıyaslama sonucu, maliyetler birbirine çok yakın çıkmıştır. Bu sonuç, yayınlanan 2017 YEKDEM birim maliyetlerini doğrulamış ve tezde YEKDEM maliyet girdilerinin etkilerinin incelenmesine olanak sağlamıştır. Amerikan Doları/TL oranı için senaryolar oluşturulmuş ve değişen kur seviyelerine göre YEKDEM birim maliyetinin ne kadar değiştiği görülmüştür. Ayrıca, yenilenebilir enerji kaynak türlerinin her birinin toplam YEKDEM maliyeti içerisindeki etkisi hesaplanmıştır.

YEKDEM birim maliyetlerinin Amerikan Doları/TL kuruna bağımlılığı, bu maliyetleri değişken ve öngörülemez yapmaktadır. Halihazırda sınırlı bir marj aralığında, küçük marjlarla satış yapmaya çalışan perakende elektrik şirketleri, YEKDEM birim maliyetlerinin değişkenliğinden ötürü yaptıkları satışlardan zarar edebilmektedir. Son yıllarda, bu sebepten dolayı bazı elektrik perakende şirketleri kapanmış ya da zararı durdurmak için portföylerindeki müşterileri çıkartmak durumda kalmışlardır. Bundan dolayı özel perakendicilerden elektrik alan müşterilerin önemli bir bölümü görevli tedarik şirketlerine geçerek ulusal perakende elektrik tarifeleri üzerinden elektrik almaya başlamıştır. Ayrıca, bazı özel tedarik şirketleri, zararı önlemek için elektriği tüketicilerine sözleşmelerinde yer alan birim fiyatlardan daha yüksek bedellerle fatura etmeye başlamıştır. Bu durum, tüketicinin özel sektör üzerindeki güvenini sarsmıştır.

Türkiye elektrik piyasasında 2001'de Elektrik Piyasası Kanunu ile başlayan özelleştirme süreci, perakende piyasayı da kapsayacak şekilde 2008-2013 arası yapılan elektrik dağıtım şirketi özelleştirmeleriyle hız kazanmıştır. Ancak, özellikle 2017 yılında perakende elektrik piyasalarında yaşanan ve yukarıda anlatılmış olan olumsuz gelişmeler özelleştirme sürecine zarar vermiştir.

Son olarak, Türkiye elektrik piyasalarında söz sahibi yetkili kişilerin, bu tez sonuçlarını da göz önünde bulundurarak yenilebilir enerji destek mekanizmalarını gözden geçirmesi ve elektrik perakende piyasalarının tam özelleşmesini sağlayacak stratejileri belirleyerek hayata geçirmesi piyasanın geleceği için önem taşımaktadır.

1. INTRODUCTION

Renewable support schemes are required for the global green energy development because renewable power investments are not competitive enough due to their higher investment costs compared to other type of power plants. Support schemes need finance sources. There is a variety of finance sources. In all cases, the end-consumers are financially affected. This situation has raised the question of renewable energy impact on the power markets.

As in global markets, renewable plants in Turkey are subsidized through support schemes. The main support mechanism in Turkey is feed-in tariff (FIT), which grants plant owners to sell electricity at a certain USD-based price for ten years. The renewable types that can benefit from the FIT are wind, solar, hydro, geothermal, and biofuel. The FIT price is higher than wholesale prices in the last years because of growing FX rates. Therefore, FIT creates a burden for the system. Electricity retailers absorb the cost, proportional to their consumption portfolio. The combination of FIT and renewable technology price reduction especially for solar energy, led to a renewable boom in the period of 2014-2017. This caused FIT cost to increase dramatically. Moreover, volatile FX rates leaded to unpredictable FIT costs. Therefore, retail costs have increased unpredictably and caused retailers make losses on their sales to end-consumers. Consequently, analyzing this and quantifying the net effect of renewables on the retail costs have become a necessity.

Turkish day-ahead market (DAM) price formation method is the merit-order curve. According to the curve principles, plants with low marginal costs construct the basis for power generation. Due to their almost no variable cost nature, renewables enter merit-order curve first and replaces traditional plants. Hence, they reduce wholesale prices. It is named as merit-order effect. Merit-order effect helps end-consumer prices to fall. The net impact of renewables is found by comparing merit-order effect with the FIT cost.

1.1 Purpose of Thesis

This dissertation is an extension of existing literature. The methodology in this thesis is similar to the approaches of Mahoney *et al.* [1], Cludius *et al.* [2] and Clò *et al.* [3] studies. The thesis aims to contribute to the merit-order effect literature using Turkish electricity market as a case study. Using an ex-post approach, the thesis examines 2014-2017 period in which the renewables installed capacity and FIT portfolio enlarged significantly. Using econometric methods, MOE of renewables in FIT portfolio is calculated. The renewables examined in this period are wind, solar, hydro, geothermal, and biofuel power plants. The second purpose is comparing FIT cost and MOE to find net renewable energy effect on retail costs. Furthermore, 2017 FIT cost is recalculated to verify realized FIT cost. As an additional work, retail costs are compared with national retail tariff to show available margin for sales.

1.2 Thesis Scope

The remaining part of the thesis is ordered as following. Second part of the thesis explains the basics of power market and trading principles that provides fundamental infromation. The chapter moves on to describe the growth being experienced in RES technology deployment, describing some recent developments on the field, with emphasis on solar and wind technologies. Moreover, this part deals with renewable support mechanisms and describes the most important instruments. The merit-order mechanism and some of its features are characterized. Then, merit-order effect of renewables and theoretical background is explained, which is the main theme of this dissertation. The chapter ends with the literature review of the previous studies regarding RES impact on power markets.

Chapter 3 focuses on the Turkish Power Market. It starts from the beginning of privatization process and summarizes important enhancements. The chapter includes main market players and explains their main functions. It also shows generation capacity and mix change change over the years. Moreover, it explains Turkish day-ahead market (DAM), merit-order mechanism and renewable support mechanism which are the basis for this dissertation. Furthermore, it explains government renewable policies which includes recent incentive methods for renewables.

Fourth chapter includes the fundamental research and modelling work done for this dissertation. It describes the methodology and important features of multiple linear regression (MLR) model. The chapter also shows the assumptions made, introduces variables and explains removing outliers. The chapter continues with checking the data fit of the model and finally expains the implementation.

Chapter 5 gives the results of MLR model and related tests to verify validity of the model. The chapter also includes the calculations on net renewables effect on retail costs. The last part of the chapter compares retail costs with the national retail electricity tariff. It shows the change in retailers' sales margin between 2014 and 2017.

Chapter 6 discusses the contribution of this study to the Turkish power market and practical applications. The chapter also suggests possible topics for future research.

2. POWER MARKETS

2.1 Power Market Fundamentals

In the millenium age, power is a must have resource and classified as a commodity, but there are some important characteristics of the power markets which differentiates it from the conventional commodities like coal, oil, gold. The most important distinctive characteristic is the necessity of instantaneous supply and demand balance. This balance is secured on transmission lines via frequency control of instantaneous up and downs in the electricity current. Since the current technology does not give us any large scale storage opportunity, monitoring of the system continuosly prevents the blockages. As in every market, supply and demand theory holds for power markets as well. Power generated in the plants is connected to the distribution line or transmission line based on its voltage level. Then, the voltage level is adjusted through the end user connection according to system specifications. Demand has seasonality and seriously affected by temperature, therefore it changes considerably over time. Furthermore, it varies within a day, showing an increase at a day time and falls during the night. The change in demand is the main factor of the change in the market equilibrium point.

As a second characteristic, the power demand is low in elasticity, since household consumptions are basic needs such as kitchen and lighting uses. Even if the retail tariff price increases in the market, nobody will stop using these equipments. The same concept is valid for the industrial firms such as steel and cement producers whose productions heavily depend on the electricity consumption. These firms search for cheaper electricity contracts, but they will never stop power consumption and switch to another commodity. Some industrial or commercial users can shift their electricity consumption to cheaper hours especially when they have spot price indexed contracts. However, this change is usually limited because the change requires adaptations in the process, machines, employee shifts, and commodity prices. For instance, an industrial manufacturer using electricity and natural gas as process inputs may consider making less production in winter season, which has higher power prices. However, it may conflict with the consumer’s natural gas contract, which may have take-or-pay constraints.

The third unique characteristic of the power market is that the supply is not directly connected to the consumer if the consumer does not generate his own need. Using huge transmission lines, all net generation is pooled in a grid and transmitted to end-users. With recent developments, rooftop solar panels might eliminate these huge transmission network in the future. Furthermore, because of the physical properties of electricity, a part of the electricity is lost while it is being carried over electricity transmission lines. Losses may be significant, sometimes between 5% and 10% of the produced electricity.

Finally, power markets are regulated and free unless there is a direct government intervention in a specific time to affect market prices drammatically. In some cases, even if there is no direct intervention on the market by the state, there can be some incentive packages by government for certain power generators, which make them not attend to spot market. Consequently, the concept of free market is affected negatively as well.

2.2 Privatization of Power Markets

First power plant started its operations in 1882. It had aimed to build the power plant close to consumers. In the earliest times of centralized power generation, it had also been figured out that the most efficient way to operate the electricity sector was as a natural monopoly, where a regulated and vertically integrated utility firm managed the generation, transmission, distribution and commercialization of electricity. This practice had been applied until transmission grids became an efficient alternative to transmit electricity over long distances. This allowed them constructing sources of electrical energy far from the consumption facilities. Then, the disintegration of generation became possible, as the first step of competitive market, leaving only the distribution and transmission activities as natural monopolies [4].

As an important privatization action, The Public Utility Regulatory Act of 1978 in the US obliged monopolistic utilities to buy electricity from independent producers. The act aimed to promote reducing demand and increasing supply from domestic energy and renewable energy sources (RES). By 1990 deregulation and privatization became a common trend worldwide. In Europe case, the English power market was the first one introducing the privatization in the power market and then it was pursued by other countries. After UK, the Scandinavian market has progressively been opened in 1991 with Norway. Finland and Sweden participated the privatization trend in 1995 and 1996, respectively [5]. Consequently, in late 1990s, EU commission made energy market liberalization a mandatory target for member countries.

With deregulation, private participation and competition were introduced to power industry. The old-fashioned regulated and vertically integrated monopolies transformed into competitive power markets in which generation, transmission, distribution and commercial activities are classified separately. The aim of this development was to renew the infrastructure by increasing investments. Rationale behind this method is to spike installed capacity so that increasing demand is met efficently. Also, growing capacity provides an opportunity for better demand management and help consumers to consume electricity at a better price [6].

Under the deregulation flow in the world, the transmission networks have been refurbished and connected to each other over the countries. In this way, power network has been secured among countries. This provided a flexibility for countries to choose cheaper electrictiy in the region because of the interconnected power system. Thus, if a country lacks electricity or produces electricity from expensive sources, it might choose to import the electricity from the countries in the near neighbourhood. This interconnection led to market coupling and cross-border trading activities as well. In 1993, Scandinavian market has become the first coupled power market to produce and consume electricity more efficiently. In this model, electricity flows from the countries generating cheaper electricity to the countries generating expensive electricity. Then the same price set up has been applied for all coupled markets. Coupling model allows countries to utilize energy resources in a more efficient way. In this model, a country with high hydro reservoirs is the main feeder to the network during the spring season, whereas a country with high natural gas resources is also the main feeder during the winter season. Thus, a country is no longer required to construct all types of power plants due to the advantage of the market coupling.

2.3 Trading

2.3.1 Day ahead market

Day-ahead market (DAM) is the market for physical delivery of electricity on next day or next working day. Delivery of electricity is based on the contracts made between sellers and buyers. Buyers put their best efforts to estimate the power consumption of their portfolio and sellers try to hedge and sell their asssets with a conditional price scheme. Each party states how much they are willing to buy and sell at each price level. They submit their bids and offers to the market operator. Then market clearing price (MCP) is released for the next day by the market operator, whose main responsibilities are to execute settlements for the transactions and provide transparent data to the market.

DAM gives the opportunity to demand side to adjust its consumption based on price levels. By this way, demand side can hedge itself against fluctuating price formations. Moreover, supply side can arrange their price levels based on their dynamic operational costs. DAM also enables market participants to balance their own portfolios. This lead to a general fall in imbalances of generation and consumption of the portfolios [7].

2.3.2 Balancing power market

Because the balance between generation and consumption has to be maintained instantaneously, transmission system operator (TSO) continuously corrects imbalances to provide a certain power frequency in the grid. It also ensures the system integrity. To provide this, system operator uses frequency control actions namely primary, secondary, and tertiary reserves. The reserve orders given by TSO increase or reduce generation in a short time depending on the instant fluctuations in the supply or demand. The reserve market products are technical and not applicable to all plants. Also, the plants are not only paid for reserve orders but also for the availability of the reserved capacity [8].

Similar to MCP, system marginal price (SMP) is formed where the actual supply balances the actual demand. SMP is also influenced by MCP because agents usually use MCP as a reference point.

2.3.3 Intraday market

Some factors cause imbalance such as power plant malfunction and fluctuations of power generation from renewables. Intraday market gives participants the opportunity to make adjustments to their positions and balance their portfolios in the short term. It acts as a bridge between DAM and balancing markets, and contributes to sustainability of electricity market [9]. Intraday market prices are also influenced by MCP because agents usually use MCP as a reference point.

2.3.4 Bilateral trading

The prices on electricity markets tend to be highly volatile and unpredictable because it is susceptible to several factors such as weather, demand, and plant availability. The risks associated with the volatility can be hedged through bilateral contracts. Bilateral agreements can also be used for proprietary trading purposes. Bilateral trading is done via contracts that involve two parties, there must be a buyer and a seller. The most common bilateral power contract types are forwards, futures, and options.

Forwards are the contracts which both parties agree on the price and quantity of power to be delivered on a future delivery date. The payment date is specified in the contract which is usually near the delivery date. Forwards are realized via over-the-counter (OTC) platforms. They are usually executed through brokers. The main advantage of the forward contracts is their non-standard structures. Buyer or seller might prefer tailor-made products which meet both parties' needs. However, forward contracts bring some risks to the parties. Since creditworthiness of the each party is pretty crucial until the settlement of the contract, these type of contracts carry counterparty credit risk and should be monitored cautiously until contract expires.

Future contracts are similar to forward contracts but the main difference is there is a central settlement unit for transactions, which are creditworthy commodity exchanges. At the end of a trading day, settlement is done. Then, the price of settlement is published so profits and losses are immediately realised in participants' accounts. Hence, the system eliminates the counterparty credit risk. This type of settlement system requires strong capital requirements for the firms since any price fluctuation might cause mark to market loss for one party and it needs to be covered immediately.

Power options grant the option owner to purchase or sell power at a predetermined option price. These contracts are not obligatory and the option holder purchases the right by paying a nonrefundable fee called option premium. The contract price is also paid if the option holder decides to exercise the contract before delivery date. Options can be traded at OTC or commodity exchanges.

2.4 Energy Exchanges

Energy exchanges are the major marketplaces for electricity trading activities. Some of the exchanges are not only marketplace for spot products but also a place for power derivatives [8]. The exchanges aim to develop, operate and connect secure, liquid and transparent markets for energy and related products.

A lot of countries have set up regulated energy exchanges in recent years. The most important energy exchanges are Nord Pool Exchange for Nordic and Baltic markets, European Energy Exchange (EEX) for Central Europe, and NASDAQ OMX Commodities Europe Exchange.

2.5 Renewables and Support Mechanisms

2.5.1 Renewables development

Renewable energy sources (RES) provide sustainable energy services in the form of electricity, transportation solutions, and heating and cooling [4]. Out of the these three sectors, especially the renewable electricity market growth has increased in recent years. There are several reasons for that: cost decline in RES technology, dedicated policy targets, better access to financing because of supporting schemes, environmental concerns, growing electricity demand.

Wind power is the leader in installed capacity growth, from 2006 to 2016, largely due to contributions from China, Germany and US (Figure 2.1). However, Solar PV is the pioneer with its accelaration in recent years and the main factor for renewable growth. (Figure 2.2). China, US, Japan, India are the main contributors of PV. The trend will continue and total global PV capacity will reach 740 GW by 2022 [8].

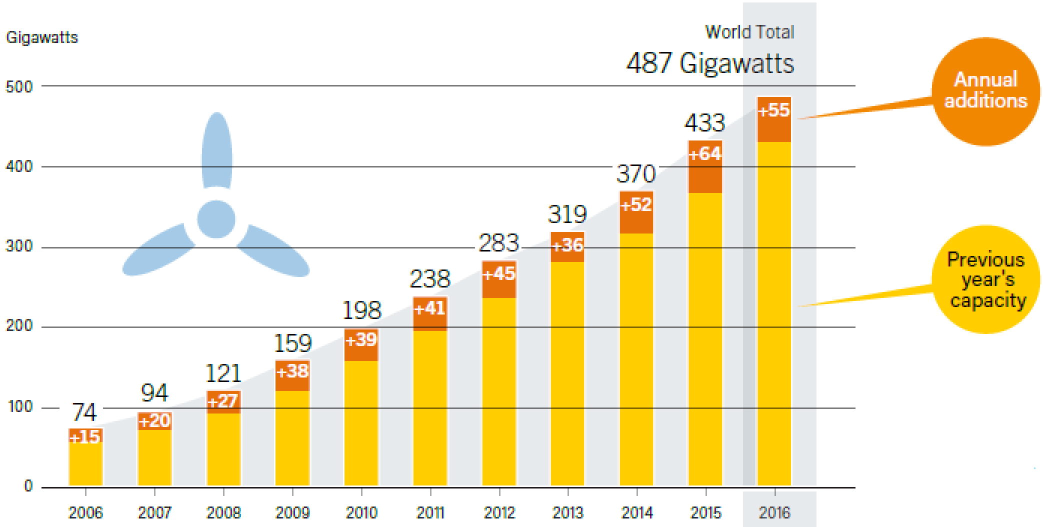

Figure 2.1 : Wind power global capacity and annual additions by years [10].

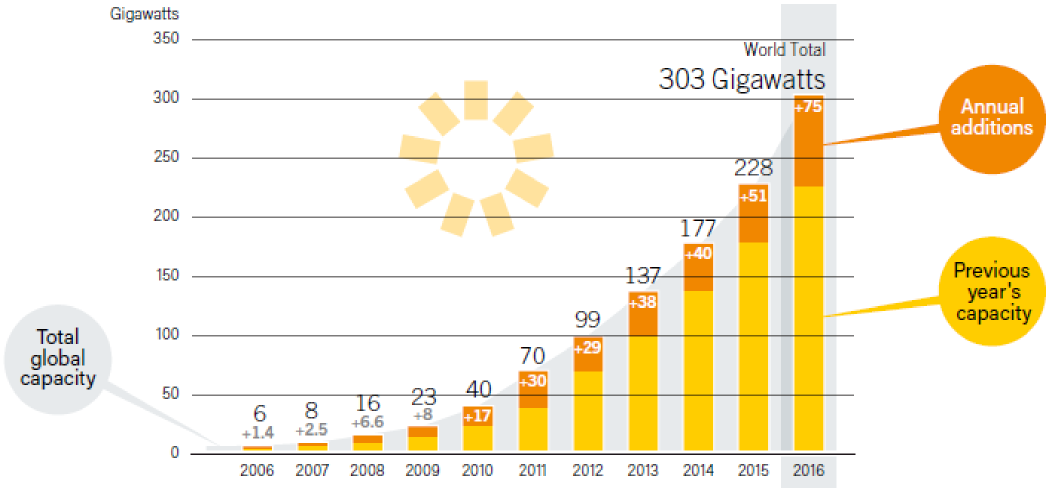

Figure 2.2 : Solar PV global capacity and annual additions by years [10].

By 2004, the deployment and manufacturing of RES technologies were mainly done in US, Europe and Japan [4]. However, later China has become the dominant player in renewable technology growth. In 2016, renewables account for most of the power capacity increase by its contribution of 165 GW. China had made half of this expansion. China also has almost 50% of solar demand. Moreover, about 60% of cell production comes from Chinese firms. Despite policy uncertainty, US follows China in terms of the renewable enlargement. It mainly stems from additional solar and wind capacities, thanks to federal tax incentives and state-level policies for distributed solar PV [11].

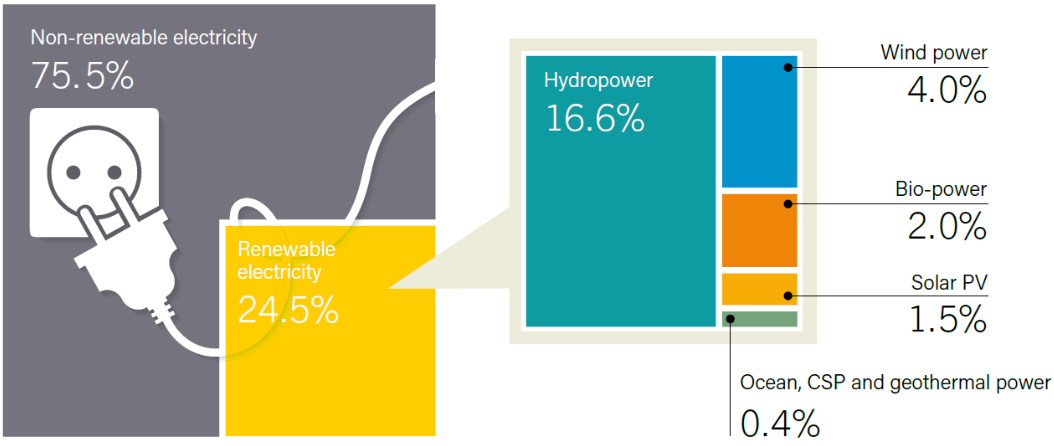

Figure 2.3 : Estimated RES share in global electricity generation (2016-end) [10].

The global growth trend of renewables will continue. By 2022, the installed capacity will increase about 33% to be more than 8000 GW. By 2022, 30% of the global energy consumption will be sourced by RES, compared to 24.5% in 2016 (Figure 2.3). Although the capacity incerase of hydropower continue to be at low-levels, it will be still the main power production source among other renewables. Wind power follows hydropower [11].

Although many coal power plants are shut down due to environmental concerns and their high-marginal costs compared to renewables, most of the power production will continue to be from these sources in 2022. However, renewable capacity additions will surpass this source and also natural gas power plants, which also have high-marginal costs [11].

2.5.2 Renewable support mechanisms

Power generation from renewable sources is supported through special schemes in almost all countries. By the end of 2015, 146 countries had support policies for renewable energy sources (RES) [4]. Support schemes are required for the green energy development because renewable investments are not competitive enough due to their higher investment costs compared to power plants utilizing conventional fuels. The important instruments to promote renewables are described in Table 2.1. Feed-in tariff (FIT) method is the most used one, which exists in almost all countries [4].

Support schemes also need to be financed. The finance source is usually one of the following: general public budget, end-consumers or retailers. In all cases, the end-consumers are financially affected, etiher directly or indirectly. Therefore, the support schemes have been a hot topic for policy makers. Policy mechanisms have evolved in last two decades and policy instruments differentiated for each renewable energy technology.

Table 2.1 : Important renewables support instruments [12].

Name	Description
Feed-in tariff (FIT)	Long-term minimum price is guaranteed for electricity
RE-Quota	End-users consume or suppliers produce a certain amount of electricity from RES
RE-Tender	The state makes a tender a for a certain RES capacity. Winners acquire the right to make PPA
Direct subsidies	A part of capital costs are covered by national authority

Globally, RE-tenders are replacing FITs, in terms of support schemes deployed. Because, RE-tenders provide more competition and results in diminished incentive prices. In some countries such as Germany, India and Turkey the price levels decreased by 30-40% in 2015 and 2016. Additionally, about 50% of renewable growth will come from tenders until 2022. Announced tender prices for wind and PV have continue to fall. In 2017-2022 period, incentive prices are forecasted to diminish 25%, 15%, 33% more for PV, onshore and offshore wind, respectively. Moreover, according to the newcoming tender prices, there will be 30-50 $/MWh more decrease for onshore wind and PV incentive prices [11].

2.6 Merit Order Approach in Price Structuring

To ensure market efficiency, producers should make offers on the spot market at their marginal costs, because economic efficiency requires marginal cost pricing. In electricity market case, the variable costs for electricity production are the marginal costs. The marginal costs can be assumed as equal to fuel costs. To minimize total electricity generation cost and ensure market integrity, the system should consist of different technologies. These technologies have two types with high fixed but low variable costs and vice versa [4].

The shape of supply curve is defined by marginal costs of each technology present in the system. Figure 2.4 shows a typical supply curve, also called a merit-order curve.

Supply curve has a stepwise shape, where each of the steps represents an offer by a generation company. Offers go from least expensive to most expensive. The costs change with technology type and cost of fuel used. Demand is shown with a vertical dashed line in the figure because inelasticity is assumed.

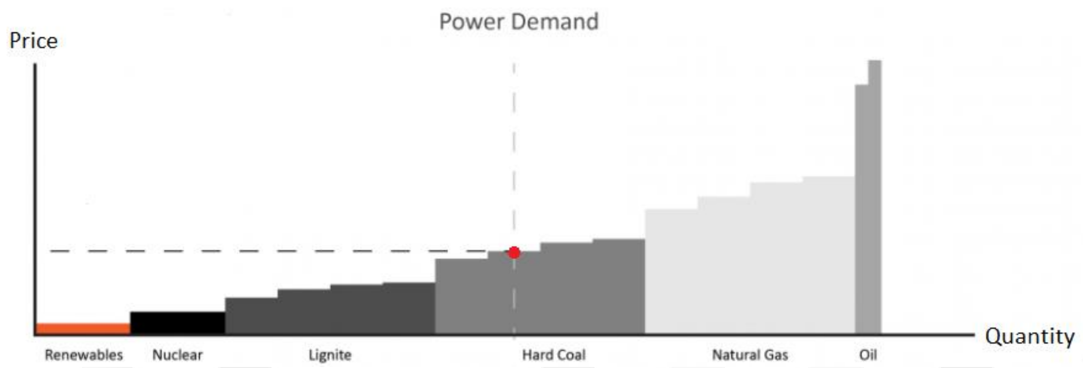

Figure 2.4 : Typical merit-order curve [13].

In spite of high investment costs, renewable technologies face the lowest marginal costs. Therefore, they come at the bottom or left part of the curve and followed by nuclear and thermal plants. At the top or the rightest side of the curve, there are oil plants, since they present the highest marginal costs. Offers from large hydropower plants are usually considered strategic and depend on the amount of water available. Thus, their position can change in the merit-order curve.

2.7 Merit-Order Effect of Renewables

Pursuant to merit-order curve, plants with low marginal costs produce electricity first instead of plants with high marginal costs. RES have almost zero marginal costs and enter the merit-order curve with the cheapest offer. Hence, if renewable power plants increase their generation, it leads to a cheaper equilibrium price. In other words, RES generate instead of plants with high marginal costs. Furthermore, more generation from cheaper resources make supply and demand curves intersect at a lower point. Therefore, electricity generated by RES creates a downward pressure on wholesale prices. This means that periods with high level of RES usually have lower prices in the spot market. This impact is named “merit-order effect” (MOE) in literature. In Figure 2.5, MOE is represented by showing the changes in demand and supply curves [14].

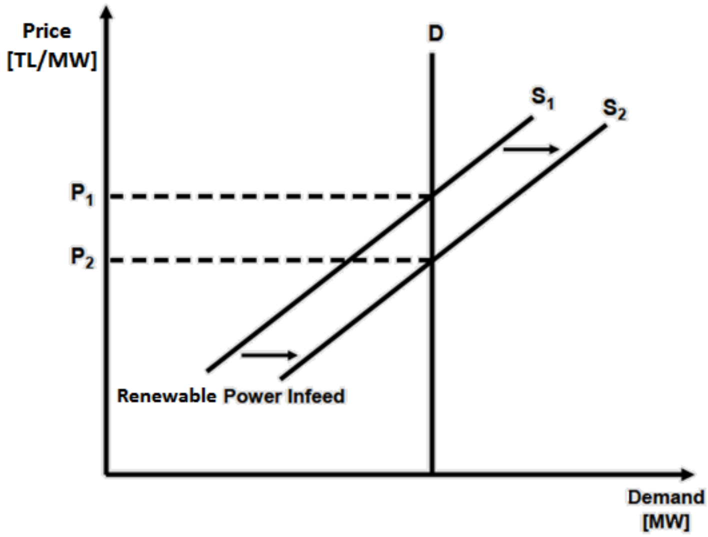

Figure 2.5 : Merit-order effect of renewables.

MOE is greater, if most of the generation is at the peak-demand hours. Because, it replaces more expensive generation. Hence, due to its nature, solar shows this pattern more than other renewable sources. Therefore, it contributes more to the merit-order effect for unit generation.

2.8 Literature Review

There is an extensive and varied literature pertaining to how generation from RES affects the electricity prices, and subsequent effect upon the merit-order and market value. This literature review utilizes a number of research methods as well as involving many different countries. This review will summarise what preceding research has discovered about how RES affects electricity prices.

In general, two ways of looking into the merit-order effect as it applies to renewable sources are reported in the literature: simulation models, i.e. electricity market modelling; or analysing actual historical data statistically i.e. an econometric approach. Simulating the price depends on models into which historical or hypothetical data are fed, whilst the econometric approach uses past price performance to analyse the trends using existing econometric frameworks [15]. Simulation scenarios need to be reasonable and realistic if prices are to be predicted with accuracy. Since the approach necessitates a host of assumptions, the conclusions derived are likely to be tentative. Compared to simulation-based approaches, using actual past conditions in models that use regression techniques has the clear advantage of not depending on hypothetical developments, such as the building of new power stations or transmission networks, the occurrence of which is impossible to foretell: conclusions are reached based on what did occur, rather than what might occur [16]. The present review thus divides the literature into those studies which rely on simulation and those which are based on historical (empirical) models.

2.8.1 Simulation-based studies

The literature examining how renewables impact the price of electricity, as considered from a simulation-informed perspective, is extensive and covers multiple different countries. Those studies of highest relevance are listed here and divided into sections according to the country to which they refer.

As usage of RES has grown to an unusually high extent in Germany within the last ten years, it has become the focus of frequent investigations. Sensfuβ and colleagues, employing a model of the power grid used in Germany, investigated what would happen if renewables were in use or not [17]. They concluded that renewables were responsible for a 1.7 €/MWh reduction in the price of electricity (to 7.8 €/MWh) in 2001, and again between 2004 and 2006. Amongst renewables, wind power was the principal factor.

Weigt [18] used the data from Germany for a different aim, wishing to see the extent to which wind power may potentially take the place of conventional power stations burning fossil fuels. Within this model, costs are kept as low as possible, then the model calculates the resulting price of electricity, adjusted according to the contribution of wind power to the total. Mean prices as calculated thus were lower by approximately 10 €/MWh in between January 2006 and June 2008. A trend appears whereby the price is progressively eroded over time: from 6.26 €/MWh in 2006 to 10.47 €/MWh in 2007 and finally 13.13 €/MWh for the initial six months of 2008. Factoring in the effect of subsidising wind power (which amounted to 5.4 €/MWh in 2006, 7 €/MWh in 2007) these data were taken to show that wind power results in greater systemic profitability.

Lise *et al.* used a model in which all the various electricity grids in Europe act like a single market, concluding that wholesale prices in Germany are lower, yet also the prices charged to end-users are slightly higher [19]. Traber and Kemfert [20], modelled two different scenarios about spot electricity prices in Germany in 2020: one in which renewable energy formed a greater percentage of electricity generation than currently; and the reverse case, where fossil fuel use grew but renewables did not. In the first case only, a spot price reduced by 3.2 €/MWh was predicted.

Olsina and colleagues employed a stochastic technique to model how wind power would influence the pricing characteristics [21]. The model resembled the magnitude and features of the electricity grid in Germany. Adding wind generation into the picture results in substantial decreases in the prices paid for electricity. Taking the reduction in electricity prices because of wind into account, also assuming absence of feed-in-tariffs, ideally wind power should have around 7.12 GW capacity, the authors concluded.

Paraschiv *et al.* [22] looked at how wind and solar power inputs affect DAM prices. Thus, they used the variables of spot price, spot price fluctuation, individual prices of oil, coal and gas, electrical load, and the contribution from renewables to perform an analysis at a fundamental level. The analysis showed that spot prices go down with increasing input from renewable sources, but the cost to the end-user goes up. Spot prices were in constant flux due to the interplay of agent experience, announcements from the regulator and events of particular significance.

Ederer and colleagues looked for significant differences between onshore and offshore-based wind in DAM prices in Germany [23]. They hypothesized that price changes may reflect the fact that offshore wind power generation is more steady than onshore. However, in modelling the merit-order effect from 2006 to 2014, the authors detected no significant difference in the impact these two forms of wind power had on electricity prices and value, albeit offshore wind-driven electrical generation does result in less fluctuation in wholesale prices than onshore generation.

Several simulation-based studies have been carried out for Spain, where renewables are also extensively promoted. Linares and colleagues [24] simulated the operation of the market, up to the year 2020, for electricity in different market conditions – with or without extra national incentives for renewable generation. Increasing incentives for renewables led to a prediction of 21.81 TWh coming from renewables in 2020. Such a prediction entails a 1.74 €/MWh drop in the price of electricity. In another Spanish study, Sáenz de Miera *et al.* [25] reveal in their study that the years 2005 to 2007 saw a significant reduction in the price paid for electricity, attributable to wind power increases. They used their model to look at how spot prices vary depending on the presence or absence of wind power, concluding that a fall between 4.75 €/MWh and 12.44 €/MWh in the period of 2005 to the initial third of 2007 was due to wind power contributions. Once the FIT is factored in, the total savings for the same periods came out as 942 M€, 306 M€ and 898 M€ respectively.

The electricity market in Scandinavia (Denmark, Norway, Sweden and Finland), known as Nordpool, has been modelled by Holtinnen *et al.* [26] with a view to understanding how wind power influences electricity prices. The model was calibrated with data on wind generation obtained between 1961 and 1990 and the authors then predicted the situation for 2010: they expected a spot price fall of 2 €/MWh each time an extra annual 10 TWh of wind-generated electricity was added.

Green and Vasilakos [27] modeled the alterations in distribution of different power sources in a high-competition market, in which wind source generates large quantity of electricity. Even where wind power contributions are large, generation using heat drops by marginal amounts only, with the balance moving towards power generation in which variable costs may be significant but fixed costs are lower. After the new equilibrium achieved, prices alter only slightly.

For the Portuguese electricity market, Sá [4] modelled the system from the point of view of different agents and concluded prices dropped on average 17 €/Mwh over the first half of 2016 in response to switching over to wind power.

Delarue and colleagues [28] used Mixed Integer Linear Programming (MILP) to model Belgian wind power units, seeing how they influence the cost of electricity production and the amount of carbon dioxide emissions. Data on actual windspeeds observed in 2006 and load for the corresponding period were entered into the model. Model predicts that 1 MW of wind power capacity lowers the wholesale costs by 56,000 € and means 1.24 kton less carbon dioxide is released on an annual basis.

2.8.2 Empirical studies

Unlike the research outlined above, there is a body of research which utilises the increasingly available retrospective data concerning the price of electricity and the availability of renewables in multiple countries. These data may be analysed from various econometric standpoints and with various methods to extract the real effect an increase in renewable capacity has on prices.

Once again, we begin with Germany. Pham and Lemoine [29] used the GARCH process to see how wind power and solar power, considered as separate cases, affected the spot price of electricity between 2009 and 2012 in Germany. Maximum likelihood estimation was employed, which revealed that renewables brought down the price of electricity. Staying within Germany, Cludius and colleagues [2] researched MOE of solar power and wind energy. OLS regressions with varying specifications were performed, showing how an increase of 1 GWh in renewables genereation brought down the spot price of electricity by 1.1 €/MWh to 1.3 €/MWh.

Nicolosi and Fürsch [14], through their use of data from 2008, proved that increasing wind power lowered wholesale prices by altering residual demand. Specifically, they look at how spot price correlated with load and the generation contributed by wind power. In addition, they looked at effects over a longer timescale. From this longer perspective, it is evident that merit-order interacts with a residual demand curve of decreasing stability, occasioning wider fluctuations in market prices.

A later study looked at how solar energy and wind power created fluctuations in market prices of Germany between 2010 and 2015 [30]. The authors believe that whilst PV and wind power produce the merit-order effect, their tendency to produce price fluctuations is not the same. Specifically, PV produces fewer fluctuations in the price of electricity and decreases the likelihood of spikes in the price, whilst wind power has exactly opposite effects.

Paschen [31] employed structural vector autoregressive analysis (SVAR) and structural impulse response functions (SIRFs) to analyze the changing impacts of PV and wind on DAM. Modeling German market with OLS, and taking data between July 2010 and March 2013, the author showed that both renewables had a negative effect upon merit-order.

A newer approach [32] has been to model the data around solar and wind power in Germany between 2011 and 2013 on a marginal cost basis. After taking merit-order and FIT into consideration, the authors conclude that end-users made a net saving of 6.1 €/MWh in 2011, 11.4 €/MWh in 2012 and 11.2 €/MWh in 2013.

Wurzburg and colleagues [15], using a multivariate regression approach towards data from 2010 to 2012, analysed the electricity market in Germany and Austria as a single entity. Wind power and solar energy were used in conjunction to form a single explanatory variable. 7.6 €/MWh was the mean amount saved due to merit-order effect. A subsequent survey of Germany and Austria considered as a single unit and utilising identical techniques to explore data from 2011 to 2013 found, in contrast, a lower saving due to merit-order than in the initial research: 1.32 €/MWh and 1.4 €/MWh for wind power and solar energy respectively [33].

Moving to Spain, Gelabert and colleagues [34] employed OLS modelling to see the effect of renewables' contributions (considered as an aggregate of PV, wind power, small-scale hydroelectric plants, biomass and waste combustion – gathered under FIT) for 2005 to 2010 on electricity spot price. Prices fell by approximately 2 €/MWh each time renewables added 1 GWh of electricity to the grid.

Gil *et al.* [16] examined impact of incorporating wind technology into Spain's DAM in 2007 to 2010. For this they employed a trio of anaytical techniques: conditional expectation sampling (CES), least-squares regression (OLS), robust locally weighted regression (RLWR). Conclusion was, higher contributions by wind power mean falls in price increase in likelihood. Had wind power not contributed during the period studied, electricity would have sold at 9.72 €/MWh higher than it in fact did.

Azofra and colleagues [35] looked at how wind power influenced the wholesale electricity prices by using the M5P algorithm (an implementation of artificial intelligence) to sort through Spanish data gathered in 2012. Spot price reductions would range between 7.42 €/MWh and 10.94 €/MWh if the actual situation varied by 10% less or more than it did. The same team [36] employed an identical methodology to see the effects of small hydropower, biomass, and solar-thermal power on spot prices in Spanish market. Resulting reductions, in the same order, were: 1.48 €/MWh, 1.45 €/MWh, 1.05 €/MWh, which translates into savings of €0.12, €3.01 and €12.39 for a typical household during 2012. Finally, in an extension of their earlier work [37], these authors used the algorithm to see how much financial benefit electricity customers got in 2012 from wind and PV. Wind technology lowered the final price of electricity by 9.10 €/MWh and PV produced a saving of 2.18 €/MWh.

Moreno and colleagues [38] attempted to measure how much renewables (solar, wind power, small scale hydroelectric, biomass and waste combustion) cost the market in Spain for the initial six months of 2010. The authors state that feed-in tariffs have produced a “financial black hole” filling the space between generation and distribution, such that it will take until the end of 2027 for the deficit to be made good.

Ballester and Furio [39] researched the impact of different sources of power generation on DAM in Spain covering 2008 to 2013. They employed linear regression techniques. All the different kinds of renewables (wind power, PV, biomass and waste combustion) that are applicable for FIT were included in the study, which concluded that spot prices had declined as renewables increased their share of the market.

Denmark has considerable volumes of wind power. Munksgaard and colleagues [40] reviewed earlier work on MOE to determine financial impact of the wind generation for 2001-2006 period. They matched subsidy payments by end-users and MOE to get measure of overall amount by which the customer was subsidising wind power, an amount they put at 5-60 €/MWh.

Jonsson and colleagues' research [41] utilises data encompassing spot price, load and predictions of wind generation as applied to the west of Denmark between 01/2006 and 10/2007. Using a model that employs non-parametric regression techniques, the authors concluded that wind has significant effect upon DAM prices. Furthermore, this impact is most marked when wind generation is highest. Indeed, the net effect of wind power accounts for 40% of the changes in price within Denmark. These effects are particularly marked as a result of Denmark's electricity market being both limited in size and with extensive wind power inputs.

Li [42] focused on the period from 2012 to the first six months of 2014, seeking an explanation of Danish wind power's role in the fluctuations and value of day-ahead system prices. The study uses ARMA-GARCH modelling which includes the effects of Nord Pool market coupling and imported power. Wind power, Li states, lowers spot prices and reduces fluctuations in the day-ahead market in Nordic.

Nieuwenhout and Brand [43] considered another case – that of the Netherlands. They used information about weather conditions and wind strengths to deduce day-ahead wind generation values between 2006 and 2009, then allocated the days to appropriate groups, including low and no-wind production periods. Using a specially-created model, the authors found that when wind power was not contributing, spot prices in the Netherlands were approximately 5% higher than at other times.

The MOE in the Irish market was investigated by O'Mahoney and Denny [1], using an extensive dataset that encompassed demand, wind power contribution and prices of fossil fuels. This dataset was examined with an OLS multiple regression methodology, which resulted in the conclusion that electricity prices dropped by 9.9 €/MWh. Looking at the DAM effect, wind technology led to €141M being saved. Also in Ireland, another study [44] looked effect of rising wind contributions on System Marginal Price (SMP). From comparisons of SMP against the price of natural gas and wind generation from 7/2007 to 12/2013, the conclusion was drawn that gas price is what principally determines SMP and increases in wind power have no effect upon SMP.

Italy is a market with relevance in terms of renewables, since the 2010's saw a marked increase in solar energy inputs. Clo *et al.* [3] took data from the period 2005 to 2013 and performed multivariate linear regression. They wished to see what effect solar panels and wind power had on spot prices in Italy. Both PV and wind technologies were examined in isolation. A 1 GWh rise in the hourly average from these two renewables meant DAM prices fell: 4.2 €/MWh for wind and 2.3 €/MWh for solar. Both types of renewable increased price fluctuations.

A different survey of the market in Italy [45] focused on four regions between 2010 and 2013 and used graphical and statistical techniques to evaluate the data. Taking the case of solar power, the authors conclude that if markets lack true competition, solar energy may do little to reduce spot prices. Conventional power suppliers can make good their losses in profit whilst PV is active by raising the price of electricity, particularly during intervals when sunlight levels are low or altogether lacking. Thus, on average the price will remain static or potentially rise. From 2010 to 2012, the 10.54 €/MWh decrease brought about by MOE was counteracted by actions of power market participants.

The Czech Republic presents a special case in terms of renewables, since here PV does not produce lower prices due to merit-order, as Luňáčková and colleagues have observed [46]. The explanation for this phenomenon lies in the low sunlight levels, which give only a few hours each day in which PV makes a significant contribution, insufficient to produce a negative MOE.

Wind energy's influence on electricity market price has received careful attention in Texas, USA, owing to the growing role of renewables in that market, analogously to Europe. The data can be seen at high resolution thanks to the Electricity Reliability Council of Texas (ERCOT), which covers four zones and utilises quarter hour intervals for setting market prices. Nicholson and colleagues [47] zoomed in on 2007 to 2009, using wind power contribution, natural gas generation, temperature and previous electricity price as explanatory variables. Employing an ARMAX model led the authors to conclude that each extra 1 GWh of wind power lowers prices by 0.67-16.4 $/MWh.

Woo and colleagues [48] modelled wind power's effects on electricity prices (and their fluctuations) in Texas between 2007 and 2010 by means of a stationary AR-process. The research encompassed nuclear power, load and the price of gas. The authors concluded that a rise in wind generation equal to 1 GWh meant a fall in balancing prices in the range 13 $/MWh to 44 $/MWh.

Zarnikau [49] also examined the Texas electricity market, concluding that non-constant wind power leads to falling prices in some areas but upswings in other areas where transmission capacity was inadequate. Baldick [50] reasons that Texas electricity price fluctuations are a result of negative correlation between peak demand periods and periods of maximum wind production.

Within the US, studies have also concentrated on California [51], where the two largest power zones have been researched for the period December 2012 to April 2015. An OLS regression methodology was utilised to investigate the merit-order effect on both the DAM and real-time market. Within the NP15 zone, the MOE on the DAM were reductions of 0.34 $/MWh from hydroelectricity, 0.34 $/MWh from PV and 5.3 $/MWh from wind power, whilst in the SP15 zone the corresponding values were 0.94 $/MWh, 3.2 $/MWh and 1.4 $/MWh.

Kaufmann *et al.* [52] looked at rooftop PV generation within Massachusetts, USA in the period 2010-2012 by means of an OLS regression methodology, observing that solar energy causes a 0.26 $/MWh - 1.86 $/MWh fall in the price of electricity, translating into $184 million less in costs to customers.

The Australian market has also been researched in numerous studies. Forrest and MacGill [53] demonstrated that wind power produced a fall in price via the merit-order effect of 8.05 $/MWh for South Australia and of 2.73 $/MWh for Victoria between 03/2009 and 02/2011.

Cutler and colleagues [54] researched retrospective data from South Australia covering the period 09/2008 to 08/2010. By plotting wind power contribution against spot price, the researchers demonstrated that greater wind power clearly led to lower prices.

Worthington *et al.* [55] looked wider, at all five Australian National Electricity zones, covering the period 01/2006 to 06/2012. The method of least squares and quantile regression was used to model the effect of different compositions of total supplied electricity (both fossil fuel and renewables, i.e. wind and hydropower) on wholesale market price. Least squares regression methodology was utilised in conjunction with a pooled interaction model and inter-regional flow of electricity was also taken into account. They also looked at four regions having large volumes of hydroelectrical generation, in two of which spot prices went up and in two of which the opposite occurred. A comparable approach was taken for wind power with the result that, again, in two regions increases were observed, in the other two decreases were seen.

There is one study about the African market which is of relevance. Adom *et al.* [56] looked at how the availability of electricity from renewables impinged on the certainty of knowing the cost of electricity in Ghana. They took data from 1970 to 2013 and analysed it by means of ARDL, FMOLS, CCR, SCVAR and Multivariate BN. The study concluded that as renewables play a larger role, so the price of electricity is expected to vary more widely.

2.8.3 Summary of literature review

The effect of renewable sources of energy is tangible and may produce a merit-order effect. The precise effect produced depends on how great a percentage of the generated electricity comes from renewables, the daily period in which renewables are available and the composition of the system of generation as a whole. RES, most markedly in the case of PV and wind, make electricity price fluctuate to a significant degree. Spot prices are typically decreased by renewables, at least over short periods [57]. Nonetheless, the behaviour of agents alters as they become more familiar with the way renewables alter the system and this may, in certain cases, abolish the merit-order effect [45].

The fact that different studies have produced varying results may be due to unequal data frequency intervals, varying methodologies, the volume of data available and the length for which analysis is undertaken, all of which may influence how merit-order effects are calculated. For countries with a greater amount of generation from wind power and solar energy, such as Germany, Spain, the US and Australia, the impact of renewables on power price is more of an issue. In addition, there are many times more studies concerning wind power than other renewables.

Denny *et al.* [58] took a quantitative approach to compare the results of simulating prices versus analysing historical data. Their chosen example was how wind generation affected the market in Ireland in 2009. Both methodologies produced similar conclusions, differing by only 25%. However, the authors point out that empirical (historical) methods require less data and are quicker to calculate. Simulations are unable to adjust for unforeseen events and the data entered need a greater degree of precision if they are to approach the accuracy of empirical modelling. Thus, taking this perspective into account, an empirical approach to analysis has been chosen for this thesis. Table 2.2 summarises empirical studies on merit-order effect which were referenced to benchmark the thesis methodology.

Table 2.2 : Empirical studies on merit-order effect.

Paper	Model	RES Type	Period	Country
[29]	GARCH	Wind, solar	2009-2012	Germany
[2]	OLS Regression	Wind, solar	2010-2012	Germany
[15]	Multivariate Regression	Wind, solar	2010-2012	Germany, Austria
[33]	Multivariate Regression	Wind, solar	2011-2013	Germany, Austria
[14]	Correlation of Variables	Wind	2008	Germany
[31]	SVAR	Wind, solar	July 2010-March 2013	Germany
[32]	Own model	Wind, solar	2011-2013	Germany
[34]	OLS	Solar, wind, small hydro, biomass, and waste	2005-2010	Spain
[16]	OLS, RLWR, CES	Wind	2007-2010	Spain
[35]	AI based M5P algorithm	Wind	2012	Spain
[36]	AI based M5P algorithm	Biomass, solar-thermal and small hydraulic	2012	Spain
[37]	AI based M5P algorithm	Wind, solar	2012	Spain

Table 2.2 (continued) : Empirical studies on merit-order effect.

Paper	Model	RES Type	Period	Country
[39]	Linear Regression	Wind, solar, biomass, and waste	2008-2013	Spain
[42]	ARMA-GARCH	Wind	January 2012-June 2014	Denmark
[43]	Own model	Wind	2006-2009	Netherlands
[1]	OLS multiple regression	Wind	2009	Ireland
[3]	Multivariate linear regression	Wind, solar	2005-2013	Italy
[45]	OLS regression	Solar	2010-2013	Italy
[46]	Own model	Wind, solar	2010-2015	Czech
[51]	OLS regression	Wind, solar, hydro	Dec 2012-April 2015	US/California
[52]	OLS regression	Rooftop PV	2010-2012	US/ Massachusetts
[53]	Own model	Wind	March 2009–February 2011	Australia
[55]	Least squares regression, quantile regression	Wind, hydro	January 2006-June 2012	Australia

3. TURKISH POWER MARKET

3.1 Market Privatization Process

Before privatization period, the generation in Turkey was mostly provided by state-owned plants. If private sector investment was needed, it was usually made with the help of the state. In 1990s, to meet increasing demand, quick large scale capacity increase was required. Therefore, the state incentivized investors to build large power plants with build-operate (BO) and build-operate-transfer (BOT) contracts. These power purchasing agreements (PPA) granted the plant owners to sell generated electricity at a certain price and for a certain period.

Following global liberalization process, Turkish Electricity Market Law in 2001 aimed an electricity market based on transparency, integrity, and competition; and integrated with other countries. The law was a milestone for liberalization. Following that, Energy Market Regulatory Authority (EMRA) has been founded in the same year. EMRA's foundation has aimed to regulate and control activities in the electricity, natural gas, petroleum, and LPG markets. Primary liabilities of the institution are giving licenses, following-up energy company activities, determining market standards, creating regulation for distribution and customer services, determining national retail tariffs. In 2001, privatization continued with state-owned Turkish Electricity Generation and Transmission Company splitting into 3 companies: Türkiye Elektrik Ticaret ve Taahhüt Anonim Şirketi (TETAŞ), Türkiye Elektrik İletim Anonim Şirketi (TEİAŞ), and Elektrik Üretim Anonim Şirketi (EÜAŞ).

Electricity generation company EÜAŞ owns the state-owned power plants. It is responsible from planning, generation and operation of the plants. EÜAŞ sells its generated electricity to TETAŞ via bilateral agreements. At the end of 2017, EÜAŞ owns 19,908 MWh installed capacity [59].

TETAŞ is the state-owned wholesale power trading company. It purchases electricity from EÜAŞ, power plants with PPA, and lignite plants with capacity agreements. The capacity agreements has been introduced in 2016 for lignite plants, which grants certain generation from these plants purchased from TETAŞ at a certain price. This mechanism helped lignite plants to work with higher capacity factor and compete with imported coal plants. TETAŞ sells the electricity to authorized retail companies which provides electricity with national retail tariffs. TETAŞ needs to balance what it purchases and sells so also makes bid/offer into DAM.

The third state-owned institution is the transmission system operator (TSO) TEİAŞ. TEİAŞ owns all high-voltage transmission lines over the country. It also has some medium voltage lines. TEİAŞ manages transmission and the real-time balancing of the market.

On 1 July 2006, monthly 3 period financial settlement system was introduced in the electricity market. This was the transition from a single buyer and single seller market model to a liberal and competitive model. Next step for transformation was Day-Ahead Planning system which started on 1 December 2009. Moreover, Balancing Power Market was established. This period can be considered as a transition period in which electricity market became stronger and had a more dynamic structure [7].

December 1st, 2011 was another milestone for the Turkish Electricity Market, because currently used DAM system has been established. Establishment of DAM was another milestone for the market and allowed formation of market structure based on competition [7].

Power plants which belong to EÜAŞ and at the end of their Build-Operate-Transfer (BOT) contracts started to be privatized with the Electricity Sector Reform and Privatization Strategy Document in 2004. The first privatization group had 9 plants with 141 MW capacity [60]. For the group, the privatization process started in 2006 and completed in 2008. The privatization of the other plants still goes on.

21 electricity distribution companies belong to Turkish Electiricity Distribution Company (TEDAŞ) have been sold to private companies between 2008 and 2013. The main targets for this privatization were to manage sales portfolios in each region more efficiently, reduce imbalances, enhance customer services, improve distribution network infrastructure, increase invoice collection rate, and reduce electricity theft. Distribution companies’ distribution and trading activities have been separated in 2013 to create a more competitive market.

In 2005, renewables support mechanism has been legislated with Utilization of Renewable Energy Sources for the Purpose of Generating Electrical Energy law. Then, it has been changed with another law named Renewable Energy Sources Support Mechanism (YEKDEM) in 2010. New law has introduced feed-in-tariff (FIT) mechanism, which provides incentives to private sector to invest in renewables capacities. This action has increased private sector share in electricity generation since then.

TEİAŞ owned Piyasa Mali Uzlaştırma Merkezi (PMUM), was conducting the settlement of the Turkish power market until 2015. It was the settlement center but not a market operator as in developed power markets. In 2015, Energy Exchange Istabul (EXIST) has been founded as the market operator. Primary liabilities of the institution are to operate and manage energy markets with an efficient and transparent manner. Other objectives of the EXIST are to increase the number of market participants, products, and market liquidity. In the same year, Intraday market has been established on 1 st of July, 2015. It enabled almost real-time trading and reduced imbalances. As part of EXIST transparency mission, in 2016 EXIST Transpareny Platform has become live with only electricity market data. The platform has given market participants the opportunity to make more robust analysis and take their trading decisions in more confidence.

The retail electricity market has been privatized in 2003 with an end-consumer eligibility limit of 9,000 MWh/year. The limit has decreased gradually over years. At the beginning of 2018, the retail electricity customers' eligibility limit has been reduced to 2 MWh/year which is about an average household consumption in Turkey. The change granted more than 90% of the electricity customers the right to choose their private electricity supplier [61].

3.2 Installed Power and Renewables Development

Turkey as an emerging market, continued its growth in terms of GDP and population over the last two decades. Due to the causality running from GDP to energy consumption, Turkey's economical growth has led to increase in electricity consumption [62]. Gross electricity demand increased from 94.8 TWh in 1996 to 279.3 TWh in 2016 as shown in Figure 3.1. The demand increase has been neccessitated new installed capacity. Privatization and renewables support mechanism accelerated the process, led to significant increase in capacity, mostly comes from private investors.

Consequently, as shown in Figure 3.2, installed capacity has been more than tripled between 2000 and 2017, increased from 27.3 MW to 83.3 MW 2017 [63].

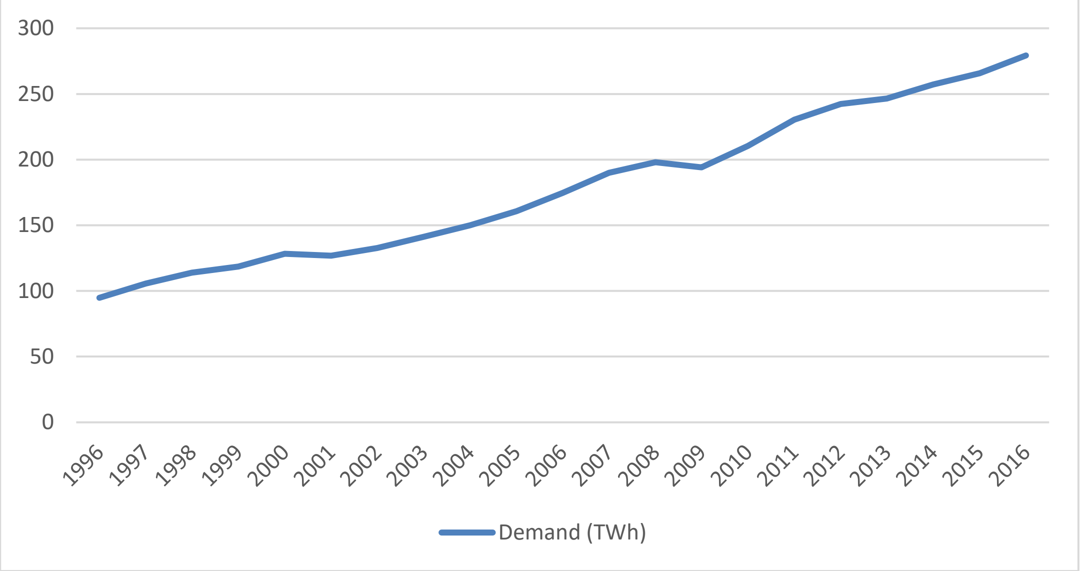

Figure 3.1 : Turkish gross electricity demand development by years [63].

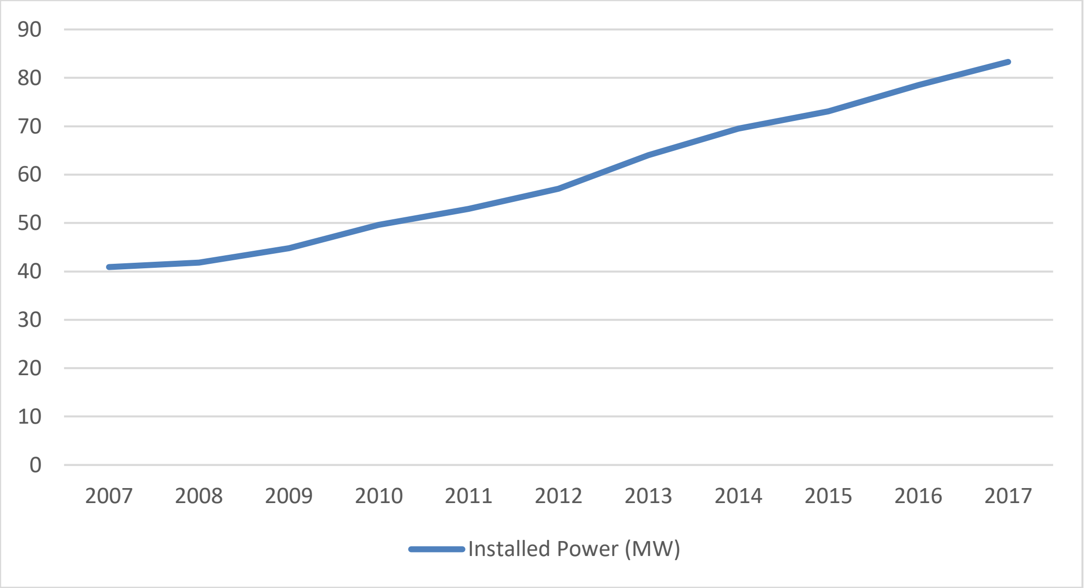

Figure 3.2 : Turkish installed capacity development by years [63].

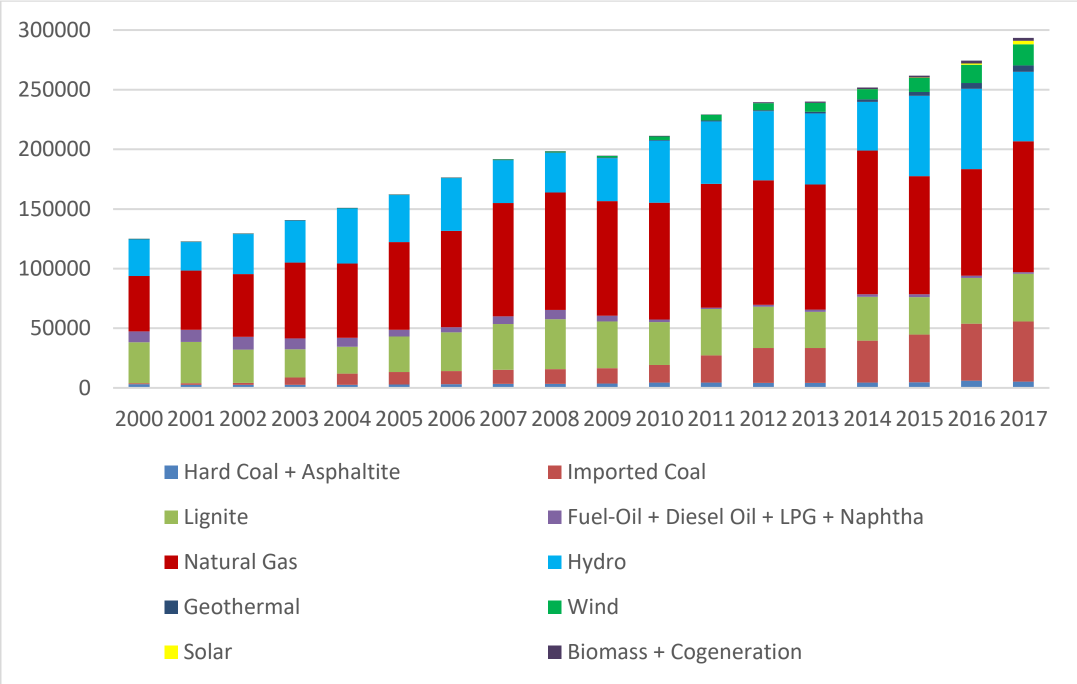

Figure 3.3 : Electricity generation (GWh) by primary sources over years [63].

Between 2000 and 2014, the share of natural gas power plants generation and installed capacity among other sources has increased substantially (Figure 3.3). Natural gas plants were the first choice in these years because relatively low investment costs, CO_2 emissions, and construction time. The natural gas investments were seen feasible by investors because there were enough spark-spread, which is the difference between electricity price sold by the generator and the cost of the natural gas. The spark spread made enough gross margin for sales of natural gas plant generation.

As shown in Figure 3.4, diminishing international coal prices between 2011 and 2016, showed its effects into Turkish electricity market. The generated electricity by imported coal power plantshave been almost tripled during the same period. The capacity incrase has diminished due to the additional tax liability, which has been brought to imported coal plants in August 2016. Because, Turkish government wanted to reduce electricity generation dependency from imported sources. Moreover, international coal prices started to increase in later 2016, therefore imported coal plants generation has become less feasible.

Figure 3.4 : International coal prices by years [64].

The Turkish government has started supporting power generation from domestic sources. One of the priorities is lignite, which is the domestic coal with limited reservoirs. Old lignite plants and their reservoir fields have been privatized aimed to modernize the plants and have more effective usage of the sources. In 2016, the capacity mechanism has been introduced for lignite power plants. Itstates that certain generation from these plants are purchased from TETAŞ at a certain price above market prices. This act helped lignite plants be competitive over imported coal plants and increased their capacity factor.

Turkey has large hydropower resources because of large number of rivers all around Turkey. Hydropower has the strategic importance in terms of available power because it provides capacity security. Therefore, although many hydropower plants were privatized, state-owned EÜAŞ still holds most of the hydropower capacity. EÜAŞ has 12,726 MW capacity, which is 64% of the total hydropower capacity at the end of 2017.

Following global trend and by the aid of renewables support schemes, wind and solar capacity significantly increased between 2014 and 2017. Annual wind generation in 2013 was 7.6 TWh, which more than doubled to be 17.8 TWh in 2017. Solar has been shown a steep increase with almost no generation in 2013 to 2.9 TWh in 2017. 2017 has become a year of record for solar PV capacity because of decreasing investment costs and expected system-usage fee increase. The solar capacity development, helped renewable generation share in total generation to reach 33.2% in 2016, as shown in Figure 3.5. The share decreased a little due to serious drought in 2017.

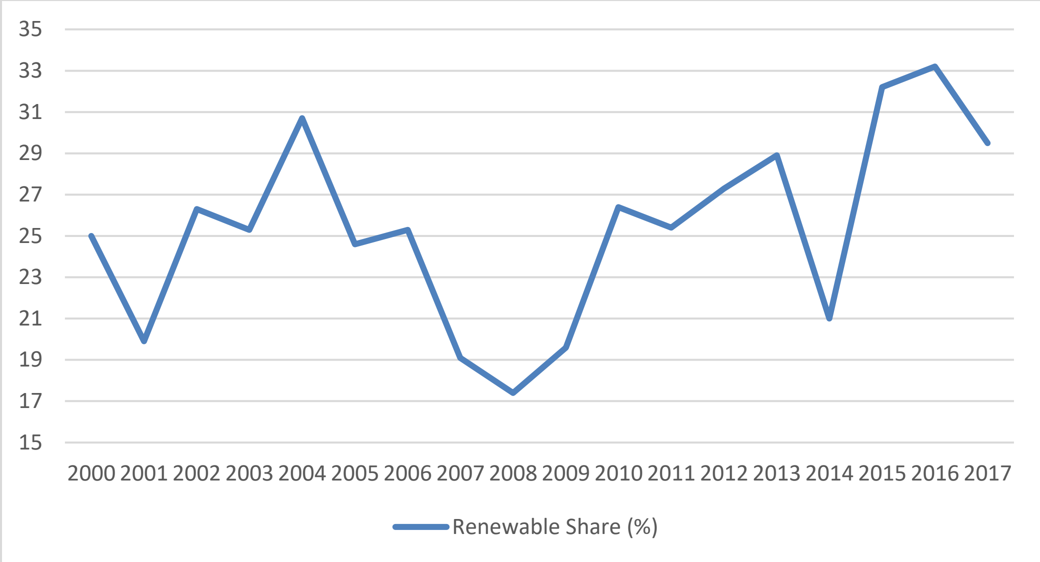

Figure 3.5 : Renewable share in total generation by years [63].

3.3 Turkish Day Ahead Market

Turkish DAM work similar to global day-ahead markets (DAM). Hourly market clearing prices (MCP) are calculated for next day based on offers and bids submitted into the DAM. The DAM information release at the end of 2017 is shown in Figure 3.6. The hourly auction for physical delivery takes place every day until 12:30 and conducted by the market operator EXIST. DAM participants can submit at least 0.1 MW for each DAM product: Hourly, Block and Flexible. The unit price must be the multiplies of 0.01 TL/MWh. Then, market closes, MCP is determined and published at 14:00.

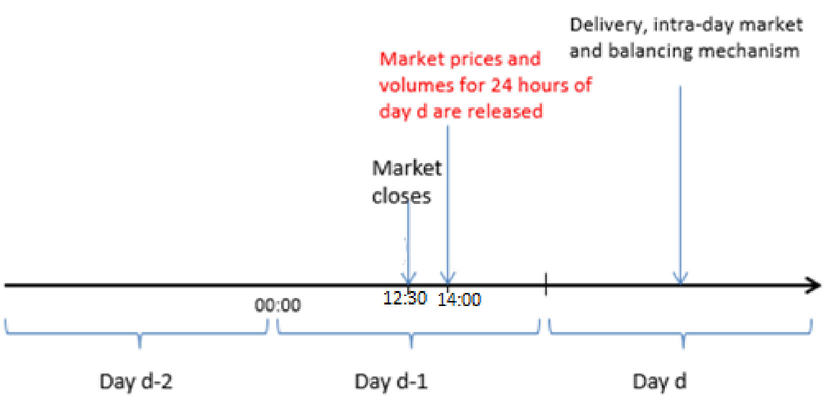

Figure 3.6 : Time framework of market information release [29].

For each DAM participant, receivables and payables are calculated based on hourly matched offers/bids. The settlement is made daily basis. This helps market participants to receive revenues immediately and creates cash flow for new trades. After a calendar month ends, between 15 and 20th days of the following month, imbalances and other fees are calculated in the monthly settlement. Credit risk management is also provided by EXIST for DAM market by collecting guarentees in necessary amounts from participants.

3.4 Turkish Market Merit-Order

As in global merit-order method, Turkish market merit-order is also based on fixed and variables costs. The offers are submitted into DAM according to these costs. Depending on the season and hour of the day, MCP are determined by marginal plants which are imported coal and natural gas. The average costs of these generation types as of November 2017 are shown in Table 3.1 as they placed in Turkish electricity market capacity mechanism in 2018 [65].

Table 3.1 : Marginal plants with their average unit costs in November 2017.

Plant Type	Fixed Cost (TL/MWh)	Variable Cost (TL/MWh)	Total Cost (TL/MWh)
Natural Gas	28,54	146,07	174,61
Imported Coal	70,65	104,35	175,01

Turkish DAM merit-order curve is calculated by EXIST's optimization software. The software aims to minimize total costs and maximize total welfare. The fundamental constraint for the optimization problem is to match cheaper offers first. MCP is not the aim or constraint of the optimization problem, it is only an outcome. Everyday the software is run to give matched amount of bid/offers for each participant and MCP for the next day. There are also other constraints depend on the products available in Turkish electricity DAM. These products are hourly, block, and flexible.

An hourly product is the most simple one. Offer/bids are given only for one hour of the next day. If there were only hourly products, the price would have been formed at the point where demand curve intersects the suppy curve. Second product is the block products which are mainly designed and used for generators. It is used by the plants (i.e thermal and natural gas plants), which don't have the capability of ramp-up or down quickly. Some plants capable of doing it but it increase their variable costs. Therefore, these type of plants usually work in blocks. If a block offer price is below the average MCP of the block, the offer is accepted. Similarly on the demand side, if a block bid price is above the average MCP of block, the bid is accepted. Block bid/offers can also be given in chains, in which the acceptance of a block is dependent of the acceptance of the previous block. The last product available in the market is the flexible offer, which is only available for supply side offers. As in other products, flexible offers include a price and amount. It is applied for a single hour but no specific hour is selected. They are accepted at the hours where MCP is above the offer price.

3.5 Feed-in-Tariff (FIT) Mechanism

3.5.1 FIT regulation

Renewable Energy Resources Support Mechanism (YEKDEM) law has introduced feed-in-tariff (FIT) mechanism in 2010. It aimed the private sector to invest more in RES power plants. Power plants, which built between 2005 and 2020, can apply to FIT mechanism.

Licensed renewable plant owners apply to enter FIT mechanism until end of October every year. Licensed renewables participate in DAM. Therefore, their settlement is done by market operator EXIST. Unlicensed renewable plant owners, which have capacities below and equal to 1 MW, apply to enter the FIT mechanism any time [66]. They do not participate in DAM they sell their electricity to local distribution companies (LDC). Hence, LDCs do the settlement and payments. FIT portfolio plants payable is calculated hourly. The payments are paid in Turkish Lira (TL). USD/TL conversion is made from Turkish Central Bank TCMB's daily USD/TL rate.

The renewable types that can benefit from the FIT are wind, solar, hydro, geothermal, and biofuel. The plants under FIT portfolio can sell their electricity at the prices in Table 3.2 for 10 years. If locally manufactured plant components are used in the construction of the renewable plants, there will be an additional price which is added on top of the regular prices. Depending on the component and plant type, additional price for a local component changes between 4 $/MWh and 35 $/MWh.

Table 3.2 : Unit base prices for electricity generated under FIT mechanism [67].

Plant Type	Price ($/MWh)
Hydro	73
Wind	73
Geothermal	105
Biofuel	133
Solar	133

Licensed renewable plants participate in DAM. They give their generation offers everyday. Based on their matched offers, they submit their conclusive hourly generation plans for the next day. It is difficult to make a precise generation forecast for renewables. Therefore, imbalance calculation is slightly different from traditional plant types. The imbalance of FIT plants are calculated with tolerance coefficients. The coefficients allow a small forecasting error. Currently, the coefficient is the same for every plant type. However, they are planned to be changed and made different for each renewable plant type.

The cost of FIT is its burden on the power market. The system takes electricity from renewable plants at their FIT price. Then, the system sells it at spot prices. The system also gets the imbalance penalty payments of FIT plants. The difference between what the system paid and got paid is the total burden on the market. Each month, burden is divided by retailers' total demand to find unit FIT cost. Hence, the FIT is added to the retailers' cost, proportional to their consumption portfolio.

3.5.2 FIT portfolio evolution

Decreasing market prices and increasing FX rates, made participating to FIT mechanism more profitable. FIT portfolio had 1,227 MW installed power in the beginning of 2014 and became 21,994 MW in the beginning of 2018. Consequently, RES in FIT share in total RES capacity has become 58% in 2018 (Figure 3.7).

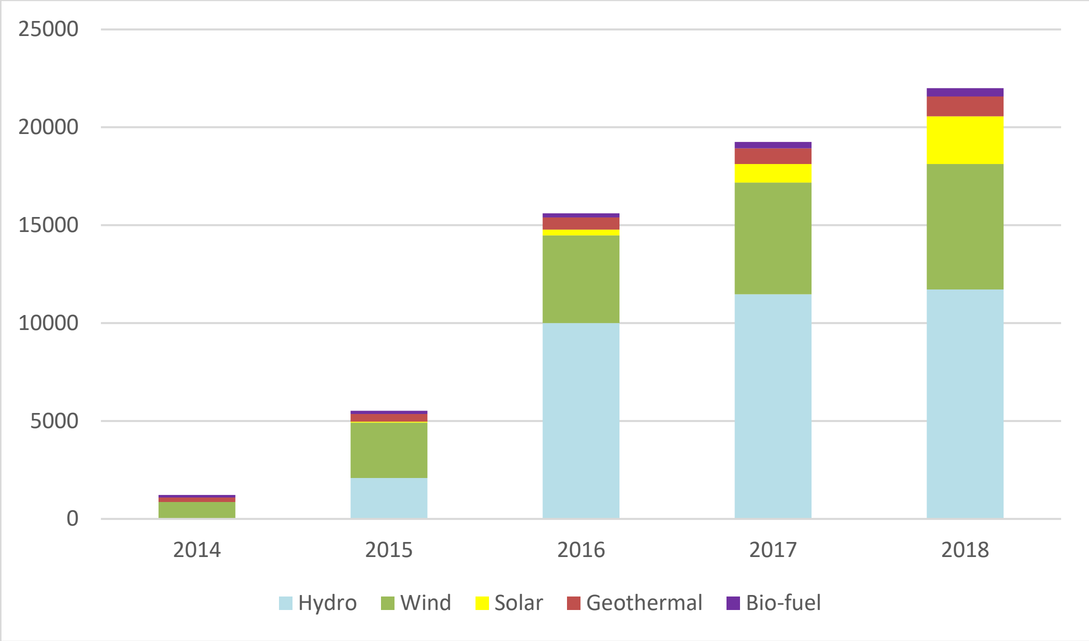

Figure 3.7 : FIT portfolio capacity evaluation over years (MW) [68], [69].

3.6 Government Power Policy and Targets

One of the government power policy is to have electricity generation from domestic sources. To do this, they incentivized lignite plants with capacity mechanism, brought additional tax liability to imported coal plants, and introduced renewable support mechanisms. These efforts worked well in last years. As shown in Figure 3.8, domestic share in primary sources for electricity production increased from 40.1% in 2008 to 49.4% in 2016.

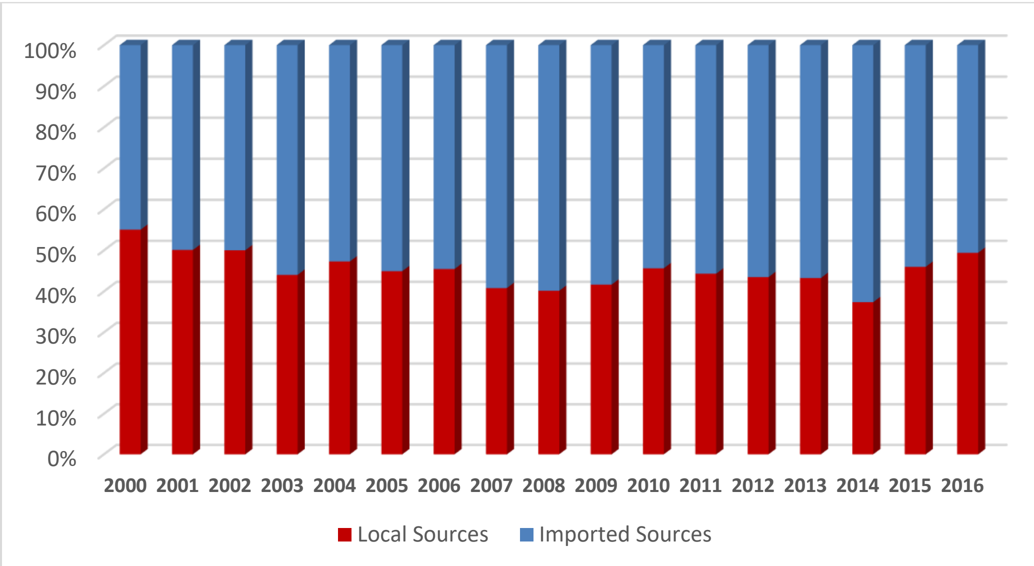

Figure 3.8 : Domestic sources share for electricity production over years [63].

Another policy of the government is to develop and use domestic electricity generation technologies. The government has increased FIT price of renewable plants, which use locally manufactured plant components. Moreover, they had stipulated building domestic factories at renewable auctions. The factories are aimed to produce local wind and solar plant components.

3.6.1 Renewable auctions

The new global trend for RES capacity expansion is auctions. Because, they result more adventageous prices for the states than FITs. Following the trend, Turkish government introduced Renewable Energy Resource Area (YEKA) mechanism in 2016. The first aim of the mechanism is to make investors join large scale renewable energy auctions. The second one is to build solar and wind plant equipment factories, which produce locally manufactured components for renewable projects. Because FIT mechanism application is ending in 2020, auctions become the only option remained for large-scale RES deployment.

The first YEKA auction for solar power was done in March 2017 for 1 GW capacity, the winner price was 69,9 $/MWh. The second one was for 1 GW wind capacity which took place in August 2017, the winner price was 34,8 $/MWh. Both auctions had local manufacturing and R&D requirements. The solar project required building a factory with at least 500 MW annual PV module capacity and an R&D center. For wind project, the factory must produce 150 turbine each year or have 400 MW turbine capacity. Futhermore, 3 zones for offshore wind and 3 zones for solar were determined for future auctions, in March 2018. These zones are Saros, Gelibolu, Kıyıköy for wind and Hatay-Erzin, Niğde-Bor, Şanlıurfa for solar.

3.6.2 Roof-top solar

EMRA published a legislation specifically for application and evaluation of the surplus energy generated by solar plants up to 10 kWh capacity on January 18, 2018. The regulation has been mainly designed for roof-tops and also facades of the building. Before the regulation, roof-top projects were being evaluated under unlicensed solar regulation. The regulation aimed to reduce the procedures for roof-top solar projects and speed up the process. For small solar projects, project approval period, connection agreement, and system usage agreement takes shorter time than the other unlicensed solar projects. One other convenience is that, small projects owners can apply to provincial units of the network operators so the applicants do not have to go to center of LDCs.

The regulation encourages internal use by putting the condition that generation and consumption units are connected from the same meter. And the units should be registered under the same person. By doing this, EMRA tries to prevent commercial usage of this application [70].

4. METHODOLOGY AND MODEL

4.1 Methodology

Some of the renewables impact on power market studies in literature focus on the renewables cost on the consumer side [17]. They mostly focus on how renewables lower the wholesale prices and decrease consumer electricity prices. Some of the works also view the topic from renewable generators point of view [40]. Since Turkish retail electricity market is not completely privatized, there are still national retail tariffs which a customer can benefit if it doesnot prefer to choose a private electricity supplier. The national retail tariff is supposed to be significantly higher than retail costs to encourage eligible customers to choose a private supplier. However, only a small proportion of retail cost increase has been reflected to the tariff. National retail tariff at the end of 2017 is at a level that private suppliers have difficulty to compete with them. Moreover, because the FIT is taken from suppliers but not from the customers in Turkey, the thesis focuses on effects of renewables on retail costs.

Munksgaard *et al.* [40] and Paraschiv *et al.* [22] focus only on MOE. As Sáenz de Miera and colleagues do [25], the thesis also includes FIT cost in the analysis to see the net effect of renewables on the renewable costs. Gonzalo *et al.* [25] claims FIT costs may be compansated by spot-price reduction and results a fall in Spanish retail prices. We have a similar approach in this work but with a claim that increase in the costs of FIT is not offset by decreasing wholesale prices as in Turkey.

A part of literature analyzes effects of the enewables on carbon emission costs [28]. This analysis is not applicable to Turkish market because there is no strict legal mechanism and a market for carbon emissions.

Literature mostly focuses on examining the effects on the costs of single or multiple renewable technologies. If a single technology is analyzed as Nicolosi *et al.* [14] do, the technology is usually wind power because wind is the dominant renewable technology in the most countries especially in Nordic countries. Azofra *et al.* [35], analyzes the wholesale price sensitivity based on wind generation for Spanish market during years from 2005 to 2010. Worthington *et al.* [55] examines wholesale price effect not only for renewables but also other generation technologies (black and brown coal, gas, and hydropower and wind power generators) for 5 electricity zones of Australia. Moreover, Cludius *et al.* [2] and Würzburg *et al.* [15] investigate the impact of wind and solar together. Moreno *et al.* [38] use more renewable technologies in order to quantify burden of RES (PV, wind, small hydro, biomass, wastes) but only examines a half-year period in Spain.

The thesis is more comprehensive than the literature in terms of the renewables included in the scope. All FIT portfolio generation technologies in Turkey are included which are solar, wind, hydro, geothermal and biofuel (biomass, biogas, wastes). As far as we know, in literature, geothermal technology has not been included so far, because they donot have a significant share among renewables or not covered in the support schemes.

The thesis improves the existing literature. One of the reason is that there is no such comprehensive analysis of renewables effect in Turkey. Another reason is that the thesis makes a detailed retailer's margin analysis. Moreover, the thesis adds geothermal technology effects on costs.

Simulation scenarios necessitates a host of assumptions. Hence, the conclusions derived are likely to be tentative. Compared to that, using actual past conditions in models that use regression techniques has the advantage of not depending on hypothetical developments [16]. Similar comments on literature review has led us to work using empirical analysis in this thesis. The thesis is done with an ex-post approach using a multiple linear regression model. The thesis methodology is similar to Mahoney *et al.* [1], Cludius *et al.* [2] and Clò *et al.* [3] studies, but improve them.

In many markets, availability of historical data have enabled using statistical methods for MOE studies. Likely in Turkish case, market operator EXIST's Transparency Platform have been live since 2016 and broadened its database widely in 2017. This improvement has enabled us to get the data required for an ex-post analysis.

One of the methods in previous studies is to use daily resolution for DAM prices. By doing this, Clo *et al.* [3] claim to decrease noise in the data, but this may cause to insufficient results. Because, each renewable technology has a different impact on each hour, i.e solar mostly generates on daytime and wind on the night [29]. Consequently, we create the model with an hourly resolution.

There are also some studies in the literature modeling the net renewables cost effect depending on some variables. For instance, Sven [12] calculates cost sensitivities depending on supply curve of renewables. A similar work is added in the thesis showing renewable cost sensitivities changing with USD/TRY rate.

4.2 Multiple Linear Regression Analysis

Multiple linear regression (MLR) examines the relation of one dependent and multiple independent variables. MLR has the task of fitting a single line into a dataset. Whereas correlation finds the power of relationship between variables, fundamental usage purposes of MLR analysis are causal analysis and forecasting. Moreover, MLR is used to predict trends and future values. Fundamental formula for MLR is shown in equation 4.1.

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_n x_{in} + \varepsilon \tag{4.1}$$

Where y_i represents dependent variable, x_i indepent variables, ε error or residual, and β regression coefficient which measures a unit change in y_i when x_i changes. Since there are many variables, each independent variable is differentiated with a number starting from 1 to number of independent variables or n.

Least-squares model minimizes sum of the squares of the errors to find the line of best fit. The error here is the vertical distance from the line to each data point. After least-squares optimization, β coefficients are found. They are also called least-squares estimates. It is difficult to calculate the coefficients so statistical softwares are used such as SPSS, SAS, R, Stata.

MLR uses some assumptions. If any of these assumptions is violated or data has missing some properties, scientific results may be inefficient. Therefore data validation is critical and below properties should be checked before implementing an MLR model:

- There should be no major outliers or points of excessive influence. Outliers can be identified by creating a scatterplot of the data.

- There should be a linearity. It can be identified by scatterplots of dependent variable against independent variables.
- The variable time series should be stationary. It can be identified using unit-root tests. (i.e Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP)).
- There should be no multicollinearity. That means, one predictor variable should not be linearly predicted from the others. Multicollinearity can be identified by a correlation matrix of variables or variation inflation factor (VIF) test.

To assess the validity and usefulness of the model, at least fundamental performance indicators should be evaluated which are standard error, the coefficient of determination, and significance of coefficients. First, standard error shows the model accuracy [71]. Coefficient of determination or R^2 measures how much of the variation in outcome can be explained by the variation in the independent variables. R^2 can take values between 0 and 1, where 0 indicates that the outcome cannot be predicted by any of the independent variables and 1 indicates that the outcome can be predicted without error [72]. Lastly, significance of the estimated coefficients or t-statistic is used to show whether the independent variable really belongs to the model. p-value, which is derived from t-statistic, is the level of marginal significance representing the probability of the occurrence of a given event. If p-value is more than 0.01, this means that the coefficient is not significant and the model should be revised.

Model observations or residuals should also have some properties. Firstly, MLR model residuals should have a normal distribution. It can be checked using a histogram with a superimposed normal curve [73]. Secondly, residuals should be independent. In other words, they should not have a constant variance. It can be tested using Durbin-Watson or Breusch-Godfrey test.

4.3 Model Data

4.3.1 Assumptions

The assumptions used in thesis are indicated below.

- Electricity demand would not change, if there were no renewables.
- Plants in FIT portfolio gives inelastic offers into the market from the min offer price possible, which is 0 TL/MWh.

- Power generation mix consist of different technologies used for electricity generation. Due to merit-order effect, high-marginal cost plants produce less because of diminished spot prices. Thus, these plants become less feasible. Consequently, investments for high-marginal costs plants fall in the long term. Therefore, generation mix changes to have more low-marginal cost plants. The change in generation mix further changes merit-order effect. Renewables impact on generation mix is neglected in the thesis. Because Turkish FIT portfolio experienced its boom in 2014-2017 period. The time passed since then is too short to see generation mix effect. If the investment plans changed in this period, we will see its impact in the future.
- Network costs and network related congestions are neglected.
- The part of unlicensed renewable generation used for internal consumption is not included in the work because there is no data available for this and the internal consumption amount is relatively small compared to generation.
- Profile cost of retailers depends on the type of customers in the portfolio. This cost is specific to each retailer. Therefore, we assume that profile cost of retailers are same as the profile cost of DAM. The profile cost is calculated by extracting average spot price from weighted average spot price and portfolio consumption for each hour. We use the method by using spot price and DAM load for each hour to find profile cost of DAM.
- Licensed renewable plants under FIT portfolio offer all their generation into DAM. We neglect their participation to Balancing Power Market.

4.3.2 Variables

The four-year period from 2014 to 2017 of the Turkish Electricity Market is examined. Most of the data used belongs to the Energy Market Regulatory Authority (EMRA), electricity market operator Energy Exchange Istanbul (EXIST), and transmission system operator TEIAS. The multiple regression model variables are examined in hourly resolution. The retail costs are examined in monthly resolution since they are invoiced monthly. The dependent variable in the model is spot prices (wholesale price or MCP). The variables are shown in the Table 4.1. The source for these variables is EXIST Transparency Platform [68].

Table 4.1 : MLR model variables with their definitions.

Variable, units	Abbreviation	Description
Spot price, TL/MWh	SpotPrice	Hourly market clearing price (MCP) or wholesale price
Lag spot price, TL/MWh	LagSpot	MCP for the same hour of the previous day
Average lag spot price, TL/MWh	AvgLagSpot	Average MCP of 24 hours of the previous day
Licenced renewables generation, GW	LicRen	Hourly licenced renewables generation in FIT portfolio
DAM Demand, GW	Demand	DAM load for each hour
Block Generation, GW	BlockGen	Hourly Generation which is part of Block Sales in DAM
Net Import, GW	NetIm	Hourly Import-Export for cross border electricity trade
Gas Plants Generation, GW	GasGen	Natural Gas Power Plants Planned Generation in DAM
Imported Coal Plants Generation, GW	CoalGen	Imported Coal Power Plants Planned Generation in DAM
Lignite PPA, GW	LignitePPA	TETAŞ Power Purchasing Agreement Amount for Lignite Plants
Marginal Capacity	MarCap	Hourly MWOffline divided by hourly DAM load (demand). MWOffline is the capacity of gas and imported coal fired plants available for generation, but they are not planned to generate

4.3.3 Removing outliers

First, we define outliers as spot price levels exceeding 237 TL/MWh, which is roughly 2 times standard deviation higher than mean. We define 135 outliers in 35,058 observations. The occurrences of extreme spikes were in winter resulted from abnormal temperature drops and natural gas curtailment. We smooth the data by setting the prices above 237 with the price 237. Figure 4.1 shows, the spot prices before and after smoothing.

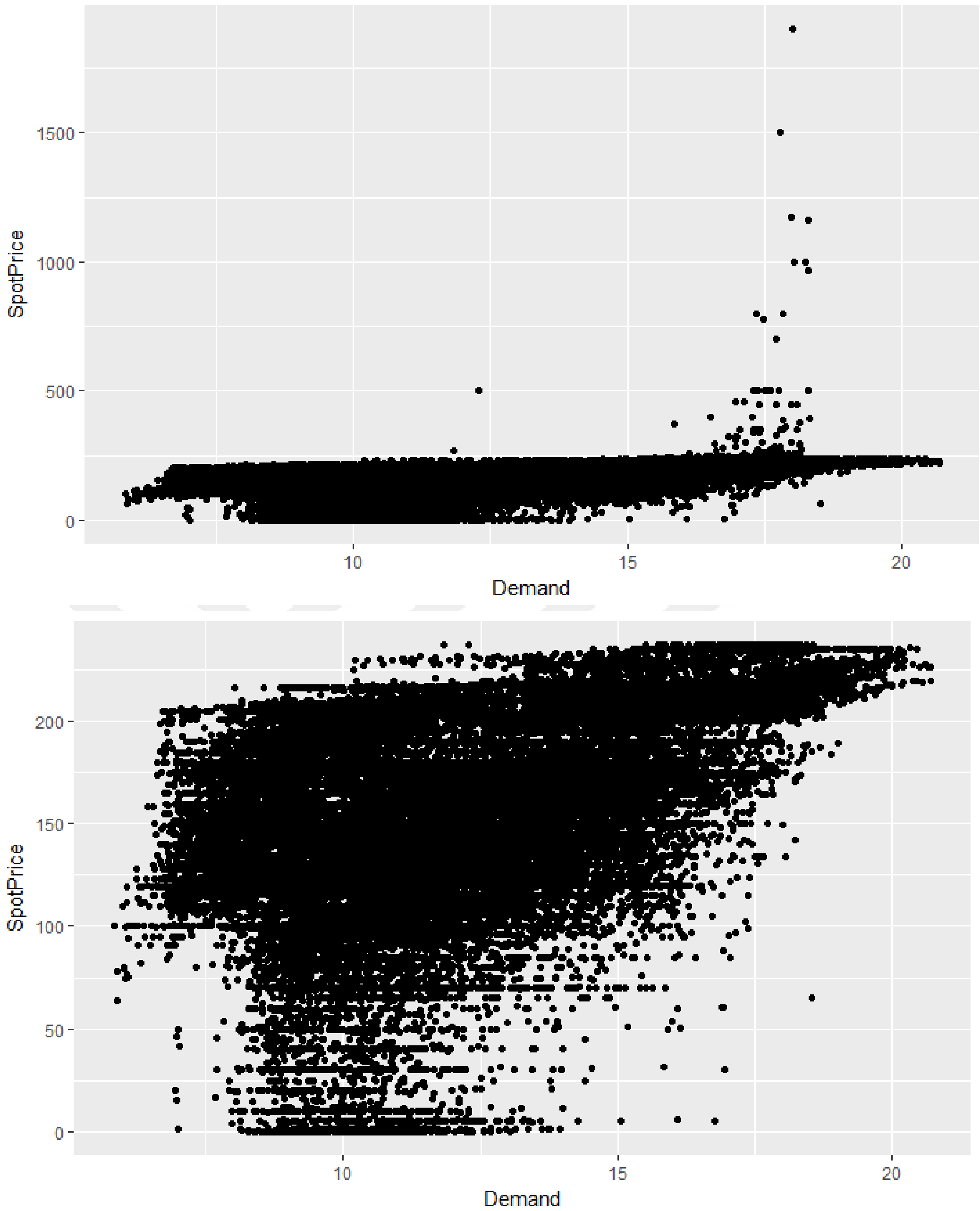

Figure 4.1 : SpotPrice vs. Demand: (a)Before (b)After removing outliers.

4.3.4 Checking data fit for model

To evaluate multicollinearity of multiple regression model varibles, variance inflation factor (VIF) test is applied. Test results are shown in Table 4.2. Because the statistics for all variables are below 10, no multicollinearity problem exists.

Table 4.2 : VIF test statistics.

Variable	VIF statistic
LagSpot	2.887
AvgLagSpot	2.313
LicRen	5.720
NetIm	3.495
GasGen	4.739
CoalGen	2.890
Demand	6.847
BlockGen	5.933
LignitePPA	5.159
MarCap	5.726

If any of the correlation of model variables exceed 0.8, there might be multicollinearity [3]. The correlation matrix in Table 4.3 shows, there is no multicollinearity problem which verifies the result of the VIF test.

The information in Table 4.4 shows that variables distribution is close to normal distribution, because the skewness is between [-1,1], the kurtosis is between [-3,3], and Jarque-Bera p-value is 0.

Augmented Dickey-Fuller (ADF) test is applied to test for unit roots. Akaike Information Criterion (AIC) is chosen for lag selection. To make the results more robust, Phillips-Perron test is also applied. The test results together are shown in Table 4.5 and the critical values for these tests are shown in Table 4.6.

The results show that, before and after including a trend term, variables are stationary at 1% except "AvgLagSpot". "AvgLagSpot" variable is critical at 5% at ADF test with no trend. However, the other test results show this variable is also critical at 1%. Therefore, the null hypothesis is rejected.

Table 4.3 : Correlation matrix of model variables.

	SpotPrice	LagSpot	AvgLagSpot	LicRen	NetIm	GasGen	CoalGen	BlockGen	Demand	LignitePPA	MarCap
SpotPrice	1.000	0.770	0.533	-0.147	0.097	0.613	0.238	0.509	0.441	0.183	-0.751
LagSpot	0.770	1.000	0.642	-0.119	0.105	0.533	0.216	0.456	0.386	0.181	-0.651
AvgLagSpot	0.533	0.642	1.000	-0.236	-0.008	0.457	0.226	0.360	0.143	0.269	-0.427
LicRen	-0.147	-0.119	-0.236	1.000	-0.541	-0.316	0.330	0.190	0.584	0.488	-0.022
NetIm	0.097	0.105	-0.008	-0.541	1.000	-0.026	-0.354	-0.298	-0.326	-0.744	0.062
GasGen	0.613	0.533	0.457	-0.316	-0.026	1.000	0.185	0.657	0.280	0.166	-0.743
CoalGen	0.238	0.216	0.226	0.330	-0.354	0.185	1.000	0.569	0.607	0.605	-0.283
BlockGen	0.509	0.456	0.360	0.190	-0.298	0.657	0.569	1.000	0.733	0.517	-0.742
Demand	0.441	0.386	0.143	0.584	-0.326	0.280	0.607	0.733	1.000	0.511	-0.637
LignitePPA	0.183	0.181	0.269	0.488	-0.744	0.166	0.605	0.517	0.511	1.000	-0.242
MarCap	-0.751	-0.651	-0.427	-0.022	0.062	-0.743	-0.283	-0.742	-0.637	-0.242	1.000

Table 4.4 : Summary statistics for model variables.

	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis	Jarque-Bera statistic	Jarque-Bera p-value
SpotPrice	151.13	150.00	237.00	0.00	47.14	-0.69	0.72	3536.45	0
LagSpot	151.14	150.00	237.00	0.00	47.17	-0.69	0.73	3579.48	0
AvgLagSpot	151.13	152.07	233.13	22.93	30.31	-0.28	0.80	1368.73	0
LicRen	3.30	2.78	12.27	0.01	2.39	0.57	-0.65	2533.01	0
NetIm	0.59	0.73	1.60	-0.71	0.45	-0.71	-0.53	3313.76	0
GasGen	10.86	11.04	17.93	2.65	2.94	-0.13	-0.71	821.41	0
CoalGen	4.32	4.28	7.21	0.94	1.00	0.33	-0.54	1076.52	0
BlockGen	3.66	3.41	10.03	0.00	2.10	0.30	-0.80	1459.88	0
Demand	11.86	11.46	20.69	5.84	2.80	0.45	-0.53	1569.82	0
LignitePPA	0.74	0.00	2.90	0.00	1.07	0.81	-1.16	5846.29	0
MarCap	0.55	0.52	1.60	0.05	0.27	0.43	-0.60	1612.98	0

Table 4.5 : Unit-root test statistics.

Variable	ADF	ADF with trend	Phillips Perron	Phillips Perron with trend
SpotPrice	-14.649	-52.543	-45.993	-46.024
LagSpot	-14.673	-52.589	-46.028	-46.059
AvgLagSpot	-2.232	-11.221	-11.493	-11.517
LicRen	-5.501	-14.057	-7.799	-11.681
NetIm	-11.931	-28.589	-13.634	-22.151
GasGen	-8.127	-31.650	-19.082	-19.099
CoalGen	-3.121	-19.658	-10.448	-15.415
BlockGen	-14.673	-35.663	-21.876	-26.576
Demand	-7.847	-48.638	-22.467	-30.872
LignitePPA	-5.849	-13.171	-3.954	-8.481
MarCap	-20.227	-49.072	-27.943	-28.432

Table 4.6 : Unit-root test critical values.

Level	ADF	ADF with trend	Phillips Perron	Phillips Perron with trend
1%	-2.58	-3.96	-3.434	-3.964
5%	-1.95	-3.41	-2.862	-3.413
10%	-1.62	-3.12	-2.567	-3.128

4.4 Model Implementation

We build the multiple linear regression model as shown in equation 4.2. The dependent variable is spot price. Where β_0 is constant intercept of the equation. Other β_t values are the variable coefficients and ε_t is the error term.

$$\begin{aligned} SpotPrice_t = \beta_0 &+ \beta_1 LagSpot_t + \beta_2 AvgLagSpot_t \\ &+ \beta_3 LicRen_t + \beta_4 Demand_t + \beta_5 BlockGen_t \\ &+ \beta_6 NetIm_t + \beta_7 GasGen_t + \beta_8 CoalGen_t \\ &+ \beta_9 LignitePPA_t + \beta_{10} MarCap_t + \gamma D_t + \varepsilon_t \end{aligned} \tag{4.2}$$

We include lag spot price and average lag spot price in the model. Because of market agents' learning, performance of previous bids/offers submitted into DAM will affect the level of forthcoming bid/offers [14].

Only renewable plants benefitting from FIT is included in the work. Because only these plants contribute to FIT. LicRen parameter is used for licensed renewables which includes wind, hydropower, geothermal, solar and biofuel power plants generation.

However, the licensed solar generation is negligibly small in this parameter, because almost all solar generation is unlicensed. LicRen parameter is given in GW. Thus coefficient β_3 gives the reduction in wholesale price corresponds to 1-GW licensed renewable generation for an hour.

As in other studies, we take DAM load as the “Demand” parameter but not the demand of Turkey [15]. Demand is the main explanatory variable for price formation. Because, merit-order curve intersects where the demand equals to supply. The intersection point has two variables, one is demand and the other is MCP.

We add BlockGen as parameter to see the effect of block orders in the Turkish market. Block orders have a price reducing effect because they are usually offered by the supply side in Turkish DAM. Some gas and coal fired plants, which are not capable of quick stop and rework, run for block hours in which some hours may not cover their variable costs. They work if the average of block hours covers their costs, so offer DAM accordingly. This factor results that if the block amount increases, spot price decreases.

Spot price is also affected by cross-border trades. In Turkey, there are cross-border trade with Georgia, Bulgaria, and Greece so market prices of these countries also have an impact on spot prices in Turkey. If Turkish spot prices increase compared to other countries’, import increase. Because, market participants wants to get cheaper power from other countries and sell at higher prices in Turkey. Hence, net import increase is an indication of high spot prices. We define NetIm parameter for net import in GW to show this effect.

Natural gas and imported coal plants are the highest marginal cost plants in 2014-2017 period. Therefore, if they generate more, spot prices will be higher. These generations are shown with the parameters GasGen and CoalGen.

MWOffline is the capacity of gas and imported coal fired plants available for generation, but they are not planned to generate. To calculate MarCap variable, MWOffline is divided by hourly DAM load. In other words, MarCap shows available capacity. A fall in availability results in an increase of spot price [1].

In 2016, Turkish state-owned wholesale company TETAŞ, made power purchasing agreement (PPA) with lignite-fired plants to increase usage of domestic coal and decrease dependency to imported fuels as part of the government power policy. PPA allows lignite power plants to sell a predetermined capacity at a predetermined price which is higher than spot price average of incentive term. TETAŞ resells the purchased electricity to DAM at a higher price, which increases spot prices. The LignitePPA parameter is special to Turkish electricity market.

We control seasonal effects by introducing dummies which is shown with D_t in the model [2]. 24 dummies indicate hours, 7 dummies indicate days of the week, 12 dummies indicate months, and 4 dummies indicating years. Additionally, 2 dummies are added, which indicates whether the day is holiday or not [15].

We run the equation for our multiple linear regression model in R Studio program to see the results and also make tests for validation of the model using the same program.

5. RESULTS AND DISCUSSION

5.1 Model Results

The statistics for MLR model is shown in Table 5.1 and Table 5.2. Based on the R^2 value, the model explains 74% of the daily spot prices. Moreover, p-value of all model variables are below 0.01 so null hypothesis can be rejected.

Table 5.1 : MLR model inputs with their statistics.

Input	Coefficient	Std. Error	p-value
Constant	98.284	2.333	<0.01
Year_Dummy	-1.446	0.425	<0.01
Month_Dummy	-0.385	0.048	<0.01
Weekday_Dummy	-1.786	0.070	<0.01
Hour_Dummy	-0.127	0.022	<0.01
Holiday_Dummy	-4.322	0.737	<0.01
LagSpot	0.413	0.005	<0.01
AvgLagSpot	0.050	0.006	<0.01
LicRen	-3.197	0.129	<0.01
NetIm	11.289	0.537	<0.01
GasGen	0.835	0.095	<0.01
CoalGen	1.377	0.218	<0.01
Demand	2.957	0.120	<0.01
BlockGen	-4.419	0.150	<0.01
LignitePPA	7.752	0.274	<0.01
MarCap	-75.107	1.153	<0.01

Table 5.2 : Summary statistics of MLR model.

Statistic	Value
Observations	35,058
R^2	0.738
Adjusted R^2	0.738
Residual Std. Error	24.123 (df=35042)
F Statistic	6,590.113 (df=15; 35042) (p<0.01)

Durbin-Watson and Breusch-Godfrey Test is applied to MLR model to test unit-roots. Test results show that null hypothesis can be rejected and therefore heteroscedasticity exists (Table 5.3). There is also positive serial correlation exists in residuals.

Table 5.3 : Durbin-Watson and Breusch-Godfrey test statistics.

Test	Statistics	p-value
Durbin-Watson	0.61724	< 2.2e-16
Breusch-Godfrey	3621.9	< 2.2e-16

As a final test, to check the normal distribution of residuals in MLR model, histogram with normal curve is drawn. It is obvious from Figure 5.1 that, MLR model residuals have a normal distribution.

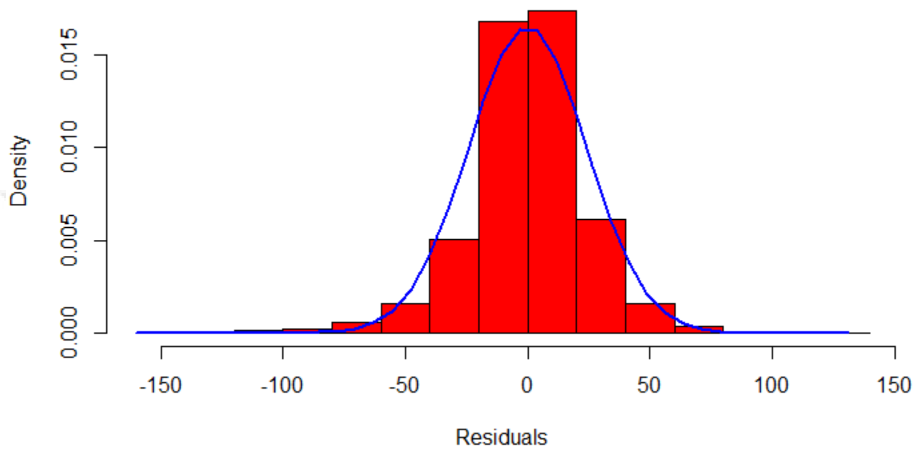

Figure 5.1 : Distribution of model residuals.

5.2 Net Effect of Renewables on Retail Costs

Results of MLR model shows that, 1 GWh in the hourly generation from licensed and unlicensed renewables reduces spot price by 3.2 TL/MWh and 3.0 TL/MWh, respectively. To find licensed renewables effect is straightforward, the corresponding MLR model coefficient is used. Whereas for the unlicensed renewables effect, which is mostly solar generation, coefficient of "Demand" variable is used. Hourly unlicensed renewables generation is sold to authorized retail companies (ARC). This generation compensates some of ARC's demand. If there were no unlicensed generation, ARC's demand, which is supplied by TETAŞ, would have been increased. This would lead TETAŞ to need more power and purchase this amount from DAM. This would increase hourly load in DAM.

Table 5.4 shows that average wholesale price reduction effect of renewables doesn't cover FIT. Therefore, renewables have a net effect of increasing retail costs.

Table 5.4 : Merit-order effect of renewables vs. FIT by years.

Year	Merit-order effect of licensed renewables (TL/MWh)	Merit-order effect of unlicensed renewables (TL/MWh)	Total merit-order effect of FIT portfolio (TL/MWh)	FIT (TL/MWh)
2014	-2.13	-0.01	-2.14	1.43
2015	-6.47	-0.08	-6.54	8.74
2016	-16.27	-0.38	-16.64	24.32
2017	-17.33	-1.04	-18.37	34.45

To see the merit-order effect of renewables on total retail costs, load-weighted averages are used [2]. The load is not DAM load in this case, but the load which the FIT is applied which is published in monthly resolution. Load-weighted average for a year is calculated by multiplying FIT cost and load in each month, summing it for all months and dividing the sum by total load of the year. Table 5.5 shows that renewables increased total retail costs by 5.3 billion TL between 2014 and 2017.

Table 5.5 : Net renewables effect on retail costs by years.

Year	Load-weighted merit-order effect (TL/MWh)	Load-weighted FIT (TL/MWh)	Net renewables effect on costs (TL/MWh)	FIT demand (TWh)	Net renewables effect on costs (MTL)
2014	-2.13	1.42	-0.71	188.47	-134.63
2015	-6.52	8.64	2.12	199.5	423.03
2016	-16.59	24.1	7.51	207.86	1561.61
2017	-18.25	34.04	15.79	218.81	3454.52

5.3 FIT Forecasting Results

In this part, FIT cost calculation mechanism of regulation is modelled and applied to 2017 data. FIT unit cost for 2017 is recalculated and compared with realized FIT unit cost in Table 5.6. The monthly results show that the model estimates the average FIT unit cost in 2017 with 0.8% error. The model verifies the realized and published FIT unit cost.

Table 5.6 : Comparison of 2017 realized and modeled FIT unit cost [68].

Month	Realized FIT (TL/MWh)	Model FIT (TL/MWh)	FIT load (TWh)
1	26.5	26.43	18.5
2	28.88	27.68	17.4
3	43.94	42.88	18.1
4	53.47	52.86	17.1
5	51.68	50.5	17.4
6	39.18	38.54	16.8
7	26.68	27.4	20.0
8	25.34	25.9	20.4
9	19.28	19.88	19.0
10	29.09	29.44	18.0
11	27.57	27.26	17.9
12	41.34	40.62	18.2
Average	34.04	33.77	

One of the main reasons of FIT's dramatical increase in 2017 is USD/TRY exchange rate increase. The effect of this variable on FIT sensitivity for 2017 is shown in Table 5.7. USD/TRY scenarios are created by keeping monthly USD/TRY shape constant.

Table 5.7 : FIT cost FX sensitivity in 2017.

2017 USD/TRY average	Load - weighted FIT average (TL/MWh)
3.28	26.77
3.46	30.27
3.64	33.77
3.83	37.26
4.01	40.76

Moreover, renewables portfolio size and distribution of different production technologies also affects FIT cost because of the different FIT price for each power generation technology. The effect of each generation technology on FIT cost for 2017 is shown in Table 5.8.

Table 5.8 : FIT cost share of each renewable technology in 2017.

Renewables plant type	Average installed power (MW)	Generation (TWh)	Average FIT price ($/MWh)	FIT cost (M$)	FIT cost %
River	5,875	13.5	73.3	989	24%
Reservoir	5,531	10.9	73.0	796	19%
Wind	5,876	16.8	77.3	1,299	31%
Geothermal	805	4.5	107.5	484	11%
Biomass	307	1.8	133.5	240	6%
Unlicensed	1,614	3.0	133.0	399	9%

5.4 Retailers Margin Analysis

In the analysis, the national retail tariff and retail costs are compared for 4 years (2014-2017) period. The monthly retail cost components are wholesale or commodity price, FIT, profile cost, and imbalance cost.

Imbalance cost of retailers depends on portfolio size, type of customers in the portfolio, and forecast performance. Thus, this cost is specific to each retailer. For the thesis, the load-weighted average imbalance cost of ENGIE Turkey Retail Company is used. To find yearly costs, FIT portfolio load-weighted average is taken. The same method is applied to find the yearly national retail electricity tariff active energy price averages.

National retail electricity tariff prices determines an upper limit for retailers' sales prices. The total retail cost and national retail tariff active energy prices for each consumer type (commercial, residential, industrial) are shown in MWh/TL in Table 5.9. The margin between the total cost and national retail tariff active energy prices are calculated. Sales margins decrease in 2016 and 2017. Especially in 2017, national retail tariff prices are not high enough, which results in diminishing retail sales gross margin.

Table 5.9 : Annual sales margin for retailers.

Year	Total retail cost	Comm. tariff	Res. tariff	Ind. tariff	Comm. margin	Res. margin	Ind. margin
2014	170	210	210	177	19%	19%	4%
2015	153	218	208	185	30%	26%	17%
2016	173	219	219	205	21%	21%	16%

2017	204	215	215	205	5%	5%	1%

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Turkish Power Market Contributions

This thesis analyzes renewable energy impacts on spot prices and shows the net burden on retail electricity companies. Because, according to the renewable energy encouraging regulations, retail electricity companies undertake the burden. Thesis also calculates average cost of retailers and compare them with national retail electricity tariff. The conclusion claims that the tariff is not high enough to provide sufficient sales margin for retailers in 2017.

The thesis explains some of the reasons for retailers’ difficult situation in 2017. FIT cost has increased dramatically and current dependency on FX rates makes them unpredictable. Therefore, retailers try to work with limited margins because of high retail costs and low tariff prices. This makes them vulnerable to volatility effect of FX on FIT cost. This effect has made suppliers lose money from their sales and caused some suppliers to get bankruptcy or get their customer out of portfolio to survive. Hence, consumers has started switching from their private suppliers to ARC companies.

Renewables have indirect impacts on consumers. Some consumers were gotten out of private retailer portfolios unexpectedly. Therefore, consumers had to fulfill some procedures such as signing an agreement with ARC in their region. Because some customers had not known these processes, they missed the time to sign the contract and got penalty for illegal usage of electricity. Furthermore, to get rid of losses, some retail companies revised contract prices suddenly and sometimes without notification. Thus, the customers faced higher bills than what they face usually. This diminished the trust of consumers to private retailers.

These consequences wasted some of the efforts for liberalization over the last decade in Turkey. Renewables is not the only cause of this unpleasant situation but an important part of it. This thesis shows consequences of renewables policy and aims to attract attention of the policy makers to point that taking corrective measures are crucial.

6.2 Practical Application of This Study

The thesis have following policy implications. FX dependency of FIT scheme increases the uncertainty in retail costs. Therefore, revision of FIT scheme is crucial. As a second point, national retail electricity tariffs create unpredictability and limit retail costs. Therefore, the tariff should be completely removed and government intervention in the market should be discouraged.

Moreover, because of wholesale reduction effect, renewables cause high-marginal cost power plants to see depressed profits. Hence, some plants may not pay their bank loans and exit the market. Government tries to take precautions for that with capacity mechanism, which subsidizes some part of generation of high-marginal cost plants. However, this creates another burden for the economy and consumers pay the cost. Furthermore, this price intervention creates uncertainty in market prices and can harm some of the market participants. Policy makers should provide more effective solutions with less intervention in the market. Because, to save a group of market participants with intervention may harm another group. In the end, it becomes more difficult to balance the system.

6.3 Further Work

RES does not only affect spot price level but also variance of prices because of espacially the physical nature of solar and wind power. Wind plants produce more at night and solar produce more at daylight. Moreover, solar radiation and wind force vary significantly. Thus, renewables change price volatility and significantly effects trading. Therefore, renewable effect on price volatility has been discussed in many literature studies. It should be also the first topic to be exlored as continue of this thesis.

In each country, power generation mix consist of different technologies used for electricity generation. Due to merit-order effect, high-marginal cost plants produce less because of diminished spot prices. Thus, these plants become less feasible. Consequently, investments for high-marginal costs plants fall in the long term. Therefore, generation mix changes to have more low-marginal cost plants. The change in generation mix further changes merit-order curve. That means, the power market adapts to merit-order effect by changing its generation mix. A limitation of this thesis is to not analyze the renewables impact on power generation mix. In the future, the Turkish market generation mix will also change to adapt merit-order effect. Thus, renewables impact on the Turkish market generation mix should be examined in further studies.

Last but not least, the net effect of renewables on Turkish market is 5.3 billion TL between 2014 and 2017, which is a big burden for the retailers and the economy. Hence, FIT scheme improvement analysis should be made for a more effective scheme. Moreover, global support mechanisms should be explored in detail and presented with their advantages and disadvantages. Additionally, the renewable auctions which is one of the priorities of the government should be monitored closely. If there is some negative consequences, before long time passed, it should be improved.

As a last proposal, as in especially US studies, effect of renewables on Turkish balancing power market can also be analyzed. Because, renewables forecasting is difficult and causes significant imbalances. This effect causes additional costs while providing instaneous system balancing at balancing power market. Wind generation is the most difficult one to predict. Therefore, the Turkish market with its high wind installed capacity will be a good case study.

REFERENCES

[1] **Mahoney, A. O., and Denny, E.** (2009). *The Merit Order Effect of Wind Generation in the Irish Electricity Market*. Retrieved from http://www.usaee.org/usaee2011/submissions/onlineproceedings/usaee washington paper.pdf

[2] **Cludius, J., Hermann, H., Matthes, F. C., and Graichen, V.** (2014). The merit order effect of wind and photovoltaic electricity generation in Germany 2008–2016: Estimation and distributional implications. *Energy Economics*, ***44***, 302–313. doi:10.1016/j.eneco.2014.04.020.

[3] **Clò, S., Cataldi, A., and Zoppoli, P.** (2015). The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices. *Energy Policy*, ***77*** (December), 79–88. doi:10.1016/j.enpol.2014.11.038.

[4] **Sá, J.** (2016). *The Merit Order Effect of Wind Power in Portugal: Quantifying the effect of Wind Energy in the Spot Market prices through Agent-based Simulations* (M.Sc. Thesis). Tecnico Lisboa, Electrical and Computer Engineering Department. Retrieved from https://fenix.tecnico.ulisboa.pt/downloadFile/1407770020544771/msc_thesis_68254_joao_sa.pdf

[5] **Shikoski, J., and Katic, V.** (n.d.). Deregulation of the Power Industry in Europe. Retrieved from http://www.emo.org.tr/ekler/06bf9581a8f1747_ek.pdf

[6] **Celik, C.** (n.d.). Privatization and Deregulation of the Electric Power Sector - Fundamentals. Retrieved from http://www.emo.org.tr/ekler/effc08cc893c51a_ek.pdf

[7] **EXIST**. (n.d.). Day-Ahead Market - Introduction. Retrieved April 1, 2018, from https://www.epias.com.tr/en/day-ahead-market/introduction

[8] **Burger, M., Graeber, B., and Schindlmayr, G.** (2014). *Managing Energy Risk* (2nd ed.). Wiley.

[9] **EXIST**. (n.d.). Intra-Day Market - Introduction. Retrieved April 1, 2018, from https://www.epias.com.tr/en/intra-day-market/introduction/

[10] **REN21**. (2017). *Renewables 2017 - Global Status Report*. Retrieved from http://www.ren21.net/mwg-internal/de5fs23hu73ds/progress?id=lSMd4fgyDYQsPg0yHXhGzYruaHWw96ZI6sij4-Vd6Uk,

[11] **IEA**. (2017). *Renewables 2017 - Analysis and Forecasts to 2022*. Retrieved from https://www.iea.org/Textbase/npsum/renew2017MRSsum.pdf

[12] **Bode, S.** (2006). *On the impact of renewable energy support schemes on power prices* (No. 4–7). Retrieved from

http://www.hwwi.org/publikationen/research-paper/publikationen-einzelansicht/on-the-impact-of-renewable-energy-support-schemes-on-power-prices.html

[13] **Appunn, K.** (2015). *Setting the power price: the merit order effect*. Retrieved from https://www.cleanenergywire.org/factsheets/setting-power-price-merit-order-effect

[14] **Nicolosi, M., and Fürsch, M.** (2009). The Impact of an increasing share of RES-E on the Conventional Power Market — The Example of Germany. *Zeitschrift Für Energiewirtschaft*, ***33*** (3), 246–254. doi:10.1007/s12398-009-0030-0.

[15] **Würzburg, K., Labandeira, X., and Linares, P.** (2013). Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. *Energy Economics*, ***40***, S159–S171. doi:10.1016/j.eneco.2013.09.011.

[16] **Gil, H. A., Gomez-Quiles, C., and Riquelme, J.** (2012). Large-scale wind power integration and wholesale electricity trading benefits: Estimation via an ex post approach. *Energy Policy*, ***41***, 849–859. doi:10.1016/j.enpol.2011.11.067.

[17] **Sensfuß, F., Ragwitz, M., and Genoese, M.** (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy Policy*, ***36*** (8), 3086–3094. doi:10.1016/j.enpol.2008.03.035.

[18] **Weigt, H.** (2009). Germany's wind energy: The potential for fossil capacity replacement and cost saving. *Applied Energy*, ***86*** (10), 1857–1863. doi:10.1016/j.apenergy.2008.11.031.

[19] **Lise, W., Linderhof, V., Kuik, O., Kemfert, C., Östling, R., and Heinzow, T.** (2006). A game theoretic model of the Northwestern European electricity market—market power and the environment. *Energy Policy*, ***34*** (15), 2123–2136. doi:10.1016/j.enpol.2005.03.003.

[20] **Traber, T., and Kemfert, C.** (2011). Gone with the wind? — Electricity market prices and incentives to invest in thermal power plants under increasing wind energy supply. *Energy Economics*, ***33*** (2), 249–256. doi:10.1016/j.eneco.2010.07.002.

[21] **Olsina, F., Röscher, M., Larisson, C., and Garcés, F.** (2007). Short-term optimal wind power generation capacity in liberalized electricity markets. *Energy Policy*, ***35*** (2), 1257–1273. doi:10.1016/j.enpol.2006.03.018.

[22] **Paraschiv, F., Erni, D., and Pietsch, R.** (2014). The impact of renewable energies on EEX day-ahead electricity prices. *Energy Policy*, ***73***, 196–210. doi:10.1016/j.enpol.2014.05.004.

[23] **Ederer, N.** (2015). The market value and impact of offshore wind on the electricity spot market: Evidence from Germany. *Applied Energy*, ***154***, 805–814. doi:10.1016/j.apenergy.2015.05.033.

[24] **Linares, P., Santos, F. J., and Ventosa, M.** (2008). Coordination of carbon reduction and renewable energy support policies. *Climate Policy*, ***8*** (4), 377–394. doi:10.3763/cpol.2007.0361.

[25] **Sáenz de Miera, G., del Río González, P., and Vizcaíno, I.** (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy*, ***36*** (9), 3345–3359. doi:10.1016/j.enpol.2008.04.022.

[26] **Holttinen, H., Vogstad, K.-O., Botterud, A., and Hirvonen, R.** (2001). Effects of large scale wind production on the Nordic electricity market. In *European Wind Energy Conference EWEC'2001* (pp. 1–4). Copenhagen, Denmark. Retrieved from https://www.academia.edu/13162218/Effects_of_large_scale_wind_production_on_the_Nordic_electricity_market?auto=download

[27] **Green, R., and Vasilakos, N.** (2011). The long-term impact of wind power on electricity prices and generating capacity. In *2011 IEEE Power and Energy Society General Meeting* (pp. 1–1). Detroit, MI, USA: IEEE. doi:10.1109/PES.2011.6039218.

[28] **Delarue, E. D., Luickx, P. J., and D'haeseleer, W. D.** (2009). The actual effect of wind power on overall electricity generation costs and CO2 emissions. *Energy Conversion and Management*, ***50*** (6), 1450–1456. doi:10.1016/j.enconman.2009.03.010.

[29] **Pham, T., and Lemoine, K.** (2015). *Impacts of subsidized renewable electricity generation on spot market prices in Germany: Evidence from a Garch model with panel data*. Retrieved from http://www.ceem-dauphine.org/working/en/impacts-of-subsidized-renewable-electricity-generation-on-spot-market-prices-in-germany-evidence-from-a-garch-model-with-panel-d

[30] **Kyritsis, E., Andersson, J., and Serletis, A.** (2017). Electricity prices, large-scale renewable integration, and policy implications. *Energy Policy*, ***101***, 550–560. doi:10.1016/j.enpol.2016.11.014.

[31] **Paschen, M.** (2016). Dynamic analysis of the German day-ahead electricity spot market. *Energy Economics*, ***59***, 118–128. doi:10.1016/j.eneco.2016.07.019.

[32] **Dillig, M., Jung, M., and Karl, J.** (2016). The impact of renewables on electricity prices in Germany – An estimation based on historic spot prices in the years 2011–2013. *Renewable and Sustainable Energy Reviews*, ***57***, 7–15. doi:10.1016/j.rser.2015.12.003.

[33] **Zipp, A.** (2017). The marketability of variable renewable energy in liberalized electricity markets – An empirical analysis. *Renewable Energy*, ***113***, 1111–1121. doi:10.1016/j.renene.2017.06.072.

[34] **Gelabert, L., Labandeira, X., and Linares, P.** (2011). An ex-post analysis of the effect of renewables and cogeneration on Spanish electricity prices. *Energy Economics*, ***33***, 59–65. doi:10.1016/j.eneco.2011.07.027.

[35] **Azofra, D., Jiménez, E., Martínez, E., Blanco, J., and Saenz-Díez, J. C.** (2014). Wind power merit-order and feed-in-tariffs effect: A variability

analysis of the Spanish electricity market. *Energy Conversion and Management*, ***83***, 19–27. doi:10.1016/j.enconman.2014.03.057.

[36] **Azofra, D., Martínez, E., Jiménez, E., Blanco, J., and Saenz-Díez, J. C.** (2014). Comparison of the influence of biomass, solar–thermal and small hydraulic power on the Spanish electricity prices by means of artificial intelligence techniques. *Applied Energy*, ***121***, 28–37. doi:10.1016/j.apenergy.2014.01.064.

[37] **Azofra, D., Martínez, E., Jiménez, E., Blanco, J., Azofra, F., and Saenz-Díez, J. C.** (2015). Comparison of the influence of photovoltaic and wind power on the Spanish electricity prices by means of artificial intelligence techinques. *Renewable and Sustainable Energy Reviews*, ***42***, 532–542. doi:10.1016/j.rser.2014.10.048.

[38] **Moreno, F., and Martínez-Val, J. M.** (2011). Collateral effects of renewable energies deployment in Spain: Impact on thermal power plants performance and management. *Energy Policy*, ***39*** (10), 6561–6574. doi:10.1016/j.enpol.2011.07.061.

[39] **Ballester, C., and Furió, D.** (2015). Effects of renewables on the stylized facts of electricity prices. *Renewable and Sustainable Energy Reviews*, ***52***, 1596–1609. doi:10.1016/j.rser.2015.07.168.

[40] **Munksgaard, J., and Morthorst, P. E.** (2008). Wind power in the Danish liberalised power market—Policy measures, price impact and investor incentives. *Energy Policy*, ***36*** (10), 3940–3947. doi:10.1016/j.enpol.2008.07.024.

[41] **Jónsson, T., Pinson, P., and Madsen, H.** (2010). On the market impact of wind energy forecasts. *Energy Economics*, ***32*** (2), 313–320. doi:10.1016/j.eneco.2009.10.018.

[42] **Li, Y.** (2015). Quantifying the impacts of wind power generation in the day-ahead market : The case of Denmark. In *AFSE 2015 64th Congress* (pp. 1–35). Rennes, France. Retrieved from https://basepub.dauphine.fr/handle/123456789/15247

[43] **Nieuwenhout, F., and Brand, A.** (2011). The impact of wind power on day-ahead electricity prices in the Netherlands. In *2011 8th International Conference on the European Energy Market (EEM)* (pp. 226–230). Zagreb, Croatia: IEEE. doi:10.1109/EEM.2011.5953013.

[44] **O'Flaherty, M., Riordan, N., O'Neill, N., and Ahern, C.** (2014). A Quantitative Analysis of the Impact of Wind Energy Penetration on Electricity Prices in Ireland. *Energy Procedia*, ***58***, 103–110. doi:10.1016/j.egypro.2014.10.415.

[45] **Gullì, F., and Balbo, A. Lo**. (2015). The impact of intermittently renewable energy on Italian wholesale electricity prices: Additional benefits or additional costs? *Energy Policy*, ***83***, 123–137. doi:10.1016/j.enpol.2015.04.001.

[46] **Luňáčková, P., Průša, J., and Janda, K.** (2017). The merit order effect of Czech photovoltaic plants. *Energy Policy*, ***106***, 138–147. doi:10.1016/j.enpol.2017.02.053.

[47] **Nicholson, E., Rogers, J., and Porter, K.** (2010). *Relationship Between Wind Generation and Balancing Energy Market Prices in ERCOT: 2007-2009*. Golden, CO (United States). https://doi.org/10.2172/993654

[48] **Woo, C. K., Horowitz, I., Moore, J., and Pacheco, A.** (2011). The impact of wind generation on the electricity spot-market price level and variance: The Texas experience. *Energy Policy*, ***39*** (7), 3939–3944. doi:10.1016/j.enpol.2011.03.084.

[49] **Zarnikau, J.** (2011). Successful renewable energy development in a competitive electricity market: A Texas case study. *Energy Policy*, ***39*** (7), 3906–3913. doi:10.1016/j.enpol.2010.11.043.

[50] **Baldick, R.** (2012). Wind and Energy Markets: A Case Study of Texas. *IEEE Systems Journal*, ***6*** (1), 27–34. doi:10.1109/JSYST.2011.2162798.

[51] **Woo, C. K., Moore, J., Schneiderman, B., Ho, T., Olson, A., Alagappan, L., … Zarnikau, J.** (2016). Merit-order effects of renewable energy and price divergence in California's day-ahead and real-time electricity markets. *Energy Policy*, ***92***, 299–312. doi:10.1016/j.enpol.2016.02.023.

[52] **Kaufmann, R. K., and Vaid, D.** (2016). Lower electricity prices and greenhouse gas emissions due to rooftop solar: empirical results for Massachusetts. *Energy Policy*, ***93***, 345–352. doi:10.1016/j.enpol.2016.03.006.

[53] **Forrest, S., and MacGill, I.** (2013). Assessing the impact of wind generation on wholesale prices and generator dispatch in the Australian National Electricity Market. *Energy Policy*, ***59***, 120–132. doi:10.1016/j.enpol.2013.02.026.

[54] **Cutler, N. J., Boerema, N. D., MacGill, I. F., and Outhred, H. R.** (2011). High penetration wind generation impacts on spot prices in the Australian national electricity market. *Energy Policy*, ***39*** (10), 5939–5949. doi:10.1016/j.enpol.2011.06.053.

[55] **Worthington, A. C., and Higgs, H.** (2017). The impact of generation mix on Australian wholesale electricity prices. *Energy Sources, Part B: Economics, Planning, and Policy*, ***12*** (3), 223–230. doi:10.1080/15567249.2015.1060548.

[56] **Adom, P. K., Insaidoo, M., Minlah, M. K., and Abdallah, A.-M.** (2017). Does renewable energy concentration increase the variance/uncertainty in electricity prices in Africa? *Renewable Energy*, ***107***, 81–100. doi:10.1016/j.renene.2017.01.048.

[57] **Resch, G., Welisch, M., and Ortner, A.** (2016). Assessment of RES technology market values and the merit-order effect – an econometric multi-country analysis. *Energy & Environment*, ***27*** (1), 105–121. doi:https://doi.org/10.1177/0958305X16638574.

[58] **Denny, E., O'Mahoney, A., and Lannoye, E.** (2017). Modelling the impact of wind generation on electricity market prices in Ireland: An econometric versus unit commitment approach. *Renewable Energy*, ***104***, 109–119. doi:10.1016/j.renene.2016.11.003.

[59] **TEİAŞ**. (2018). TEİAŞ YTBS. Retrieved February 1, 2018, from https://ytbs.teias.gov.tr/

[60] **T.C. Başbakanlık Özelleştirme İdaresi Başkanlığı**. (n.d.). Elektrik Üretim A.Ş.ye Ait Elektrik Üretim Santrallerinin Özelleştirme Çalışmaları. Retrieved April 23, 2018, from http://www.oib.gov.tr/Türkçe/Portfoy/Portfoy_Detay/Elektrik_Üretim_AŞ%60ye_Ait_Elektrik_Üretim_Santralleri/1488900223.html?

[61] **Deloitte**. (2017). Elektrik Piyasalarında Ticaret ve Tedarik. In *ISTRADE 2017*. Istanbul: Deloitte. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/tr/Documents/energy-resources/170525-istrade-sunum-deloitte.pdf

[62] **Lise, W., and Montfort, K. Van**. (2005). Energy Consumption and GDP in Turkey: Is there a Cointegration Relationship? In *International Conference on Policy Modeling*. Istanbul, Turkey. Retrieved from https://www.ecn.nl/docs/library/report/2005/rx05191.pdf

[63] **TEİAŞ**. (2017). Elektrik Enerjisi Üretimi -Tüketimi - Kayıplar. Retrieved April 8, 2018, from https://www.teias.gov.tr/tr/iii-elektrik-enerjisi-uretimi-tuketimi-kayiplar

[64] **ECONOMICS, T.** (n.d.). Coal 2009-2018 Chart. Retrieved April 9, 2018, from https://tradingeconomics.com/commodity/coal

[65] **EPDK 7698-2 sayılı Kapasite Mekanizması Sabit Maliyet Bileşeni, Değişken Maliyet Bileşeni ve Öngörülen Kapasite Kullanım Oranının Belirlenmesi Hakkında Kurul Kararı**. (2018). February 22, 2018.

[66] **Yenilenebilir Enerji Kaynaklarının Belgelendirilmesi ve Desteklenmesine İlişkin Yönetmelik**. (2013). *T. C. Resmi Gazete*, *28782*, October 1, 2013.

[67] **Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına İlişkin Kanunda Değişiklik Yapılmasına Dair Kanun.** (2010). *T. C. Resmi Gazete, 27809*, January 8, 2011.

[68] **EXIST**. (2018). EXIST Transparency Platform. Retrieved February 1, 2018, from https://seffaflik.epias.com.tr/

[69] **EPDK**. (2018). *Elektrik Piyasası Aylık Sektör Raporları*. Retrieved from http://www.epdk.org.tr/TR/Dokumanlar/Elektrik/YayinlarRaporlar/AylikSektor

[70] **Elektrik Piyasasında Tüketim Tesisi ile Aynı Ölçüm Noktasından Bağlı ve Güneş Enerjisine Dayalı Üretim Tesisleri için Lisanssız Üretim Başvurularına ve İhtiyaç Fazlası Enerjinin Değerlendirilmesine İlişkin Usul ve Esaslar**. (2017). *T. C. Resmi Gazete, 30305,* January 18, 2018.

[71] **Duke**. (n.d.). Linear regression models. Retrieved April 11, 2018, from http://people.duke.edu/~rnau/411regou.htm

[72] **Investopedia**. (2018). Multiple Linear Regression - MLR. Retrieved April 14, 2018, from https://www.investopedia.com/terms/m/mlr.asp

[73] **Quick-R**. (2018). Regression Diagnostics. Retrieved April 14, 2018, from https://www.statmethods.net/stats/rdiagnostics.html

CURRICULUM VITAE

Name Surname: Burak Gökçe
Place and Date of Birth: Ereğli/06.05.1990
E-Mail: bkgokce@gmail.com
Address: Agaoglu Maslak 1453, C3/52, Maslak Istanbul / Turkey

EDUCATION:

- **B.Sc:** 2013, Boğaziçi University, Engineering Faculty, Electrical&Electronics Engineering

PROFESSIONAL EXPERIENCE AND REWARDS:

- Between July 2013 – February 2015, worked as Strategic Market Analyst at Turk Telekom Consumer Segment Strategy Department
- Between March 2015 – June 2016, worked as Senior Analyst at Volt Energy Product and Project Management Department
- Between July 2016 – November 2016, worked as Quantitative Analyst at 2M Energy Trade Department
- Between December 2016 – March 2018, worked as Pricing&Reporting Expert at ENGIE Turkey Retail Marketing Department
- Started in April 2018, working as Information Manager at ENGIE Turkey Global Energy Management Department