DEEP DIVE INTO POWER GENERATION TECHNOLOGY COSTS: TURKEY

ELEKTRİK ÜRETİM TEKNOLOJİLERİNİN MALİYETLERİNE DERİN BİR BAKIŞ: TÜRKİYE

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ETHICS

In this thesis study, prepared in accordance with the spelling rules of Institute of Graduate Studies in Science of Hacettepe University.

I declare that

- all the information and documents have been obtained in the base of academic rules
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- all cited studies have been fully referenced
- I did not do any distortion in the data set
- and any part of this thesis has not been presented as another thesis study at this or any other university.

16.06.2015

BURAK ELİBOL

ÖZET

ELEKTRİK ÜRETİM TEKNOLOJİLERİNİN MALİYETLERİNE DERİN BİR BAKIŞ: TÜRKİYE

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Ülkeler ve şirketler enerji politikalarını ve stratejilerinin belirlerken enerji piyasasının farklı sektörleri için farklı analizler gerçekleştirirler. Bu analizlerin başlıca çıktıları Seviyelendirilmiş Enerji Maliyeti (SEM) ve Toplam Gecelik Maliyet (TGM) olarak sıralanabilir. SEM, elektrik üretim sektöründe kullanılan ve farklı teknolojilerin elektrik üretim maliyetlerinin kıyaslanmasını ve elektrik üretim maliyetlerinin projeksiyonunun yapılmasını sağlayan bir yöntemdir. Toplam gecelik maliyet ise tesisin bir gecede kurulduğu varsayıldığında ortaya çıkan maliyetlerdir ve farklı teknolojilerin maliyetlerinin karşılaştırılmasında kullanılmaktadır.

SEM çalışmaları genellikle uluslararası organizasyonlar ve lokal firmalar tarafından gerçekleştirilirler. Temel olarak SEM hesabı maliyetin üretime oranı olarak özetlenebilir. Görece geleneksel bir SEM değeri; yıllık yatırım harcamaları, sabit operasyonel harcamalar, değişken operasyonel harcamalar ve yakıt maliyetlerinin günümüze belirli bir iskonto değeri ile indirgenmiş toplamının yıllık yoplam elektrik üretim miktarına bölünmesiyle hesaplanır. Fakat farklı çalışmalar arasında, CO_2 maliyetleri, çevreye olan maliyeti, insan sağlığına olan maliyeti gibi ek faktörlerin eklendiği de görülmüştür.

Norveçli, bir yenilenebilir enerji firması olan Statkraft ile ortak yürütülen bu çalışmada ise Türkiye'deki kombine çevrim gaz santralleri, kömür ve linyit santralleri, güneş ve rüzgar

enerjisi santralleri incelenmiştir. İki aşama olarak gerçekleştirilen bu incelemede 2015-2035 yılları için SEM ve TGM projeksiyonları yapılmıştır. Yapılan projeksiyonlar üç farklı senaryo altında incelenmiştir. Birinci senaryo baz senaryo olarak alınmış ve hükümet planları ve öngörüleri göz önünde alınarak oluşturulmuştur. İkinci senaryo ise mevcut durumdaki lisans başvuru sayıları baz alınarak oluşturulmuştur. Üçüncü senaryo ise dışsal maliyetleri içeren güneş enerjisi senaryosudur. Türkiye'de lisanslı güneş enerji santralleri katkı payı ihalelerine tabidir. Yapılan ilk ihalelerde katkı paylarının yüksek seviyelerde seyretmesi sonucu maliyetlerin artması sebebiyle ek bir senaryo oluşturulmuştur.

Model tasarımının arka planında ise 2035 yılındaki ekipman,ve iş gücü gibi fiyatlar sabit kalmayacağından dolayı Balassa-Samuelson Etkisi baz alınarak fiyat artışının etkisi eklenmiştir. Yapılan çalışmada kullanılan SEM ve TGM formülleri;

$$\mathrm{SEM} = \sum_{k=1}^{N}[\mathrm{Y_k} + \mathrm{SOM_k} + \mathrm{DOM_k} + \mathrm{YM}]$$

Yk ($/MWh) tesisin yatırım maliyetinin toplam ekonomik ömrüne dağılımının yıllık toplam elektrik üretimine bölünmüş tutarına, SOMk ($/MWh) 2015'e indirgenmiş sabit operasyonel giderlerin yıllık elektrik üretim miktarına bölünmüş tutarına, DOM ($/MWh) PPP/FX ile ölçütlenmiş değişken operasyonel maliyet tutarına, YM ($/MWh) ise 2015-2035 arasında projeksiyonu yapılmış ve santralin verimlilik değerine bölünmesiyle hesaplanmış maliyet tutarına, N ise tesisin ekonomik yaşam ömrüne karşılık gelmektedir.

$\mathrm{TGM} = [\mathrm{TGM_k} * \mathrm{KÖD_{küm}}$ * Küresel PPP Ölçütleme Değeri] + $[\mathrm{TGM_l} * \mathrm{LÖD_{küm}}$ * Lokal PPP Ölçütleme Değeri]

$\mathrm{TOC_k}$, TOC'nin küresel kısmını; $\mathrm{TOC_l}$ ise TOC'nin lokal kısmını kapsar. $\mathrm{KÖD_{küm}}$ öğrenme değerinin küresel kümülatif komponentine, $\mathrm{LÖD_{küm}}$ iselokal komponentine tekabül etmektedir. PPP ölçütleme değeri ise PPP/FX değeri ile hesaplanmaktadır ve bahseidldiği üzere Balassa-Samuelsson etkisindeki fiyat artışını yansıtması amacıyla modele eklenmiştir.

Yapılan analizlerde veri listesi 2014 yılında devreye alınmış veya 2015 yılında devreye alınacak santrallerin teknik ve finansal verileri ile oluşturulmuştur. Veriler, halka açık platformlardan alınmış ve / veya şirket yetkilileri ile yapılan görüşmelerde elde edilen bilgilere dayanmaktadır. Bu kapsamda 9 adet rüzgar enerjisi santrali, 6 adet kömür santrali, 3 adet doğal gaz santrali ve kısıtlı kurulu güç nedeniyle yalnızca 1 adet güneş enerjisi santrali incelenmiştir. Termik santrallerde santral seçimi 100 MW üzeri kurulu güç kapasitesine sahip santraller arasından yapılmıştır.

Değişken ve sabit operasyonel giderler ve yakıt maliyetleri Statkraft analistleri tarafından sağlanmıştır. İskonto değeri olarak ağırlıklı ortalamalı sermaye maliyeti değeri kullanılmış olup bu değerler BNEF tarafından Türkiye'deki elektrik üretim teknolojileri için ayrı ayrı hesaplanan değerler baz almaktadır.

Analizlerin sonucunda 2015 yılında TGM değerleri güneş ve rüzgar enerjisi santralleri için yüksek çıksa da 2035 yılında güneş enerjisi santrallerinin TGM değeri bütün incelenen santral tipleri arasında en düşük değerde görülmektedir. Rüzgar enerjisinin TGM değerindeki düşüş güneş enerjisinin değeri kadar olmasa da linyit santrallerden daha düşük değere sahip olacağı hesaplanmıştır. Termik santrallerin TGM değerleri ise yakıt maliyetlerinin artış göstermesi ve öğrenme değerinin PPP ölçütleme değerinden düşük olması nedeniyle öğrenme etkisinden dolayı gerçekleşen maliyet azalışının yüksek fiyat artışı dolayısıyla etkisini gösterememesi nedeniyle iki faktörden kaynaklanmaktadır.

SEM sonuçlarına bakacak olursak, yakıt maliyetleri nedeniyle termik santrallerin SEM değerleri 2035 yılında 2015'e kıyasla daha yüksek görülmektedir. Yenilenebilir enerji santrallerinin SEM değeri ise bütün santral türlerinin değerleri arasında en düşük olanı olarak hesaplanmıştır. Güneş ve rüzgar enerjisinin SEM değerleri ise neredeyse eşit olarak görülmektedir.

Yapılan çalışmada devreden çıkarma, hurda ve karbon maliyetleri göz önünde bulundurulmamıştır. Devreden çıkartma maliyetleri henüz lokal veri bulunmadığından eklenememiştir. Karbon maliyetleri ise henüz Türkiye enerji/ulaşım piyasasına entegre edilmediğinden dolayı eklenememiştir. Fakat yenilenebilir enerji teknolojilerinin teşvik edilmesi adına karbon vergileri ve karbon ticareti piyasalarının kurulması büyük önem taşımaktadır.

Bu sonuçlara göre 2035 yılında hem TGM hem de SEM bakımından üretim yöntemlerine göre yenilenebilir enerji sistemleri daha kazançlı olacaktır. Fakat Türkiye'nin 2023 ve 2030'u kapsayan resmi planlarındaki seviyelerine ulaşabilmeleri için bir çok engelin aşılması gerekmektedir. Bu engellerin en önemlisi ise 2005 yılında yürürlüğe giren yenilenebilir enerji kanunu sonrasında ortaya çıkan bürokratik süreçlerinin uzunluğu, karmaşıklığı ve birbirleriyle olan bağlayıcı etkileridir. Bu süreçlerin serbestleştirilmesi ve

kısaltılmasıyla hem yatırımcı üzerindeki yük hem de bakanlık ve düzenleyici kurumlar üzerindeki yük azaltılabilecektir.

Anahtar Kelimeler: SEM, Türkiye enerji piyasası, termik santral, güneş enerjisi, rüzgar enerjisi, yatırım maliyeti.

ABSTRACT

DEEP DIVE INTO POWER GENERATION TECHNOLOGY COSTS: TURKEY

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Countries, international organizations and private enterprises determine their policies and strategies in the energy market by conducting different analysis for different sectors of energy market. Levelised cost of electricity (LCOE) is a method that is used in the power generation sector to compare different technologies and calculate generation cost projections for the future.

LCOE studies are commonly conducted and used by international organizations and local private enterprises. Mainly LCOE calculation bases on the same logic; discounting yearly investment expenses, fixed and variable operational expenses and fuel costs by a discount rate and dividing this figure with the annual discounted electricity generation. But several differences can be observed in various studies such as; addition of CO_2 costs, environmental costs and human health costs.

In this study, conducted in co-operation with a Norwegian renewable energy company Statkraft AS, combine cycle gas plants, coal and lignite power plants and solar PV and wind power plants are investigated. Study was conducted under two steps, total overnight cost (TOC) and levelised cost of electricity (LCOE) projections between 2015 and 2035. Conducting the analyses two different scenarios were considered; a base scenario formulated over state plans and projections and a current policies scenario formulated over the information on license applications.

Data list which is used in the conducted analyses consists technical and financial properties from power plants taken into commission in 2014 or will be taken into commission in 2015. Variable and fixed OPEX figures and fuel costs are provided by Statkraft analysts. Weighted average cost of capital (WACC) which was used as the discount rate is taken from BNEF figures.

Regarding to the analyses conducted, regardless of the high TOC values of solar PV and wind power technologies in 2015, TOC of solar PV gradually decreases which makes it the technology with the lowest TOC figure in 2035. In the case of wind power, TOC does not decrease as much as it is observed in solar PV but TOC of wind power in 2035 is lower than lignite fired power plants'.

According to the LCOE results, thermal power technologies' have increasing and higher LCOE through 2035 compared to renewable energy technologies regarding to the increasing fuel costs overtime. LCOE values of renewable technologies are the lowest in 2035 among all technologies.

In conclusion, according to the TOC and LCOE results of renewable energy systems, official targets and plans of Turkish State for 2023 and 2030 are considerable. However there are certain challenges. The most important challenge is the bureaucratic complexity in the applications of renewable energy systems which has been in the agenda since renewable energy law was introduced first in 2005. In order to achieve those plans and targets these complexities must be eased for investors, ministry and regulatory authority.

Keywords: LCOE, Turkish energy market, coal-fired, gas-fired, solar PV, wind power, overnight cost.

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ABBREVIATIONS

Abbreviations

BNEF	Bloomberg New Energy Finance
CASES	Cost Assessment of Sustainable Energy Systems
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture System
CFB	Circulating Fluidized Bed
CHP	Combined Heat Power
CSP	Concentrated Solar Power
DCF	Discount Cash Flow
EIA	Energy Information Administration
EMRA	Energy Market Regulatory Authority
EPIA	European Photovoltaic Industry Association
EUSUSTEL	European Sustainable Electricity
EWEA	European Wind Energy Association
FX	Forex
GDP	Gross Domestic Product
HPP	Hydropower Plant
IDC	Interest During Construction
IGCC	Integrated Gasification Combined Cycle
IRENA	International Renewable Energy Agency
LCOE	Levelised Cost of Electricity
NREL	National Renewable Energy Laboratory
NT	Non-tradables
OCC	Overnight Construction Cost
OECD	Organisation For Economic Co-Operation And Development
O&M	Operation and Maintenance
OPEX	Operational Expense
PC	Pulverized Coal
PPP	Purchasing Power Parity
PV	Photovoltaic
R&D	Research and Development

RER	Real Exchange Rate
SPP	Solar PV Power Plant
TOC	Total Overnight Cost
VGB	VGB PowerTech Co.
WACC	Weighted Average Cost of Capital
WEC	World Energy Council
WPP	Wind Power Plant

1. INTRODUCTION

Levelised cost of energy (LCOE) is an indicator of power generation costs which enables comparing different technologies such as wind power, solar PV, gas-fired power and coal-fired power among each other. Mainly LCOE is used as a tool for policy makers in order to observe the future projections of each technology. Thus they can relate their policy assumptions in regard to LCOE projections. However, LCOE is not only a handy tool for policy making but also an important tool for investors in search for creating strategic plans in which way to shift their portfolio compared to long-term wholesale price forecasts. Basically, LCOE is calculated by the ratio of accumulated discounted costs occur while constructing and operating to the sum of annual discounted power generation. Unit of LCOE is defined as $/MWh.

Despite the wide usage of LCOE, there are certain shortcomings of the methodology. First of all, LCOE does not consider all annual cash flows at different stages. Secondly, LCOE alone is not enough for investors to make decisions. Additional factors such as; Net Present Value, Internal Rate of Return should also be considered. Finally, LCOE calculations rely on the quality of data source. Fuel costs, overnight costs, and even discount factors should be based on solid assumptions for reliable LCOE results [1].

This thesis study covering the deep-dive in power generation technology costs is conducted for emerging market countries such as; Brazil, India, Peru, Chile, China and Turkey. This report covers the analysis of Turkish market. Turkey, with fast growing economy and energy consumption, stands out among the emerging economies. Several global energy players seek out potential investments in the energy sector. At this point LCOE stands out as a useful tool for future market analysis of electricity generation industry. This LCOE study was carried out in co-operation with Statkraft AS, a leading renewable energy company based in Norway. Currently Statkraft AS has two hydro power plants (HPP) commissioned in Turkey (total of 122 MW) and one hydro power plants (517 MW) under construction. Resulting figures are confidential and might be used for corporate strategy formulation.

1.1.Relationship between Energy Consumption and Economic Growth

Throughout the last three decades there have been numerous studies on the relationship between energy consumption and economic growth. These studies support that there is a strong correlation between energy consumption and economic growth, yet this correlation does not necessarily relate that it is a causal relationship. Causality here is defined with four different approaches, namely growth hypothesis, conservation hypothesis, feedback hypothesis and neutrality hypothesis [2].

Growth hypothesis suggests that, causality is from energy consumption to GDP growth and it is uni-directional. This implies that any conservation in energy consumption would result in economic slowdown [3]. On the other hand, conservation hypothesis suggests that causality is from GDP growth to energy consumption and it is also uni-directional, which implies that energy conservation wouldn’t affect the economic growth [4]. While feedback hypothesis suggests that causality is bi-directional between economic growth and energy consumption, neutrality hypothesis suggests that there is no causality between two factors [5][6]. There are a few studies resulted in favor of neutrality hypothesis [7][8]. On the other hand Mehrara clearly states that causality is directly related to the growth conditions and economic situation a country is faced with [9]. Thus, we can conclude that the developing economies will not show the effects of neutrality hypothesis. We can relate this expectation to two motives; first, in the developing economies it is easier for consumers to borrow money to buy houses, vehicles, home appliances such as air conditioning and refrigerators. These goods generally consume more energy which directly affects the whole energy demand country wise. Secondly, it is also easier for businesses to reach financial capital to expand business, buying machinery, hiring more labour which increases the energy demand of the business as well. Thus in the developing economies, such as Turkey, China, Brazil, India, Peru and Chile; neutrality hypothesis is not expected be seen.

There are several studies conducted on Turkey in order to determine the causality. G. Erdal et al. [10] and I. Ozturk et al. [11] concluded that there is a bi-directional causality between economic growth and energy consumption with a strong positive correlation between these two factors. Soytaş and Sarı [12] concluded that causality is under growth hypothesis while Lise and Montfort [13] suggests that causality is under conservation hypothesis. However, contradicting with the suggestions presented above, Altınay and Karagöl [14], Jobert and Karanfil [15] suggests that neutrality hypothesis is applicable. But, those two studies disregarded the structural breakings in the Turkish economy for the studied periods which resulted in no causality. Also differences in results are caused by the periods each study covers.

1.2.Turkish Electricity Market

Turkey has a fast growing, dynamic electricity sector that gained massive acceleration by the liberalization started in 2001. Increase in the installed capacity was 150% from 28 GW in 2001 to 70 GW's in 2015. As mentioned in the previous section, economic growth and increase in consumption is parallel in Turkey, while the average growth of economy was around 5,2% between 2002-2012 increase in electricity consumption averaged at 6,4% [16].

Currently installed capacity is at 70.913 MW and breakdown of each generation technology can be listed as; 34.1% hydropower 30.7% gas-fired power plants, 21% coal and lignite fired power plants, 5.3% is wind power plants, 0.6% is geothermal power plants, 0.1% is the solar PV power plants whereas remaining 8.2% is thermal power plants fueled with fuel oil and asphaltites [17]. However, breakdown of electricity generation is considerably different than installed capacity in which share of gas-fired power plants increase to 48.1%. It can be concluded that Turkey is substantially dependent on natural gas while the country can only produce 2% of total natural gas consumed. Therefore current policies are based on reducing the dependency on natural gas by increasing the share of domestic lignite usage and integration of renewable energy systems.

According to the official numbers, by the year 2023, installed capacities for wind power, solar PV, coal, and nuclear will be 20 GW, 3 GW, 30 GW, and 4.8 GW, respectively and the total installed capacity is expected to rise 120 GW from 70 GW in 2015 [18]. With the associated capacity increase, total share of natural gas in electricity generation is expected to decrease from 48% in 2015 to 30% in 2023 [19].

From the consumption point of view, total consumption is expected to double by the year 2023. According to state plans, consumption is expected to be between 450-500 billion kWh increasing from 250 billion kWh in 2014 [19].

Despite the official targets, it is crucial to make an economic analysis of those potential investments in order to determine how to incentivize each power generation technology. At this point, LCOE analysis should be carried out.

1.3.Reviewed Studies

As mentioned in the first section, LCOE is mainly used for policy making for governments and institutions; and investment planning for private enterprises. Thus, LCOE studies are not covered by the academics but by the international organizations such like; OECD [20], EIA [21], IRENA [22], CASES [23], WEC [24], BNEF [19], Fraunhofer ISE [25], EWEA [26], NREL [27], VGB [28], EPIA [29] and EUSUSTEL [30]. LCOE studies conducted by private enterprises are not published publicly regarding to the confidentiality of competitive concerns. Therefore proceeding literature review includes only a portion of existing studies which are conducted by academics and international organizations.

Throughout the thesis, literature review is mentioned in section 2, method and materials are explained in section 3, results of LCOE model are presented in section 4 and discussion is carried out in section 5.

2. LITERATURE REVIEW

Literature review of this thesis consists of 12 studies conducted by different international and national organizations. While some of these studies provide global LCOE results, some of them provide local results such as BNEF study, which only covers the technologies in Turkish electricity mix, Fraunhofer ISE covers German LCOE values, EIA and NREL covers U.S. LCOE values, WEC covers several different countries' LCOE results, EUSUSTEL covers only European LCOE values. Throughout the literature review, there were 11 factors focused on; technologies covered, input data source, Weighted Average Cost of Capital (WACC), Total Overnight Cost (TOC), Operational Expense (OPEX), Fuel Costs, Construction Time, Economic Lifetime, Capacity Factors, Efficiency and Model Type. Proceeding section will provide an insight for these subjects.

2.1.Technologies Covered

Most of the studies investigated CCGT, coal-fired power plants, Wind Power Plants (WPP) and Solar Power Plants (SPP). Since CCGT and coal-fired power plants are the most mature and widely available technologies and WPP and SPP's are the most promising renewable energy technologies (in contrast to fossil fuel technologies) they are most commonly covered technologies in the reviewed studies. Combined Heat and Power (CHP), wave and tidal technologies are the least covered ones, while CHP is covered by only 2 studies and ocean technologies are covered by the World Energy Council (WEC) study only. Table 1 provides the information on the technology coverage.

Table 1. Technologies covered in the reviewed literature

	Technologies Covered												
Reporting Institution	**CCGT**	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Wind/Onshore**	**Wind/Offshore**	**Solar PV**	**CSP**	**Biomass**	**Geothermal**	**Hydro**	**Wave &Tidal**
OECD/IEA	x		x		x	x		x					
EIA	x		x		x	x	x	x	x	x	x	x	
IRENA						x	x	x	x	x	x	x	
CASES	x		x	x	x	x		x	x			x	
EPIA								x					
WEC	x		x		x	x	x	x	x	x	x	x	x
Fraunhofer ISE	x	x	x			x	x	x	x	x			
EWEA	x		x		x	x	x						
NREL	x		x		x	x	x	x	x	x	x	x	
VGB	x	x	x		x	x	x	x	x	x		x	
EUSUSTEL	x	x	x	x	x	x	x	x		x		x	
BNEF	x	x	x		x	x		x		x	x	x	

2.2.Input Data

Input data sources differ for each study. VGB and CASES does not provide any information on the input data source, EIA and Fraunhofer ISE studies rely on the data collected from U.S. and German power plants respectively. Power plant data can be found in OECD, NREL and EUSUSTEL studies while remaining studies does not provide any information about the power plants but only provide the sources.

2.3.Weighted Average Cost of Capital (WACC)

In order to calculate the LCOE one should discount the future cash flows to today's rates. Therefore discount rate is substantially important for discounting the future cash flows. WACC is the most commonly used method for discount rate calculations. Thus 10 out of 12 studies specifically cover the assumptions on WACC (Table 2).

While Fraunhofer ISE assumes different WACC for different technologies, remaining studies assume constant WACC rates for each technology ranging from 5% to 10%. However, assuming same WACC rate for each technology is not an adequate way regarding to the expectations of higher return on investment figures for large power plants such as CCGT, Coal-fired and Nuclear power plants.

Table 2. WACC assumptions from reviewed literature

Reporting Institution	WACC Estimations
OECD/IEA	5%-10%
EIA	6,50%
IRENA	7,5% for OECD & China - 10% for RoW
CASES	5%
EPIA	5%
Fraunhofer ISE	2.8%-6,9% (Solar PV - Coal)
EWEA	5,61%
NREL	7%
VGB	10%
EUSUSTEL	5%-10%

2.4.Total Overnight Cost (TOC)

CASES, EIA and NREL studies do not provide any information about TOC. Despite, EIA providing the discounted TOC values for LCOE calculation, it is not suitable for TOC comparison with other studies. Figure 1 provides the maximum, minimum and median values of TOC figures collected from remaining studies. According to the figure, wave and tidal technologies have the highest median at $9,03 M/MW where CCGT has the lowest at $0,90 M/MW.

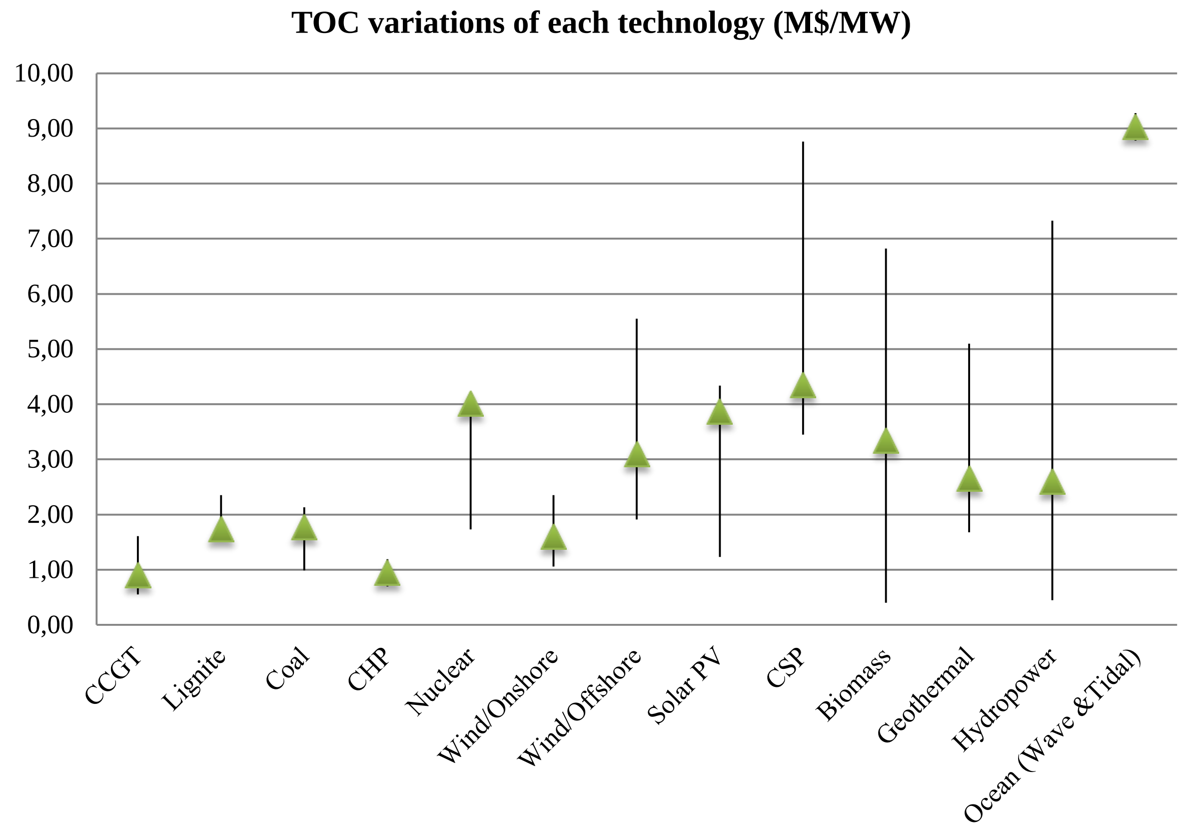

Figure 1. TOC variations from the reviewed literature

2.5.OPEX

Despite the importance of variable OPEX and fixed OPEX in LCOE calculations, only limited number of studies provided the OPEX values. Fixed OPEX ($/MW) values are the expenses that are constant over time and includes wages, regular O&M, securities, taxes etc. and variable OPEX ($/MWh/yr) varies with the generated electricity annually and includes maintenance, contracted personnel, consumed material (non-fuel) and cost for disposal of normal operational waste table 3 and table 4 provides the available OPEX values from investigated studies.

Table 3. Fixed OPEX values from reviewed literature

	Fixed OPEX (k$/MW)											
Reporting Institution	**CCGT**	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Wind Onsh.**	**Wind Offsh.**	**Solar PV**	**CSP**	**Biomass**	**Geoth.**	**Hydro**
OECD/IEA	4,48	-	6,02	-	14,74	21,92	-	29,95	-	-	-	-
EIA	1,70	-	4,20	-	11,80	13,00	22,80	11,40	42,10	14,50	12,20	72,00
EUSUSTEL	25,33	50,67	45,33	36,67	51,47	100,00	80,00	125,33		44,00	-	73,33

Table 4. Variable OPEX values from reviewed literature

	Variable OPEX ($/MWh)											
Reporting Institution	**CCGT**	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Wind Onsh.**	**Wind Offsh.**	**Solar PV**	**CSP**	**Biomass**	**Geoth.**	**Hydro**
EUSUSTEL	1,5	1	2,6	1,53	1	0	0	0	0	-	0	0
EIA	49,1	-	30,3	-	11,8	0	0	0	0	39,5	0	0

Since EUSUSTEL covers European data and EIA covers U.S. data, we can directly observe the differences. However, table 3 suggests that fixed OPEX values for European study are significantly higher. We can conclude that average wages can differ from EU to U.S. Comparing the OECD and EIA Fixed OPEX values, we can observe that they are parallel to each other which makes them more reliable.

From the variable OPEX point of view; we can conclude that values for U.S. are considerably higher than in EU. However, fuel costs are included to variable OPEX of EIA study. Thus difference occurs.

On the other hand, VGB and EWEA study compiled all O&M costs, both fixed and variable, under one OPEX group where it is defined as $/MWh/yr (Table 5)

Table 5. Overall OPEX figures from VGB study

Reporting Institution	**CCGT**	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Wind Onsh.**	**Wind Offsh.**	**Solar PV**	**CSP**	**Biomass**	**Geoth.**	**Hydro**
VGB	5,7	6,7	6,4	-	12,9	29,3-34,3	38,2-55,7	28,7-32,9	41,2-47,2	18,3	-	4,9
EWEA	3,0	-	3,0	-	26,6	19,3	25,3	-	-	-	-	-

2.6.Fuel Costs

Despite the zero fuel costs of renewable energy technologies, they are significantly important for CCGT, coal and lignite-fired, biomass and nuclear technologies' LCOE calculations. Most of the studies investigated do not provide any information on the fuel costs although stating the sources. EIA study integrated the fuel costs to the variable OPEX, which directly increases the variable OPEX rate compared to other studies. Available information on the fuel costs can be found in the Table 6.

Table 6. Fuel costs from the reviewed literature

	Fuel Costs ($/MWh)				
Reporting Institution	**CCGT**	**Coal**	**Lignite**	**Biomass**	**Nuclear**
OECD/IEA	61,12	18,11	-	-	9,33
Fraunhofer ISE	36,79	14,62	2,05	38,46	-
VGB	61,50	29,00	11,00	88,40	13,90
EWEA	32,80	112,40	-	-	6,66

2.7.Construction Time & Economic Lifetime

Importance of the construction time arises while calculating the IDC component of the cost structure. As the construction time increases, share of IDC increases in the total CAPEX, decreasing the TOC share. However, only limited number of studies provides information about the construction time, which can be seen in Table 7**.**

Table 7. Construction times of each technology form the reviewed literature

	Construction Time (years)										
Reporting Institution	**CCGT**	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Wind Onsh.**	**Wind Offsh.**	**Solar PV**	**CSP**	**Biomass**	**Geoth.**	**Hydro**
OECD/IEA	2	4	4	-	7	1	-	1	-	1	1	-
EUSUSTEL	2	4	4	2	5	0,5	1	0,3	-	2	-	1

On the other hand, the duration of economic life time is important while discounting the figures to today’s rates. As the economic lifetime increases, LCOE drops down and vice versa. According to the Table 8, HPPs have the highest economic lifetime while commonly renewable energy power plants have the lowest varying between 20-30 years.

Table 8. Economic lifetime of each technology from the reviewed literature

	Economic Lifetime (years)												
Reporting Institution	**CCGT**	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Wind Onsh.**	**Wind Offsh.**	**Solar PV**	**CSP**	**Biomass**	**Geoth.**	**Hydro**	**Wave &Tidal**
OECD/IEA	30	-	40	-	60	25	-	25	-	-	-	80	20
EIA	30	-	30	-	30	30	30	30	30	30	30	30	-
IRENA	-	-	-	-	-	25	25	25	25	20	25	30	-
EWEA	30	-	30	-	40	-	-	-	-	-	-	-	-
CASES	35	35	35	35	40	20	20	25	30	-	-	70	-
EPIA	-	-	-	-	-	-	-	25	-	-	-	-	-
Fraunhofer ISE	30	40	40	-	-	20	20	25	25	20	-	-	-
NREL	30	-	60	-	60	20	20	30	30	45	20	-	-
VGB	25	35	35	-	40	25	25	25	30	30	-	50-60	-
EUSUSTEL	25	35	30	30	40	20	20	25	-	30	-	70	-

2.8.Capacity Factor & Efficiency

Capacity factors define the operating rate of power plants which is calculated by dividing the operating hours to 8.760 (total number of hours in a year). According to the Table 9 NPPs have the highest capacity factor whereas SPPs have the lowest capacity factor regarding to the irradiation times globally.

From the technology efficiency point of view, rates listed in Table 10 are the net efficiency values in terms of heat value. Therefore renewable energy systems with no fuel are not included into the comparison. Among the clean energy systems hydropower has the highest efficiency while among the thermal power technologies CCGT has the highest.

Together capacity factors and efficiencies are commonly a part of electricity generation calculations which is then used as a dividend for LCOE calculation.

Table 9. Capacity factors of each technology from the reviewed literature

	Capacity Factor (%)											
Reporting Institution	**CCGT**	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Wind Onsh.**	**Wind Offsh.**	**Solar PV**	**CSP**	**Biomass**	**Geoth.**	**Hydro**
OECD/IEA	85%	-	85%	-	85%	26%	-	13%	-	-	-	-
EIA	87%	-	85%	-	90%	35%	37%	25%	20%	83%	92%	53%
WEC	40%	81%	68%	-	-	-	-	-	-	-	-	-
EWEA	80%	-	80%	-	85%	25%	35%	-	-	-	-	-
NREL	85%	-	85%	-	90%	43%	45%	21%	32%	84%	85%	-
VGB	68%	86%	86%	-	90%	21%	37%	23%	32%	86%	-	68%
EUSUSTEL	80%	85%	91%	85%	90%	25%	34%	10%		95%		60%

Table 10. Efficiency rates of each technology from the reviewed literature

Reporting Institution	Efficiency (%)						
	CCGT	**Lignite**	**Coal**	**CHP**	**Nuclear**	**Biomass**	**Hydropower**
OECD/IEA	57%	41,1	-	-	33%	-	-
Fraunhofer ISE	60%	45%	46%	-	-	-	-
VGB	60%	43%	45%	-	36%	40%	90%
EUSUSTEL	57,50%	45%	46%	45%	36%	37,20%	93%

2.9.LCOE Methodology

LCOE calculations generally base on discounting the costs and generation capacities, therefore while building the models and methodologies there might be different assumptions for different institutions. Through the literature review there were several different methodologies however name of the methodologies were grouped under LCOE, ALLGC and Advanced DCF.

- Model used by OECD and CASES is;

$$\text{LCOE} = \sum_{k=0}^{n} \left(\frac{(investment_k + O\&M_k + Fuel_k + Carbon_k + Decommissioning_k * (1+r)^{-t})}{Electricity_k * (1+r)^{-t}}\right) \qquad (1)$$

Where Investment ($/kW) accounts for total project cost, O&M accounts to the operation and maintenance costs, Fuel for the fuel costs, Carbon for the carbon costs, Decommissioning for the decommissioning costs and Electricity for the amount of electricity generated for each kth year and $(1+r)^{-t}$ accounts for the discount factor for projecting kth year costs to today's terms.

- Model used by EPIA and EWEA is;

$$\text{LCOE} = \frac{\text{L.I.} + \text{DO\&M} + DC_k + DC_{CO_2}}{\text{E}} \qquad (2)$$

$$\text{L.I.} = \text{C} * \text{P} * \text{CRF} \qquad (3)$$

$$\text{CRF} = \frac{d}{\left(1-(1+d)^{(-N)}\right)} \qquad (4)$$

Where L.I. (€/y) is the levelized investment, DO&M (€/y) is the annual discounted operation and maintenance cost, DC_k (€/y) is the annual discounted fuel cost, DC_{CO2} (€/y) is the annual discounted carbon emission cost and E (MWh/y) is the annual discounted energy production, C (€/kW) is the capital cost, P (MW) is the installed capacity, CRF is the capital recovery cost, d (%) is the discount rate and N (y) is the economic lifetime.

- Model used by Fraunhofer ISE is;

$$\text{LCOE} = \frac{I + \sum_{k=1}^{N} \frac{A_k}{(1+i)^k}}{\sum_{k=1}^{N} \frac{M_k}{(1+i)^k}} \tag{5}$$

Where I (€) is the investment expenditures, A_k (€) is the total annual costs in year k, M_k (kWh) is the generated electricity, i (%) is the interest rate, N is the economic lifetime.

- Model used by NREL is;

$$\text{LCOE} = \frac{OC*CT*S + \sum \frac{[FC*(1+FE)+FOM*S+VOM*MWh*(1-DF)^n]}{(1+DR)^n}}{\sum \frac{[MWh*(1-DF)]^n}{(1+DR)^n}} \tag{6}$$

Where OC ($/kW) is the overnight capital cost, CT is the construction cost multiplier, FC ($/MMBtu) fuel cost, FE (%) fuel escalation factor, FOM ($/kW/yr) fixed O&M, VOM ($/MWh) variable O&M, DF (%) is the degradation factor, S (MW) is the plant capacity, CF (%) is the capacity factor, MWh (MWh/yr) is the annual electricity production (S * CF * 8.760h), n is the number of years and DR (%) is the discount rate.

3. METHODS

3.1.Learning Rate

3.1.1. Definition

Learning curve, i.e., learning by doing, stands for the cost reductions of goods such as energy generation technologies, vehicles and packed food; as labor gains more experience manufacturing costs decrease from chain reactions of reduced costs of input materials. Learning curve originates from a study conducted on workers in a manufacturing plant [31]. It was observed that plant became more efficient as workers produce more units in time. This result was also supported by several studies conducted later on [32][33].

In the last decades, a shift towards to more econometric analysis on technical changes in energy technologies has been observed [34]. This shift was originated from the desire to create a logic for policy making by understanding the role of technological change in different electricity generation technologies [35]. Adoption and integration of emerging technologies such as wind and solar PV and further cost developments of mature electricity generation technologies carry significant importance from the perspective of policy makers, investors, local communities and global deployment. Thus, analysis on the energy sector should be carried out empirically in order to provide more precise projections for the future.

The method used for electricity generation technologies rely on the concept of experience curves. These curves describe the unit cost decline with the increase in the cumulative installed capacity which was first introduced by The Boston Consulting Group in 1972 [36]. Figure 2 represents the price, cost and experience factors as proposed by BCG. In the development phase, which is the introduction phase of the product, prices are usually set below the costs when it is anticipated that costs will decline in the future. Then in the Price Umbrella phase, competitors enter the market while the first mover’s costs are getting lower but the prices are kept at the same level. Shakeout phase is the time where price level drops drastically with the increasing competition and continuous decreasing of costs. Lastly the stability phase is the time where profit margins return to normal and prices follow costs pattern.

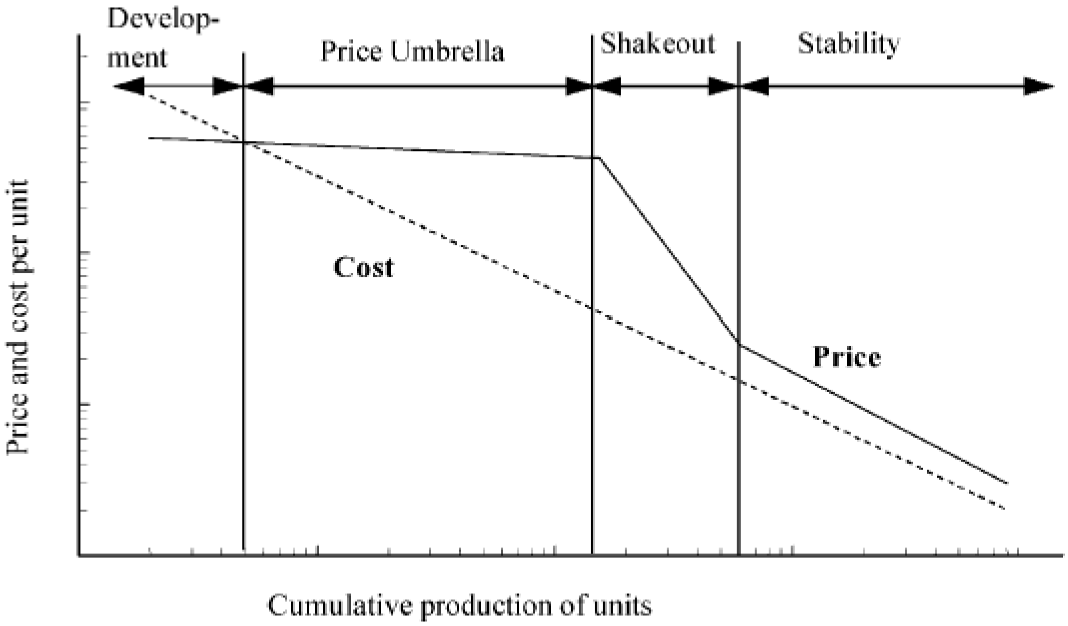

Figure 2. Cost and price developments through each phases of product introduction

3.1.2. Methodology of Learning Rates

Specific usage of experience curves lie beneath the logic of rate of reduction in the costs when the number of produced units is doubled. Thus equation (7) was proposed for measuring the rate of reduction in the costs by doubling the production

$$C_{cum}= C_o{*}CUM^b \tag{7}$$

Where, C_{cum} is the cost per unit as a function of output, Co is the cost of first unit produced, CUM is the cumulative production over time and b is the learning elasticity. Considering the doubling cumulative production; $CUM_2=2{*}CUM_1$, relative cost reduction can be calculated as;

$$\text{Learning Rate} = \frac{Ccum1-Ccum2}{Ccum1} = 1-\frac{C_0{*}(2{*}Cum1)^b}{C_0{*}Cum1^b} = 1-2^b \tag{8}$$

Where relative cost reduction in percentage is also defined as learning rate. 2^b is also referred as progress ratio; which denotes the cost reduction progress rate of each product [37]. As an example 70% progress ratio means that whenever the production is doubled, costs will decline by 30%. Finally the equation sums up to;

$$LR = 1-2^b \tag{9}$$

Regarding to the formula shown in Equation (9), it can be concluded that, experience curves yield to learning curves in the long-term as cumulative capacity doubles each time.

As a result, using experience rates in place of learning rate is suitable for long-term projections.

3.1.3. Weaknesses of Experience Curves

Although experience curves are widely used, from energy systems to the numerous other products, either on sector basis or plant basis, there are several concerns on the shortcoming properties of experience curves. First of all, experience curves do not enable us to predict the discontinuities in the learning rate. Secondly, uncertainties are usually overcome by historical assumptions but this methodology does not take technical boundaries into account. Technical boundaries can limit the future learning rates and yield to a deviation from historical rates. Secondly, uncertainties are usually overcome by historical assumptions. However this approach does not support the environment that has technical limitations important factors in reducing the costs. Finally, experience curve ignore the effect of R&D from other industries that are related with the subjected generation technology.

In order to overcome the weaknesses of experience curves, rather than relying on historical assumptions it is necessary to integrate the additional developments on related industries considering the technical boundaries. For example, global learning rate obtained from Fraunhofer ISE report was calculated based not only on the historical developments but also expected silver shortage in the mid-term and R&D studies on efficiency increase. based on the historical development of experience, expected silver shortage in the near future and expected efficiency increase (R&D) rather than only relying on historical developments.

3.1.4. Learning Rates For Energy Sector

3.1.4.1.Renewable Power

Emerging technologies like solar PV and wind power, systems benefit from high learning rates. The level of rates is not only related to the increase in the capacity deployment but also to the developments in the production technologies, experience in learning and modularity that allows mass production of these technologies.

In contrast to the components of a thermal power plant, the components of renewable energy technology carry modularity feature that enables mass production. This modularity is parallel to the system analyzed in very first study on learning rates conducted by Wright, (1936). Results suggest that, modularity gradually increases the learning rates. That directly increases the learning rates gradually. For the solar PV case, the most recent study was conducted by Agora Energiewende on the cost projection of solar PV electricity generation systems [38]. According to the study, despite the expected silver scarcity in the short-term, cost of the modules is expected to decrease by 19-23% until the year of 2030.

Wind power technology was deployed far earlier than solar PV. Learning rates on wind power resulted between 8-17% [39]. In order to have consistency in the learning rates, 20% learning rate for solar PV and 17% for wind was chosen from same study.

3.1.4.2.Thermal Power

Compared to the renewable energy systems, there are a limited number of researches on the learning rates of thermal power plants regarding to the maturity of technologies and changing economic analysis framework in the last decades. In general, these power plants deploy mature technologies such as; pulverized coal, circulating fluidized bed and gas combined cycle technology. Learning rate for CCGT was taken as 5% [39] and for coal 2-5% [40].

These types of mature technologies with high efficiency combustion methods were expected to have an increase in the efficiency rates regarding to the trends in R&D studies. However, improvements were rather made parallel to the concerns in environmental point of view instead of just focusing on increasing the efficiency. Thus introduction of decarbonisation systems and carbon capture and storage systems were observed. These systems have increased the initial costs of these power plants while reducing the overall efficiency compared to IGCC power plants with cleaner technology for coal sources [39].

3.2.Macroeconomic Structure

As it is outlined in the model description part, the model that was used for the cost projection analysis majorly relies on learning rates and certain macroeconomic indicators. Reliable learning rates are available in the literature review covering learning rates but macroeconomic indicators to be integrated in the model are not readily available and should base on solid assumptions for the reliability of the model.

Basically, macroeconomic structure was built on providing a framework for understanding the cost of technology variations among countries and projection of prices for cost calculations. As an example, although 63% of wind power plant cost is turbine cost and price of the turbine is determined globally, overall project costs varies significantly over countries[41]. At this point, it is concluded that overall cost have 2 components; tradable and non-tradable. Tradable component is the part of the cost in which the items' and goods’ prices are determined in global markets and are tradable such as iron, food grains, oil etc. On the other hand, non-tradable cost components are the part of overall cost that are manufactured, produced and consumed locally and are not exposed to international competition. Non-tradable components such as; land, construction services, utilities, labour and etc. are country specific, determined by local market equilibrium, and were found to be the primary reason of cost variability [41].

In order to fully understand the setting of NT prices, a Big Mac study was conducted [42]. A Big Mac which can be found over 120 countries has components that are internationally traded items. Results of this study suggest that prices of Big Mac differentiate from purchasing power parity (PPP) levels of each country. Despite consisting tradable items such as; beef patty, lettuce, onions and etc. in order to produce a Big Mac one should buy or lease a store, purchase utilities and hire employees which on the average constitutes to 97% of the price of a Big Mac that differentiates it across countries. Study suggests that PPP for price comparison and price projection is not sufficient alone [41].

A macroeconomic approach called Balassa-Samuelson Effect helps understanding the relationship between tradable and NT sectors, and also price variations through productivity levels and real exchange rates. According to Balassa-Samuelson Effect, as the productivity of tradable sector increases relative prices of NT sector increases as well. Increase in the productivity of traded sector causes a pull effect on the wage levels of labour and assuming both sectors compete in the same labour market, there will be inflation in the prices of NTs thus, causing inflation in overall price indexes. Therefore we can conclude that high income countries have higher prices and overvalued currencies. Improvements in the developing countries result in increased productivity and income causing higher inflation on NTs than in developed countries [41].

As Balassa-Samuelson Effect describes the foundations for understanding the relationship between NTs, productivity and real exchange rate, it is simply too generalized in order to be integrated into the model. Thus there is a need for a more applicable linkage that can be added in the model. However, literature review suggests four different conditions for the linkage between prices of NTs and real exchange rate [41].

“1. Countries with strong trade relationships and greater share of exports to GDP have shown to exhibit strong relationship between RER and relative prices of NTs.

2.It has been found that in floating rate regimes, variations in market exchange rates and deviation in PPP levels caused due to it in relative prices of traded items causes more impact as compared to variation in relative prices of BTs. This effect is reduced in case of fixed rate regime or incidence of tghitly management of exchange rates by central banks.

3.Balassa Samuelson Effect (i.e effect of relative prices of NTs) is more evident when pair of high income – low income countries are analysed due to difference in relative price movements of NTs between these 2 set of countries. However, if we compare the relative price development for US and any other country say, Europe, then this difference is going to be much more lower or almost negligible to cause any impact in RER variations.

4.There are number of papers including Engel (1999), which showcases the variations in outcomes with change in approaches of constructing the RERs and price indexes from tradable and NT goods. Further, as explained earlier, there are multiple ways of classifying sectors as tradable and NT, therefore results of these studies are bound to vary based on methodology used” [41].

Although there are several different approaches to understand the relationship between RERs and relative prices of NTs by using different price indexes, even developed countries do not have separate price indexes for NT sector. Therefore, in order to integrate the cost projections to the model, a simplified approach had been chosen. Regarding to this approach, as mentioned above there were several studies that came up with results supporting the high level of correlation between relative prices of NTs and RERs in the long term in developing countries such as; Turkey, China, Peru, Brazil and Chile in comparison to high income countries like USA. Thus, discussion on macroeconomic indicators results in a way that increase in prices of local cost components should be scaled over a factor relative to RERs and scaling factor can be defined as PPP/FX.

3.3.Model Description

The model used while conducting the thesis study is Cost Projection Model and focuses on two separate financial indicators; Total Overnight Cost (TOC) and Levelized Cost of Electricity (LCOE). TOC ($/MW) includes, engineering, procurement, construction, land acquisition, mechanical and electrical equipments, labour and permits that are necessary for building a power plant. On the other hand LCOE is a completely different indicator, that provides the cost of electricity generation in the form of \$/MWh. Despite their differences, LCOE can be connected to TOC mathematically.

Formulas of LCOE and TOC are;

$$\text{LCOE} = \sum_{k=1}^{N} [I_k + FOM_k + VOM_k + FC] \tag{10}$$

Where I_k (\$/MWh) is the construction cost (TOC * IDC) divided to total generation in a year and spread over the economic lifetime of the power plant, FOM_k (\$/MWh) is the discounted fixed OPEX which is then divided to discounted annual generation, VOM (\$/MWh) is the variable OPEX scaled by PPP/FX, FC (\$/MWh) is the fuel costs which is extrapolated to 2015-2035 then divided to efficiency rate, and N is the economic lifetime of the power plant.

$$\text{TOC} = [\text{TOC}_g * \text{GLR}_{cum} * \text{Global PPP Scaling Factor}] + [\text{TOC}_l * \text{LLR}_{cum} * \text{Local PPP Scaling Factor}] \tag{11}$$

Where TOC_g is the global TOC component and TOC_l is the local TOC component, GLR_{cum} is the global cumulative learning rate and LLR_{cum} is the local cumulative learning rate and scaling factors are the PPP/FX values on the global and local basis that integrates the price increase following the Balassa-Samuelsson effect mentioned in the previous section.

From the TOC point of view, there are two major factors affecting TOC levels; global learning rate and local learning rate. While global learning rate provides the cost reduction that comes from global deployment and developments in energy technologies, local learning rates are projected over the local deployment of energy technologies. At this point, TOC should be separated into two components as global component and local component. As mentioned in the above section, price differences occur from the variations in NTs among countries. Therefore local components were determined as NTs of each technology that actually covers, labor, utilities, construction, land acquisition, permit and license expenses whereas global component includes the equipment costs in which prices are subjected to international competition.

In order to calculate the effect of learning rates; first, global and local accumulated learning rates should be calculated by the rate of global and local deployment of each technology and global and local learning rates of each technology which are then multiplied by the global and local cost components. Final step of this section is to adjust prices for the future projections which can be done by scaling PPP to FX based on the macroeconomic structure presented above. Therefore we can't always state that costs will be reduced overtime, if the price adjustments surpass the learning effect then the cost might increase overtime.

From the LCOE point of view, calculation steps are comparably more complex than TOC. LCOE has several components; such as fuel costs, variable OPEX, fixed OPEX and construction costs (TOC component). All of the components are projected for 2016-2035 by extrapolating them with Weighted Average Cost of Capital, Scaling factor (PPP/FX), plant's capacity factor and availability over the construction time of the power plant. Since scaling factor, capacity factor, availability, construction time and TOC components are readily available from the data list prepared, WACC was the only component to be calculated. WACC calculations were made based on the data received from Bloomberg New Energy Finance with the equation WACC = (Debt Ratio*Cost of Debt)+(Equity Ratio*Cost of Equity). Since, nearly 80% of the companies analyzed in this thesis are not publicly traded, rather than calculating an average rate for cost of debt and cost of equity, cost of debt was calculated based on the LIBOR + premium and cost of equity was directly taken from BNEF averages for each country.

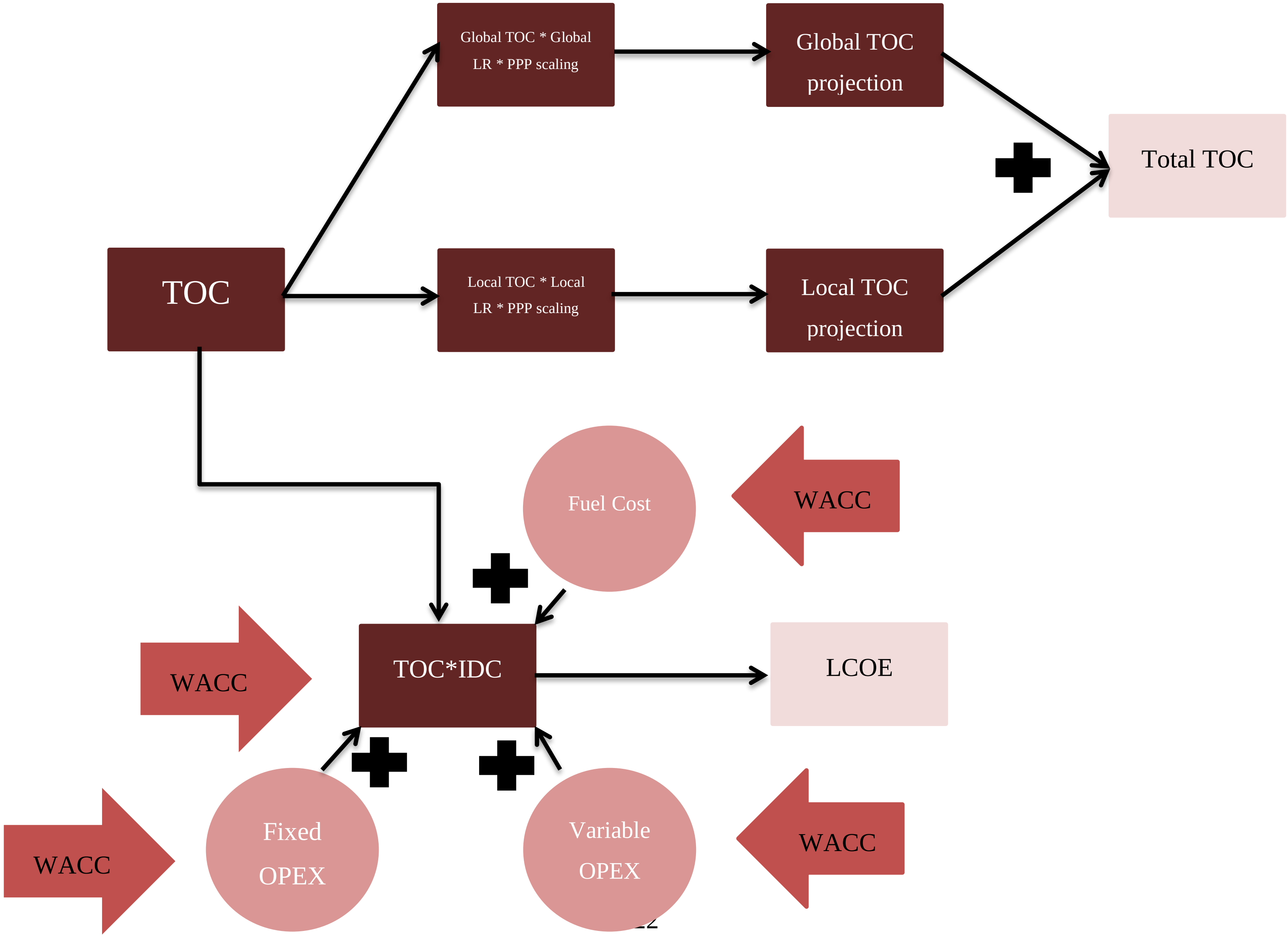

Figure 3. Demonstration of TOC and LCOE calculations

4. TECHNOLOGY DESCRIPTION AND DATA LIST

4.1.Solar PV Power Technology

4.1.1. Crystalline Silicon

Crystalline silicon solar modules are the most widely used modules in the world. As of the year 2013, 90% of total installed PV capacity is c-Si modules [43]. These cells completely base on a p-n junction system and can be in the form of monocrystalline silicon, poly-crystalline silicon or ribbon silicon. Conversion efficiencies of these modules are rated between 20-25% [25].

4.1.2. Thin Film

After the c-Si modules, thin film modules are the most commonly used ones. As of the year 2013, 10% of total installed PV capacity is thin film modules [43]. These modules are basically created by placing a very thin photosensing material onto a low cost surface and can be manufactured in the forms of cadmium telluride, silicon thin film, copper indium gallium selenide and gallium arsenide thin film. Conversion efficiencies of CdTe and a-Si are rated at around 20% [25].

4.1.3. Global Solar PV Market

Utilization of solar PV systems started in 1980s. However utility scale solar PV power plants gained importance by the early 2000s. While the total installed capacity was 1.2 GW in 2000, it has reached to 177 GW in 2014 [44]. Distribution of installed capacity can be seen in Figure 4. Cumulative capacity is expected to reach at least 321 GW in 2018 and 500 GW in 2019 [45].

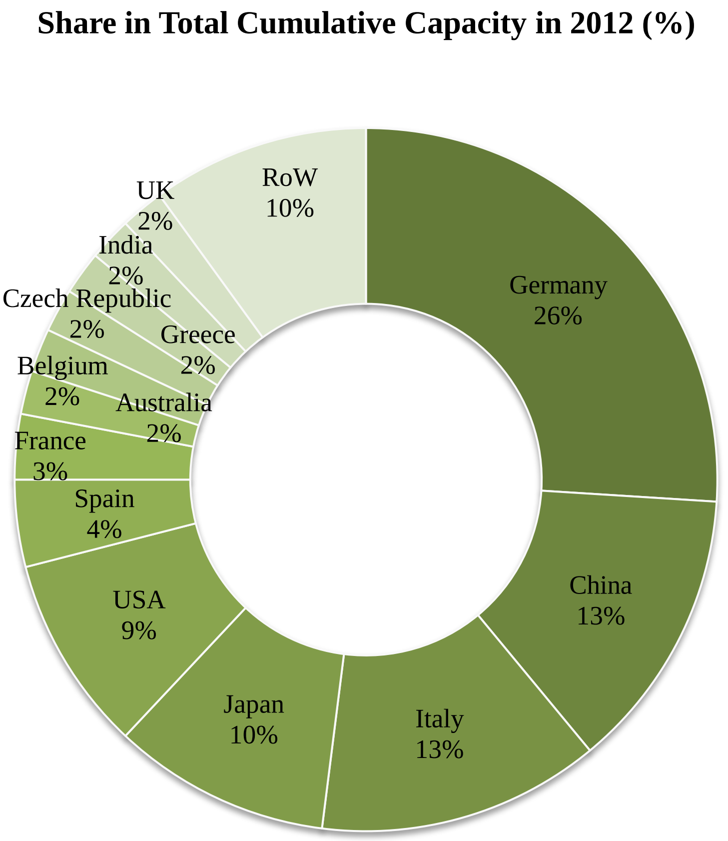

Figure 4. Distribution of global cumulative solar PV capacity

4.1.4. Solar PV Power Plants in Turkish Electricity Mix

Utilization of solar PV power plants started in 2013. Despite the global developments, current installed capacity is 71,2 MW that accounts around 0,1% of total installed capacity [17]. Current legislative environment allow investors to build solar PV power plants under two options; licensed and non-licensed.

4.1.5. Licensed Solar PV Power Plants

In order to build a licensed solar PV power plant, investors should apply for the periodically announced capacities. First announcement was held in 2013 in which the capacity was limited to 600 MW. Regarding to the regulative complexity and lack of experience in solar PV projects had made State to postpone announcing auctions for subjected capacities to April 2015. Licensed power plants are expected to be taken into commission by the late 2015 and 2016. According to the future plans, 3 GW licensed solar PV power plants are expected to be installed by the year 2023.

4.1.6. Non-licensed Solar PV Power Plants

Another investment opportunity for solar PV is the non-licensed power plants. These types of power plants have 1 MWp capacity limitations as well as they should be connected to a consumption unit. However limits of consumption are not defined clearly, thus most of the plants sell as much as they can generate under the feed-in-tariff.

Currently all of the installed capacity (71,2 MW) is non-licensed solar PV power plants and approved capacity of non-licensed power plants is 510 MW while the applications reach to 1,8 GW in total [46].

4.1.7. Data Set for Solar PV Power Plants

As it is mentioned in the above section, there are two types of Solar PV power plants in Turkey such as; licensed and non-licensed plants. As the analysis subjected to this thesis was conducted, there weren't any utility scale licensed solar PV plant. However, there are numerous 1 MWp solar PV power plants that are combined 5 MW to 7 MW utility scale sizes. Therefore initial cost analysis is based on the data combined for several non-licensed power plants.

Table 11. Technical properties of solar PV project

Name of the Project	Unit Capacity	Total Units	Installed Capacity	Lifetime
Solar Project	1 MW	1	1	25

Commenting on the initial cost analysis, project cost is calculated as 1.47 M$/MW which is assumed to consist 0,1 M$/MW owner's cost. However recent auctions for licensed SPP's, which will be covered in detail in the results section, suggests that average owners cost is around 0,64 M$/MW with the addition of contribution margins subjected to the auctions. These rates directly affect the project cost where the highest cost is 2,37 M$/MW, lowest is 1,47 M$/MW and average is 2,01 M$/MW.

Table 12. Financial properties of solar PV projects

	Capex (M$/MW)			
Name of the Project	**Total Investment**	**Total OCC**	**Total Owner's cost**	**Total Overnight Cost**
Solar Project - No Cont. Mar.	1,47	1,31	0,10	1,41
Solar Project - Low Cont. Mar.	1,67	1,31	0,30	1,61
Solar Project - Avg Cont. Mar.	2,01	1,31	0,64	1,95
Solar Project - High Cont. Mar.	2,37	1,31	1,00	2,31

Cost breakdown analysis suggests that, IDC component of the cost is nearly 5% while share of taxes is also included in the IDC component. Compared to wind power plants, solar PV power plants can be constructed over in a shorter period which directly decreases the IDC rate. Calculated WACC rate is 7,3% with average debt ratio of 75%, cost of debt of 5,3% and cost of equity of 13%.

Table 13. WACC features of solar PV projects

Name of the Project	IDC share	Debt Ratio	Cost of Debt	Cost of Equity	WACC
Solar Project	5,0%	75%	5,3%	13,0%	7,3%

According to the data presented in the next sections, solar PV and wind power technologies require higher initial investment figures (CAPEX) compared to thermal power technologies. But from the fuel cost perspective, renewable energy technologies don’t have fuel costs while it is the significant part of the calculated LCOE rates of thermal power technologies.

4.2.Wind Power

4.2.1. Global Wind Market

Wind power had been in use for centuries mainly for agricultural purposes. Despite the efforts made on electricity generation by wind turbines in the beginning of 20th century, commercial studies started with the oil crisis in 1973 in search of the alternative power sources. From that point onwards, utilization of onshore turbines has gained importance. However, offshore wind power plants were not utilized until the late 2000s in Norway.

Utilization of wind power in utility scale had gained acceleration by the early 1990s. Global installed capacity reached to 7GW in 1997 and 369,7GW in 2014 where only 4.6 GW of total is offshore power plants. Table 14 provides the information on the distribution of installed capacity. While Asia has the highest installed capacity accounting 38% of total, 36% is installed in Europe. Among the countries deploying wind power, China has 114 GW installed capacity, followed by USA with 65 GW, Germany with 39 GW, India and Spain with 22 GW [47].

Table 14. Distribution of global cumulative wind power capacity

Region	Cumulative Capacity in 2014 (MW)	Share (%)
Africa & Middle East	2.535	0,69%
Asia	141.964	38,41%
Europe	134.007	36,26%
South America	8.526	2,31%
North America	78.124	21,14%
Pacific Region	4.441	1,20%
Total	369.597	100%

According to a study conducted by Global Wind Energy Council, under a moderate scenario, in 2020 total installed capacity will increase to 712 GW and 1.479 GW in 2030 that will presumably account to 15% of total global demand [48].

4.2.2. Wind Power Plants in Turkey’s Electricity Mix

Despite the earlier developments in the global market, wind power entered Turkish market by the introduction of Renewable Energy Law in 2005. Throughout the nine year development in the wind power market, as of January 2015 installed capacity is topped at 3.806 MW [17] that accounts for the 5,3% of the total installed capacity. However, capacity factors made wind power plants contribution to electricity generation limited to 3,3% in 2014. Current policies aim to have at least 20 GW of installed capacity by the year 2023; however, feasibility of these targets are questionable. Current licensing regulation lack in the investigation to be carried out in post-application process which allows arbitrageurs to apply licenses and disrupt the deployment projections by postponing construction until the project is sold to the sponsors.

4.2.3. Data Set for Wind Power Plants

Having selected the power plants that were commissioned in 2014 or will be commissioned in 2015, data set for wind power plants consists nine power plants that are larger than 10 MW (Table 15). Although there were more wind power plants taken into commission in the course of 2014, data set listed below provides an adequate sample.

Table 15. Technical properties of wind power projects

Name of the Project	Unit Capacity (MW)	Total Units	Installed Capacity (MW)	Lifetime (Years)
Günaydın WPP	2,5	4	10	25
Karadere WPP	1,6	10	16	25
Salman WPP	2,75	10	27,5	25
Şadıllı WPP	2,75	14	38,5	25
Gökres WPP	2,75	13	35,75	25
Atik Belen WPP	2	7	14	25
Kıyıköy WPP	2	12	24	25
Kapıdağ WPP	2	12	24	25
Geres WPP	2,5	11	27,5	25

Commenting on the initial cost analysis, Gökres WPP and Atik Belen WPP have the lowest project cost observed at 1,32 M$/MW whilst the highest cost was observed for Günaydın WPP at 2,33 M$/MW. Compared to remaining projects, the logic behind having a high project cost for Günaydın WPP can be explained by the extreme terrain conditions.

Table 16. Financial properties of wind power projects

	CAPEX (M$/MW)			
Name of the Project	**Total Investment**	**Total OCC**	**Total Owner's cost**	**Total Overnight Cost**
Günaydın WPP	24,54	2,28	0,05	2,33
Karadere WPP	33,23	1,93	0,04	1,97
Salman WPP	44,69	1,51	0,03	1,54
Şadıllı WPP	61,16	1,48	0,03	1,51
Gökres WPP	49,64	1,29	0,03	1,32
Atik Belen WPP	19,45	1,29	0,03	1,32
Kıyıköy WPP	36,58	1,42	0,03	1,45
Kapıdağ WPP	47,06	1,82	0,04	1,86
Geres WPP	40,58	1,37	0,03	1,40

Cost breakdown analysis suggests that, IDC component of the cost is nearly 7% for all projects while share of taxes is also included in the IDC component. Compared to coal fired power plants and natural gas power plants, wind power plants can be constructed over in a much shorter period (1 year) which directly decreases the IDC rate. Calculated WACC rate is 7,5% with average debt ratio of 65%, cost of debt of 5,6% and cost of equity of 11%.

Table 17. WACC features of wind power projects

Name of the Project	IDC share	Debt Ratio	Cost of Debt	Cost of Equity	WACC
Günaydın WPP	7,0%	65%	5,6%	11,0%	7,5%
Karadere WPP	7,0%	65%	5,6%	11,0%	7,5%
Salman WPP	7,0%	65%	5,6%	11,0%	7,5%
Şadıllı WPP	7,0%	65%	5,6%	11,0%	7,5%
Gökres WPP	7,0%	65%	5,6%	11,0%	7,5%
Atik Belen WPP	7,0%	65%	5,6%	11,0%	7,5%
Kıyıköy WPP	7,0%	65%	5,6%	11,0%	7,5%
Kapıdağ WPP	7,0%	65%	5,6%	11,0%	7,5%
Geres WPP	7,0%	65%	5,6%	11,0%	7,5%

Compared to thermal power plants, wind power plants require higher initial investment and lower plant capacity factor. However, wind power plants do not have variable OPEX rate.

4.3.Global Coal Market

4.3.1. Coal Categorization

Coal has been used as a fossil fuel for centuries. It did not only accelerated the industrial revolution, it was also the main component of market driving factor for electricity generation for the last decade.

Mainly we can divide coal into two sub categories; hard coal and brown coal. Commonly hard coal can be found in anthracite form or bituminous form while brown coal can be found in sub-bituminous form or lignite form. According to the specifications listed in Table 18, anthracite has the highest calorific value (higher than 7.000 kcal/kg) where lignite has the lowest calorific value (lower than 4.610 kcal/kg) [49].

Table 18. Properties of coal segmentation

	Lignite	Sub-bituminous	Bituminous	Anthracite
Calorific Value	< 4610 kcal/kg	4610-6930 kcal/kg	5390-7700 kcal/kg	>7000 kcal/kg

4.3.2. Global Reserves

In the case of global coal and lignite reserves, USA has the largest bituminous coal reserves with 108.501 million tones as well as lignite reserves as 128.794 million tones that covers the 27,6% of all coal reserves. Followed by Russia that accounts for the 18,2%, China with 13,3%, Australia with 8,9% and India with 7,0% of all coal reserves. Looking at the Turkish coal reserves share in total reserves is 0,3% that covers 524 million tons of bituminous coal and 1.814 million tons of lignite [49].

Table 19. Distribution of global coal reserves

	North America	South America	Europe & Eurasia	Middle East & Africa	Asia-Pacific
Global Coal and Lignite Reserves	28,50%	1,50%	35,40%	3,80%	30,80%

4.3.3. Coal Production

Taking a look at the global coal production, as of 2012, total hard coal production has topped at 6,9 billion tones and lignite production remained in the same level as it was in 2011 with 0,9 billion tones. According to the distribution of global coal production, while 77% of the lignite is produced in Europe and Eurasia, 72% of hard coal was produced in Asia-Pacific in which China covers 51,2% of hard coal production in 2012 [50].

From the electricity generation point of view; 40% of the electricity generated in 2013 was from coal-fired power plants that make them the most common source of energy [51].

4.3.4. Coal Technologies

Coal-fired power plants had been in the market for more than a century. Initially these power plants were standardized. However developments in understanding coal properties lead to several new type of power plants using new technologies. Currently there are 3 main types of utilized coal-fired power plants in use; pulverized coal (PC), integrated gasification combined cycle (IGCC) and circulating fluidized bed (CFB) combustion technology. Nearly 97% of installed capacity of coal-fired power plants relies on pulverized coal technology whereas remaining 3% is IGCC and CFB technologies [52]. The reasoning behind these different technologies relies on the properties of coal or lignite to be used in the power plant and environmental concerns aroused in the last decades.

Coal and lignite fired power plants are cheap and reliable source of power generation which is the core factor triggering economic expansion in emerging markets. Despite these features, increasing environmental and health related concerns forced players to design more environmental friendly thermal electricity generation technologies such as IGCC and Carbon Capture Systems (CCS). It is worth to note that high initial investment rates of CCS compared to IGCC have made IGCC to be more feasible under today’s conditions.

4.3.4.1.Pulverized Coal

Pulverized Coal power plants are the oldest type of technology used for coal combustion. Main working principle relies on a simple combustion technique where coal is pulverized in the pre-treatment facility then fed to the boilers where hot air combustion burns the pulverized coal. However this technology is not applicable for all coal types. Depending on its nature, coals with high ash content show low efficiency and high environmental effects when they are burned in PC power plants.

There are 3 types of PC power plants, sub-critical, super critical and ultra-supercritical. The main difference among these three types is the operating temperatures and pressures. While sub-critical PC power plants operate at 163 atm and 538 °C which below the critical point of water, super critical PC power plants operate at 238 atm and 566 °C and ultra-supercritical PC power plants operate at 316 atm to 600 °C. These differences enable ultra-super critical power plants to have 42-47% overall efficiency while super critical PC power plants to have 40-42% overall efficiency [53].

4.3.4.2.Integrated Gasification Combined Cycle

Main working principle of IGCC relies on converting the fuel into syngas that is a hydrogen and carbon monoxide mixture, which is then transferred to gas turbine and steam turbine for electricity generation (a regular combine cycle system). Currently utilization of IGCC power plants is not common. Main problem of IGCC power plants compared to PC power plants is that they require considerably higher initial investment.

IGCC power plants commonly have 2 systems consisting several blocks. Process in system 1 consists, creating hot raw syngas, which is then cooled down and cleaned through particulate and sulfur removal which in the end results in clean syngas. Process in system 2 is a regular combined combustion process where clean syngas is first fed to gas turbines then hot steam is fed to the steam turbine [54]. Efficiencies of this technology varies between 39,9% - 45% [55].

4.3.4.3.Circulating Fluidized Bed

Fluidized Bed technology was first introduced in 1970s in order to provide a technology that enables the usage of low calorific fuels and high-ash fuels such as lignite and high-moisture fuels such as municipality wastes [56]. Main working principle of CFB combustion system relies on combusting primary air to fluidize limestone mixture in the bed that burns the coal and coal char fed to the bed. There are several advantages of CFB combustion systems;

- Low combustion temperatures results in low NO_x emission
- High combustion efficiency (95-99%)
- High heat transfer coefficient that enables compact boiler design

- Absorption of SO_2 by the limestone in the bed that leads to reduced SO_2 emission [57].

Overall thermal efficiencies of CFB power plants vary from 36% to 46% depending on the type of fuels used [58].

4.3.5. Coal Power Plants in Turkish Electricity Mix

4.3.5.1.Current Situation

In today’s market coal-fired power plants account for 14.650 MW of installed capacity which is 20,9% of the total installed capacity and covers 29,2% of total generated electricity in 2014 (250,4 billion kWh) [17].

Coal-fired power plants are generally categorized into two groups in Turkey; hard coal fired PC power plants and lignite fired CFB power plants. 55% of installed coal-fired power plants are lignite fired power plants whereas 45% is hard coal power plants.

4.3.5.2.Domestic Lignite

Compared to hard coal reserves, lignite reserves of Turkey have higher potential for electricity generation. However, low calorific values (Table 20), high ash content, high Sulphur content and high moisture rates of domestic lignite requires a specific CFB combustion system design for lignite-fired power plants [59]. Distribution and size of the reserves of lignite are listed in Table 20 [60].

Table 20. Distribution and size of the coal reserves in Turkey

	Reserves (thousand tons)				
	Proven	**Possible**	**Probably**	**Total**	**Calorific Value (kcal/kg)**
Public Sector	8.759.064	1.007.812	124.524	9.891.400	550-3340
Private Sector	1.077.834	337.569	138.617	1.554.018	860-4900

Analyzing the future of lignite fired power plants in Turkey, recent explorations in Konya-Karapınar reserve enables a 5,800 MW plant alone to be built in the field and according to the current policies there will be at least additional 14 GW capacity which is expected to be deployed until 2030 [60].

4.3.5.3.Import Hard Coal

As mentioned in the first part of this section, Turkey has limited hard coal reserves with rather low calorific valued for electricity generation. The only domestic hard coal power plant is ÇATES with 300 MW installed capacity and the remaining hard coal fired power plants rely on import coal. Table 21 provides the information on coal imports of Turkey in which 81% is steam coal [50].

Table 21. Distribution of import coal origins

Country	Total Imports (million tons)	Share (%)
Russia	8,6	32,33%
Columbia	7,2	27,07%
U.S.	4	15,04%
South Africa	3,3	12,41%
Ukraine	1,1	4,14%
Australia	0,9	3,38%
Canada	0,3	1,13%
Others	1,2	4,51%
Total	26,6	100,00%

4.3.6. Data Set for Coal Power Plants

Power plants that will establish the fundamentals for cost projections were chosen from power plants that were taken into commission in 2014 and will be taken into commission in 2015. In the current market outlook, there were 6 power plants that are larger than 100 MW and suitable for commissioning conditions (Table 22). Three out of these six power plants rely on domestic lignite whereas remaining three relies on import coal.

Table 22. Technical properties of coal and lignite fired power plants

Name of the Project	Unit Capacity (MW)	Total Units	Installed Capacity (MW)	Type Of Fuel	Lifetime (years)
Bekirli TPP	600	1	600	Import Coal	35
İzdemir TPP	350	1	350	Import Coal	35
Yunus Emre TPP	145	2	290	Domestic Lignite	35
Göynük TPP	135	2	270	Domestic Lignite	35
Atlas TPP	600	2	1200	Import Coal	35
Tufanbeyli TPP	150	3	450	Domestic Lignite	35

Domestic lignite fueled power plants; Yunus Emre (290 MW), Göynük (270 MW), Tufanbeyli (450 MW), require significantly higher investments compared to import hard coal fueled power plants, Bekirli (600 MW), İzdemir (350 MW), Atlas (1200 MW). This significant difference on initial investment occurs from the low calorific value of domestic lignite requires an initial process prior sending out to the power plant. Although domestic lignite fired power plants require higher amount of initial investment, Tufanbeyli TPP is an outlier with Overnight Cost of 2,3 M$/MW.

Table 23. Financial properties of coal and lignite fired power plants

	CAPEX (M$/MW)			
Name of the Project	**Total Investment**	**Total OCC**	**Total Owner's cost**	**Total Overnight Cost**
Bekirli TPP	500	0,74	0,04	0,79
İzdemir TPP	350	0,89	0,05	0,94
Yunus Emre TPP	530	1,63	0,10	1,72
Göynük TPP	320	1,05	0,06	1,12
Atlas TPP	1200	0,89	0,05	0,94
Tufanbeyli TPP	1100	2,18	0,13	2,31

Cost breakdown analysis suggests that, IDC component of the cost is nearly 7% for all projects and the share of taxes is also constant at 4%. Calculated WACC rate is 9,1% with share of debt is averaged on 70%, cost of debt at 7,8% and cost of equity at 12% and construction time of all power plants regardless of size is 3 years with exception of Tufanbeyli TPP which is an outlier.

Table 24. WACC features of coal and lignite fired power plants

Name of the Project	**IDC share**	**Taxes and other costs share**	**Debt Ratio**	**Cost of Debt**	**Cost of Equity**	**WACC**
Bekirli TPP	7,0%	4,0%	70%	7,8%	12,0%	9,1%
İzdemir TPP	7,0%	4,0%	70%	7,8%	12,0%	9,1%
Yunus Emre TPP	7,0%	4,0%	70%	7,8%	12,0%	9,1%
Göynük TPP	7,0%	4,0%	70%	7,8%	12,0%	9,1%
Atlas TPP	7,0%	4,0%	70%	7,8%	12,0%	9,1%
Tufanbeyli TPP	7,0%	4,0%	70%	7,8%	12,0%	9,1%

On the financing side of coal power plants, companies were having difficulties since project financing in Turkey had not been settled yet. However, from the recent projects such as Göynük TPP was financed through loans combined from several institutions that actually fits to the project financing framework [61]. As it was mentioned in the above section, Chinese technology is dominating the import coal fired power plants, but recently they were able to participate in the domestic lignite fired power plant constructions by not only transferring the technology but also providing loans from Chinese institutions [62].

4.4.CCGT Technology

CCGT technology like OCGT includes compressor/gas turbine blocks and it additionally requires a heat recovery steam generator in order to increase the efficiency by using the waste hot exhaust rather than discharging to the atmosphere. Commonly, which is also the case for our data list, one third of the net power is generated by steam turbine and the remaining power is generated by gas turbine.

Compared to 45% full-load efficiency of PC power plants, CCGT type power plants have 46-60% full-load efficiency as well as up to 95% reduction in NOx gas emissions [63].

4.4.1. Global Gas Reserves

There are two types of reserves for gas in the World; conventional and non-conventional reserves. As of 2012, proven conventional reserves are 486 billion m^3 and non-conventional reserves; 212 billion m^3 shale gas, 81 billion m^3 compressed gas, 50 billion m^3 coal reserve gas [64].

4.4.2. Global Gas Supply and Demand

According to BP's statistical review report, 38,5% of global gas production is controlled by two countries; Russia and USA which are followed by Iran with 4,9%, Qatar with 4,7%, Canada with 4,6%, China with 3,5%, Norway with 3,2% and Saudi Arabia with 3,0% which adds up to 62,4% of total global production [65].

At the consumption side, highest consumption occurs in the Europe and Eurasia region which accounts for 31,7% of total consumption and this region is followed by North America with 27,8% and Asia-Pacific with 19% of the total consumption [65].

Table 25. Distribution of natural gas production and consumption

Region	Production (bcm)	Consumption (bcm)
Total North America	26,90%	27,80%
Total South America	5,20%	5%
Total Europe & Eurasia	30,60%	31,70%
Total Middle East	17%	12,80%
Total Africa	6%	3,70%
Total Asia Pacific	14,50%	19%

Looking at the break down of total consumption on sector basis; it is observed that 40% of the consumed natural gas had been used for electricity generation in 2011 [64]. This rate accounts for 23% of total electricity generation whereas 40% of electricity generation is realized by coal-fired power plants. (**worldbank data**)

4.4.3. CCGT Power Plants in Turkish Electricity Mix

In today's conditions market of natural-gas power plants account for 21.528 MW of installed capacity which is 31% of the total installed capacity and covers 48,1% of total generated electricity in 2014 (250,4 billion kWh) [**TEİAŞ**]. According to Energy Market Regulatory Authority's database; total capacity of combined cycle natural gas power plants had made license application or in the construction phase is totaled around 35 GW. However, low wholesale prices, high gas prices and appreciation of USD had put those potential power plant projects in risk.

4.4.4. Data Set for CCGT Power Plants

Having selected the power plants that were commissioned in 2014 or will be commissioned in 2015, data set for CCGT power plants consists three power plants that are larger than 100 MW (Table 26). Erzin NGPP consists 3 units with sizes of 2x 292 MW, 1x319 MW; Cengiz NGPP consists 2 units with sizes 401,33 MW and 208,67 MW; and finally Yeşilyurt NGPP consists, 10 units with 8x18,321 MW and 2x5 MW. Since it is be classified as highly confidential, natural gas supply origins are unknown but it will be assumed to be same for for all three plants.

Table 26. Technical properties of CCGT power plants

Name of the Project	Unit Capacity (MW)	Total Units	Installed Capacity (MW)	Type Of Fuel	Lifetime (Years)
Erzin NGPP	2x292 MW | 1x319 MW	3	600	Natural Gas	30
Cengiz NGPP	1x401,33 MW | 1x208,67 MW	2	610	Natural Gas	30
Yesilyurt NGPP	8x18,32 MW | 2x5 MW	10	158	Natural Gas	30

Taking a look at the cost breakdowns, total OCC rates are equal for Yeşilyurt and Cengiz NGPP at 0,95 $M/MW while it is considerably higher for Erzin NGPP at 1,41 M$/MW. Despite the similar levels of total OCC of coal power plants and natural gas power plants, on the OPEX side, natural gas power plants have comparably lower fixed OPEX and variable OPEX. The reason why fixed OPEX is significantly low is that natural gas power plants require less operational stuff and lower maintenance yearly costs.

Table 27. Financial properties of CCGT power plants

	CAPEX (M$/MW)			
Name of the Project	**Total Investment**	**Total OCC**	**Total Owner's cost**	**Total Overnight Cost**
Erzin NGPP	930	1,41	0,08	1,50
Cengiz NGPP	640	0,95	0,06	1,01
Yesilyurt NGPP	165	0,95	0,06	1,01

Cost breakdown analysis suggests that, IDC component of the cost is nearly 5% for all projects while share of taxes is also same for all at 4%. Compared to coal fired power plants, natural gas power plants can be built in less time (2,5 years) which directly decreases the IDC rate. Calculated WACC rate is 9,1% with average debt ratio of 70%, cost of debt of 7,8% and cost of equity of 12%.

Table 28. WACC features of CCGT power plants

Name of the Project	IDC share	Taxes and other costs' share	Debt Ratio	Cost of Debt	Cost of Equity	WACC
Erzin NGPP	5,0%	4,0%	70%	7,8%	12,0%	9,1%
Cengiz NGPP	5,0%	4,0%	70%	7,8%	12,0%	9,1%
Yesilyurt NGPP	5,0%	4,0%	70%	7,8%	12,0%	9,1%

Compared to coal fired power plants, natural gas power plants nearly have similar initial investment figures with import coal fired power plants. Additionally, with the liberalization of the energy market and geopolitical location of Turkey, natural gas fired power plants were always the first choice of the investors with its fast construction period, availability of the fuel, and flexibility compared to other power plants. However, Turkey’s dependency on imported natural gas bases on wrong policies in gas supply agreements and gas-fired power plant licensing processes. Recently observed low electricity prices in the market had made natural gas power plant investments unattractive and unprofitable.. Strengthening the regulations on license applications and current market conditions had decreased the level of applications on natural gas fired power plants.

4.5.Data Set for Cost Projection Model

In order to calculate LCOE, data presented in the previous section will not be sufficient. As discussed in the LCOE section, variable & fixed OPEX rates, economic lifetimes, construction times, efficiencies, capacity factors, plant availabilities, fuel costs and also local and global cumulative capacity deployments are necessary. Data presented below covers these factors.

Table 29 presents the local & global learning rates as well as local and global cost component rates. Regarding to the learning rate section and macroeconomic structure of the thesis, these 4 factors are crucial for future TOC projections which affects LCOE calculations. While all of the global learning rates were taken from the same study [39], local learning rates based on different assumptions.

Global learning rates for each technology were taken as constant for all countries. However, local learning rates differ significantly based on the experience and future capacity deployment projections. Coal and lignite fired technologies have 5% and CCGT technology has 10% learning rate whilst PV and wind technologies have 20% and 17% learning rates, respectively. Despite the global 10% learning rate of CCGT technology, local learning is taken 2% for Turkey. The main motive beneath this assumption is that capacity deployment of CCGT technology is expected to cut off from year 2025 while total increase in capacity is expected to be 6 GW which is far behind the global capacity deployment rate. From the hard coal perspective, installed capacity is expected to rise 333% until 2035 according to the base scenario. Thus local learning rate was assumed to be parallel with the global rate. If we consider the lignite-fired power plants, total increase in the installed capacity is expected to be around 100% until 2035. Compared to hard coal-fired power plants, deployment rate is lower which might result in lower local learning rate. However, deployment rate is not the only factor. Current market conditions for lignite-fired power plants suggest that western technology is by far the market leader. But, recently cheaper Chinese technology has started to increase its market share which has taken the costs down. Consequently same learning rate with hard coal-fired power plants is applicable to lignite-fired power plants.

From the renewable energy point of view, local learning rates were assumed to be 10% for both technologies. Western dominance on the wind power market is expected to keep its pace and on the PV market China is the market leader already. Therefore cost reductions on both wind and PV markets from change in market structure is unlikely. That is why, only deployment rates were taken into consideration.

Considering the global and local cost components, as mentioned in the previous sections, global cost components are the costs that are determined under international competition and local cost component is the cost that is determined in the local market such as labor, utilities, construction and etc.

Table 29. global and local learning rates and cost components in the model

Technology	Global Learning Rate (%)	Local Learning Rate (%)	Global Cost Component (%)	Local Cost Component (%)
CCGT	10%	2%	85%	15%
Coal	5%	5%	85%	15%
Lignite	5%	5%	85%	15%
Solar PV	20%	10%	75%	25%
Wind	17%	10%	75%	25%

Thermal power plant OPEX values listed in Table 30 are provided as the internal data prepared by Statkraft analysts. However, fixed OPEX values for renewable energy systems were taken from projects reviewed.

Table 30. Fixed and variable OPEX rates in the model

Technology	Fixed OPEX (k$/MW)	Variable OPEX ($/MWh)
CCGT	2	4,21
Coal	6,41	5,53
Lignite	5,83	5,03
Solar PV	25	0
Wind	20	0

In addition, fuel costs that are integrated in the model can be seen in table 31. Prices of natural gas, and hard coal can be derived from global markets. Consequently fuel costs of hard coal and gas are determined by Statkraft analysts. On the other hand, lignite prices are determined locally and even vary in the country. Thus, lignite prices in Turkey are calculated according to the average price reported in [66], converted to $/MWh accordingly with the calorific value and power plant efficiency assumptions, and then extrapolated to 2025 by the price increase on hard coal.

Table 31. Fuel costs in the model

Fuel Prices ($/MWh)	2015	2025
Coal Turkey	11	15
Gas Turkey	28	34
Lignite Turkey	8	12

Economic lifetimes of power plant technologies were chosen constant for each country. Renewable energy systems assumed to have 25 years of lifetime while coal and lignite fired power plants have 35 years and CCGT has 30 years. Construction times of each technology were determined from the plants reviewed in the previous section. Coal and lignite fired power plants are built in 3 years, CCGTs are built in 2,5 years and renewable energy systems are built in a year on the average. As mentioned, duration of construction time affects the IDC component of CAPEX and regarding to the LCOE formula used in the model, IDC share is significantly important for TOC discounting. Higher the IDC, higher the discounted value.

While capacity factors and efficiencies were determined from the plant data list, availability rates were chosen to be constant for all countries for the sake of the study conducted. From the capacity factor point of view, coal and lignite fired power plants have the highest rate at 92% and solar PV has the lowest rate at 20%.

Table 32. Other technical factors in the model

Technology	Economic Lifetime (yrs)	Construction Time (yrs)	Fuel Net Efficiency (%)	Capacity Factor (%)	Availability (%)
CCGT	30	2.5	56%	100%	90%
Coal	35	3	43%	100%	90%
Lignite	35	3	39%	100%	90%
Solar PV	25	1	100%	20%	99%
Wind	25	1	100%	30%	95%

Importance of the cumulative installed capacities is necessary for the TOC projections and local learning rate assumptions. Local cumulative capacity deployments until 2030 were taken from BNEF-WWF study covered in the literature review. Capacity rates were determined accordingly with the future plans and projections tracked in Turkish energy market. Increase in the CCGT capacity is expected to cut down by the year 2025 while share of lignite and coal fired power plants increase overtime.

Considering the global deployments which are related to the global learning rate in the projections, different studies were investigated. For wind and solar PV technologies rates were taken from BNEF and rates for gas and coal are taken from IHS.

Table 33. Cumulative capacity deployments according to state plans and projections

	Local Cumulative Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
Gas	21	24	25	25	25
Coal	6	8	10	12	14
Lignite	8.5	13	17	22	27
Wind	4	17	25	38	51
Solar PV	0	2	8	16	25

Table 34. Global cumulative capacity deployments

	Global Cumulative Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
Gas	1582	1746	2019	2394	2848
Coal	1901	2031	2168	2350	2530
Wind	408	662	903	1217	1531
Solar PV	243	589	1137	1841	2545

5. RESULTS

In this chapter, results of the cost projection model are presented. Analysis of the model is conducted over 2 different scenarios. Scenario-1 (Base scenario) relies on the official state plans for years 2023 and 2030. Scenario-2 (Current Policies scenario) bases on the data implemented from EMRA web site according to current applications for licenses regardless of the state plans and projections.

5.1.Base Scenario

Cumulative capacity deployments for future projections on the base scenario are taken from official state plans for 2023 and 2030. According to these plans share of gas-fired power plants in power generation will fall to 30% in 2023 from 48,1% in 2014. Table 35 presents the capacity deployment rates for base scenario and figure 5 presents the share of technologies in the installed capacity in 2035. It is worth to mention that, hydropower plants, nuclear power plants and other thermal power plants are excluded since they are not included in the scope of this study.

Table 35. Cumulative capacity deployments under base scenario

	Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
Gas-Fired	21	24	25	25	25
Coal-Fired	6	8	10	12	14
Lignite-Fired	8,5	13	17	22	27
Wind	4	17	25	38	51
Solar PV	0	2	8	16	25

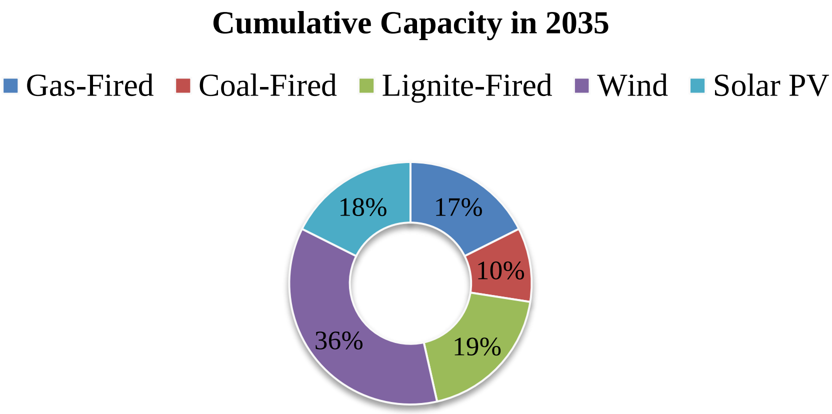

Figure 5. Distribution of cumulative capacity according to base scenario

As can be seen in Table 35, increase in the CCGT technology capacity will be limited to 25 GW with the interest of reducing its share in power generation to 30% in 2023. On the coal and lignite perspective, domestic resources gain importance compared to imported coal power plants. Deployed capacity is stated as 14 GW for import coal power plants and 27 GW for lignite power plants in the year 2035. Renewable energy deployments, which is the most important section of the Table, suggests that while capacity deployment on wind power will far exceed all technologies with 51 GW, solar PV will gain fast deployment rate compared to other thermal technologies with an increase from 54 MW in 2014 to 25 GW in 2035.

5.1.1. LCOE Results of Base Scenario

According to the results observed in the base scenario analysis despite the high LCOE rates of PV and wind in 2015, rates fall down drastically through 2035 making them the most profitable technologies. On the other hand, CCGT technology has the highest LCOE rate in 2035 regarding to the high fuel prices despite high efficiency rates (Figure 6).

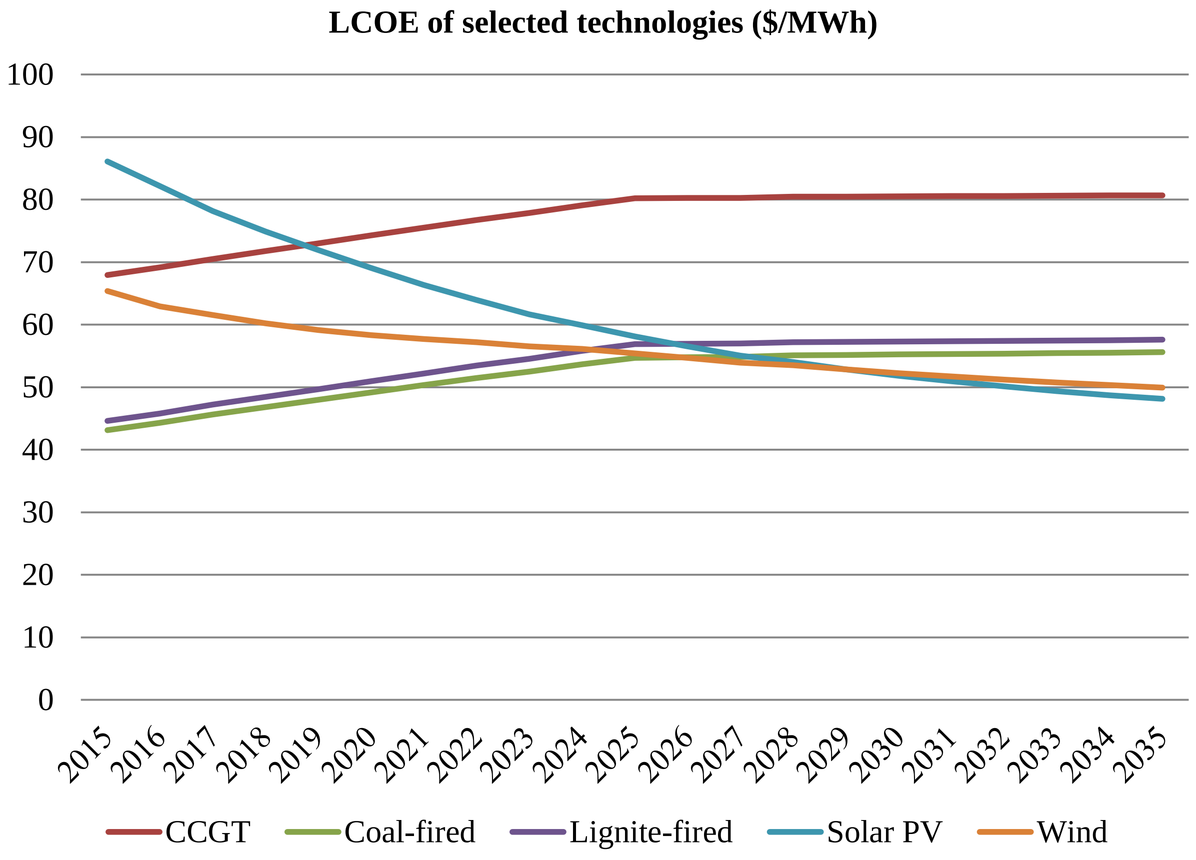

Figure 6. LCOE projections according to base scenario

In the light of the presented LCOE results in Table 36, LCOE of CCGT, coal, lignite, solar PV and wind is 80,18 $/MWh, 55,58 $/MWh, 57,57 $/MWh, 48,11 $/MWh, 49,92 $/MWh respectively in 2035. While LCOE of CCGT, coal and lignite increases by 18,7%, 28,8% and 29% respectively, LCOE of Solar PV decreases by 44% and LCOE of wind decreases by 23% from 2015 to 2035.

Table 36. LCOE results according to base scenario

LCOE selected technologies [$/MWh]	2015	2020	2025	2030	2035
CCGT	67,95	74,16	79,98	80,15	80,18
Coal-fired	43,15	49,14	54,68	55,22	55,58
Lignite-fired	44,62	50,94	56,87	57,31	57,57
Solar PV	86,07	69,03	58,11	51,82	48,11
Wind	65,35	58,31	55,42	52,24	49,92

5.1.2. TOC Results of Base Scenario

Regarding to the results observed in the base scenario analysis high TOC figures of PV and wind in 2015, rates fall down drastically towards the year 2035. Especially, the decrease in PV TOC making it the one with the lowest TOC. On the other hand lignite-fired technology has the highest TOC rate in 2035 regarding to the high initial investment rates and low learning rates. (Learning rates are lower than the expected price increase. Thus TOC rates increase for thermal technologies (Figure 7).

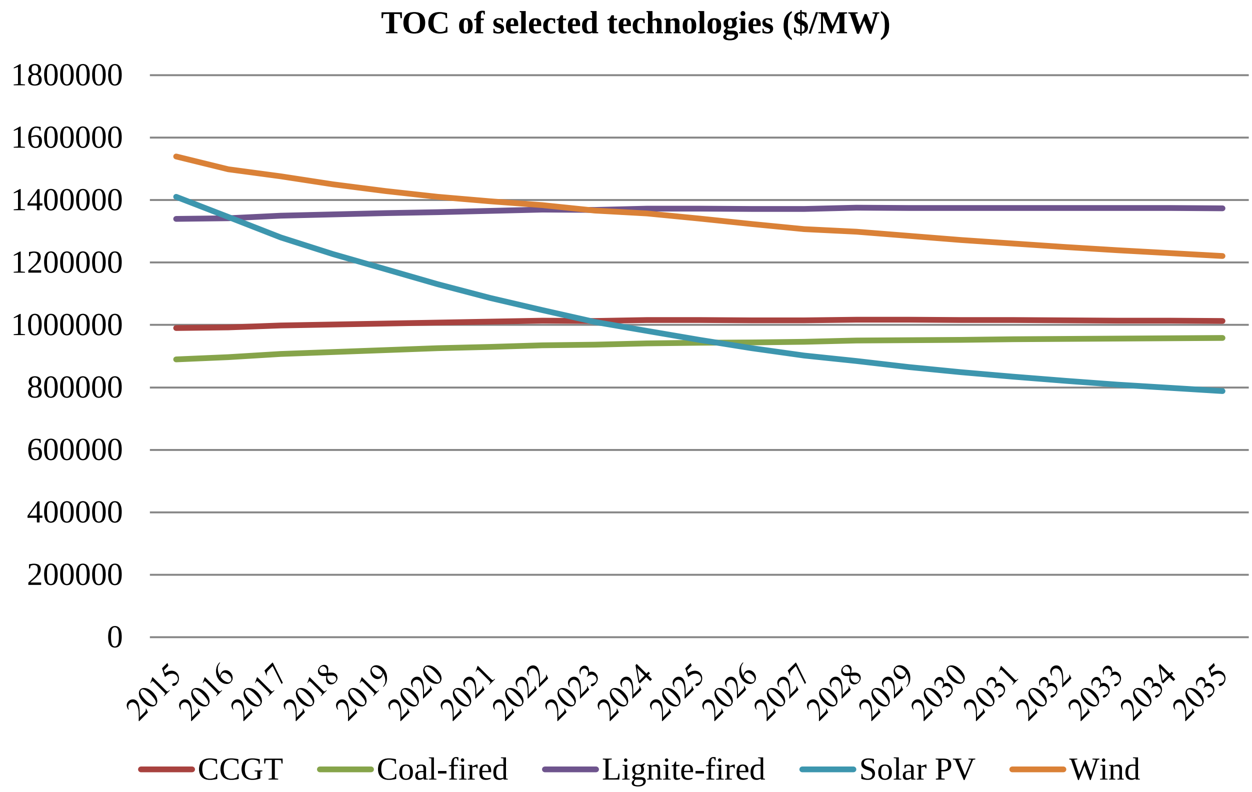

Figure 7. TOC projections according to base scenario

Considering the presented TOC results in Table 37 CCGT, coal, lignite, solar PV and wind has 1,012 $M/MW, 0,968 $M/MW, 1,374 $M/MW, 0,788 $M/MW and 1,176 $M/MW TOC figures in 2035. While TOC of CCGT, coal and lignite increases by 2,3%, 8,8%, 2,5% respectively, TOC of Solar PV decreases by 44% and TOC of wind decreases by 23% from 2015 to 2035.

Table 37. TOC results according to base scenario

TOC of selected technologies [M$]	2015	2020	2025	2030	2035
CCGT	990.000	1.007.701	1.015.581	1.015.992	1.012.976
Coal-fired	890.000	926.428	948.463	960.702	968.524
Lignite-fired	1.340.000	1.360.343	1.372.414	1.374.757	1.374.084
Solar PV	1.410.000	1.130.937	952.016	848.974	788.177
Wind	1.540.000	1.374.045	1.305.916	1.230.953	1.176.355

5.1.3. Sensitivity Analysis

Under the base scenario, a sensitivity analysis is conducted in order to observe the primary factors affecting the LCOE levels of each technology. In the context of this sensitivity analysis; discount rate, efficiency factor, capacity factor, lifetime, TOC, fixed OPEX, variable

OPEX and fuel price variations were observed. Variations on each factor were taken ±5%, ±10%, ±15%, ±20%, ±25%. Results of sensitivity analysis is presented at the Table 38.

From the efficiency perspective which is the most commonly effecting variable, 25% increase in efficiency causes 22,2%, 19,3%, 14,8% decrease in LCOE of CCGT, coal and lignite, respectively. On the contrary, 25% decrease in efficiency rate results in 13,3%, 11,6% and 8,8% increase LCOE of CCGT, coal and lignite, respectively. Fuel prices, which is the second most commonly effecting variable of thermal power technologies; 25% increase in fuel prices cause 16,6%, 14,5% and 11% increase in LCOE of CCGT, coal and lignite respectively. On the other hand, 25% decrease in fuel prices results in 16,6%, 14,5%, 11% decrease in LCOE of CCGT, coal and lignite technologies, respectively.

Compared to thermal power plants, capacity factor and TOC are the most important variables effecting LCOE of renewable energy technologies. 25% increase in the capacity factors results in 20% increase in LCOE of both wind and solar PV technologies whilst 25% decrease results in 33% decrease in the subjected LCOE. From the TOC point of view, 25% decrease in the TOC results in 20.8% and 21.1% decrease in LCOE of solar PV and wind respectively. On the other hand, 25% increase in the TOC causes 20.8% and 21,1% increase in LCOE of solar PV and wind power, respectively.

Despite the importance of WACC in calculating the discounted rates for LCOE; variability of WACC in LCOE deviations is quite small compared to other factors affecting each technology. Additionally, variable OPEX and fuel prices do not affect LCOE at all in renewable energy technologies, since both variables are set to zero for both technologies. From the CO_2 price point of view, currently CO_2 does not has a price in the means of trading in Turkey. Therefore, it was not calculated for all technologies analyzed. Power plants in EU are on the other hand subjected to a carbon price plus carbon tax in numerous countries. Price of the carbon is set on a market scheme called as The EU Emissions Trading System. E.g. in the UK carbon tax is 18.08 £/ton with the addition of carbon price from Emissions Trading System total floor price of carbon is observed as 23 £/ton.

Table 38. Sensitivity analysis results of the base scenario

	Discount Rate		Efficiency		Capacity Factor		Lifetime		TOC		Fixed OPEX		Variable OPEX		Fuel Price		CO2 Price	
Technology	**-25%**	**25%**	**-25%**	**25%**	**-25%**	**25%**	**-25%**	**25%**	**-25%**	**25%**	**-25%**	**25%**	**-25%**	**25%**	**-25%**	**25%**	**-25%**	**25%**
CCGT	4,2%	-4,6%	-24,5%	14,7%	-6,7%	0%	-1,6%	0,7%	5%	-5%	0,1%	-0,1%	1,5%	-1,5%	18,4%	-18,4%	0,0%	0,0%
Coal	6,2%	-6,8%	-19,8%	11,9%	-9,7%	0%	-1,6%	0,7%	6,8%	6,8%	0,4%	-0,4%	2,9%	-2,9%	14,8%	-14,8%	0,0%	0,0%
Lignite	9,0%	-9,9%	-15,3%	9,2%	-13,9%	0%	-2,4%	1,0%	10,0%	-10,0%	0,5%	-0,5%	3,1%	-3,1%	11,5%	-11,5%	0,0%	0,0%
PV	13,0%	-13,8%	0,0%	0,0%	-33,3%	20,0%	-10,8%	5,7%	20,8%	20,8%	4,2%	-4,2%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Wind	13,4%	-14,3%	0,0%	0,0%	-33,3%	20,0%	-10,7%	5,6%	21,1%	21,1%	3,8%	-3,8%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

5.2.Current Policies Scenario

Current policies scenario is based on the information compiled from EMRA's website that presents the pre-licensing applications, licensed projects and licensed projects that are in the construction phase (Table 38). According to the data compiled; 24% of the licensed gas-fired power plants, 6,8% of the import coal fired power plants, 17,5% of lignite fired power plants and 47,1% of the wind power plants are cancelled between the years 2007-2015. Assuming 100% acceptance rate for all projects in pre-licensing period total licensed capacity is presented in Table 40. Multiplying total licensed project capacity with the cancellation rate for each technology yields the total increase in capacity deployment. Resulting capacities are; 19 GW for CCGT, 2,8 GW for lignite-fired, 9,7 GW for coal-fired and 4,8 GW for wind power. These capacities for thermal power plants are expected to be commissioned by 2025, commission date for wind power plants is 2020 according to EMRA (Table 41).

Table 39. Capacity projection calculations of current policies scenario (I)

Technology	Pre-licensing (MW)	License acquired (MW)	Under Construction (MW)	Total Cancelled (MW)	Cancellation rate (%)
CCGT	6.778	18.347	1.275	6.192	23,99%
Domestic Coal	825	2.269	3.736	165	6,78%
Import Coal	8.310	3.545	3.545	750	17,46%
Wind	3.347	5.808	1.028	5171	47,10%

Table 40. Capacity projection calculations of current policies scenario (II)

Technology	100% acceptance of Pre-licensing (MW)	Total Licensed (MW)	Cancellations (MW)	Total Increase in Deployment (MW)
CCGT	6.778	25.125	6.027	19.098
Domestic Coal	825	3.094	210	2.884
Import Coal	8.310	11.855	2.070	9.785
Wind	3.347	9.155	4.312	4.843

Table 41. Cumulative capacity deployments according to current policies scenario

	Capacity Deployments (GW)				
Technology	**2015**	**2020**	**2025**	**2030**	**2035**
Gas-Fired	21	31	40	49	58
Coal-Fired	6	9	16	23	30
Lignite-Fired	8,5	12	17	22	27
Wind	4	9	14	19	24
Solar PV	0	2	8	16	25

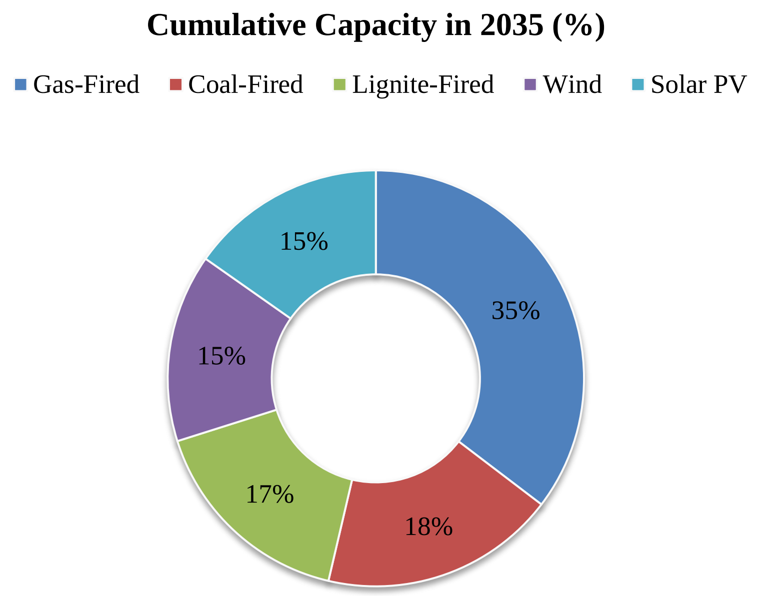

Figure 8. Distribution of cumulative capacity according to current policies scenario

5.2.1. LCOE Results of Current Policies Scenario

According to the results observed in the base scenario analysis, despite the high LCOE rates of PV and wind in 2015, rates fall down drastically towards the year 2035 making them the most profitable technologies. On the other hand CCGT technology has the highest LCOE rate through 2035 regarding to the high fuel prices despite its relatively high efficiency rates (Figure 9).

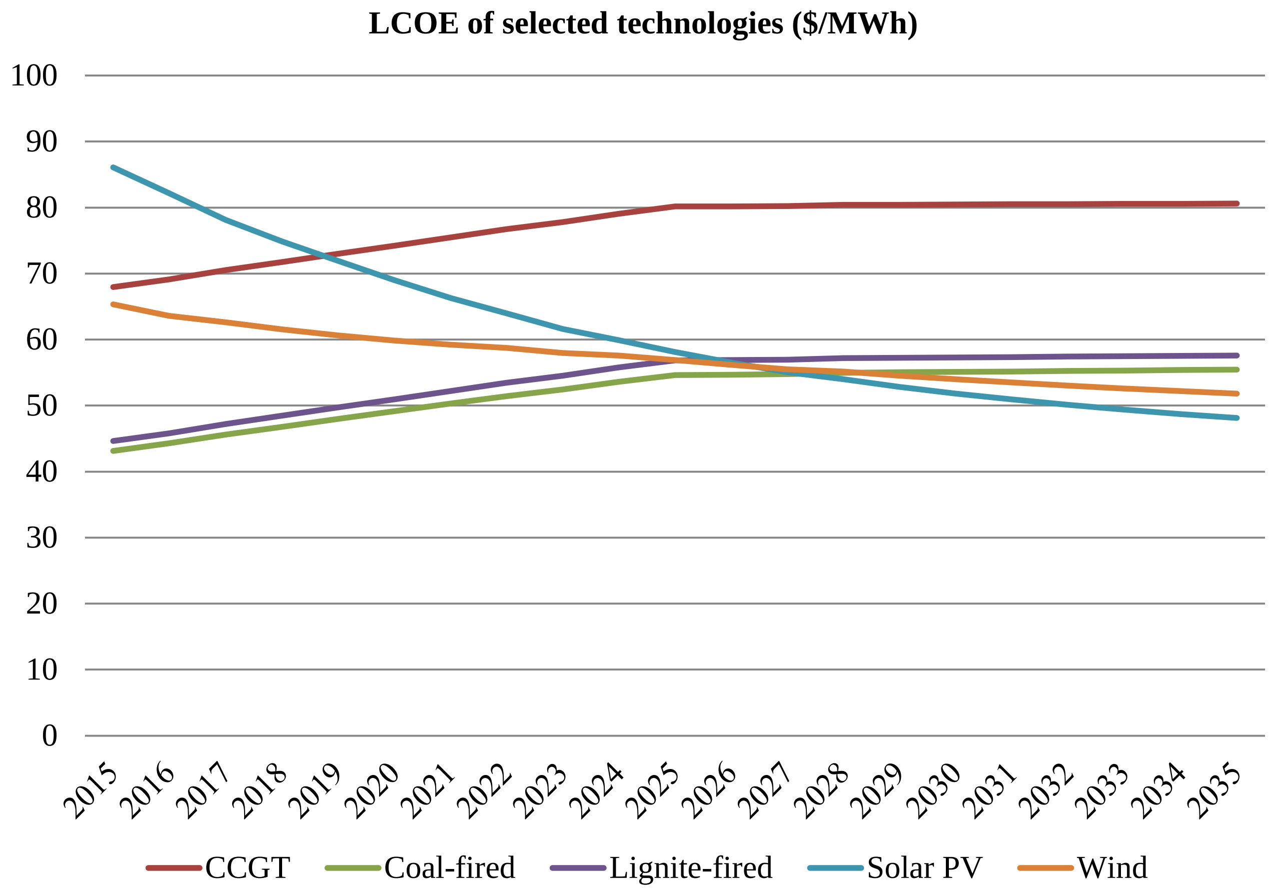

Figure 9. LCOE projctions according to current policies scenario

In the light of the presented LCOE results in Table 42**,** LCOE of CCGT, coal, lignite, solar PV and wind is 80,61 $/MWh, 55,45 $/MWh, 57,57 $/MWh, 48,11 $/MWh and 51,81 $/MWh, respectively in 2035. LCOE of CCGTs increases by 18,6%, LCOE of coal and lignite increases by 28,5% while LCOE of solar PV decreases by 44% and LCOE of wind decreases by 20,7% from the year 2015 to 2035.

Table 42. LCOE results according to current policies scenario

LCOE selected technologies [$/MWh]	**2015**	**2020**	**2025**	**2030**	**2035**
CCGT	67,95	74,23	80,16	80,46	80,61
Coal-fired	43,15	49,12	54,60	55,11	55,45
Lignite-fired	44,62	50,96	56,87	57,31	57,57
Solar PV	86,07	69,03	58,11	51,82	48,11
Wind	65,35	59,86	56,88	53,98	51,81

Compared to base scenario analysis, same trends have been obtained. LCOE of thermal power technologies show an increase from 2015 to 2035 while LCOE of renewable technologies decrease. The main difference observed is the increase of CCGT LCOE and decrease of wind LCOE was less than the results of base scenario.

5.2.2. TOC Results of Current Policies Scenario

Regarding to the results observed in the current policies scenario analysis despite the high TOC figures of PV and wind in 2015, rates fall down drastically towards the year 2035. Especially PV TOC falls down, making it the technology with the lowest TOC in 2035. On the other side, lignite-fired technology has the highest TOC rate in 2035 regarding to the high initial investment rates and low learning rates (Figure 10).

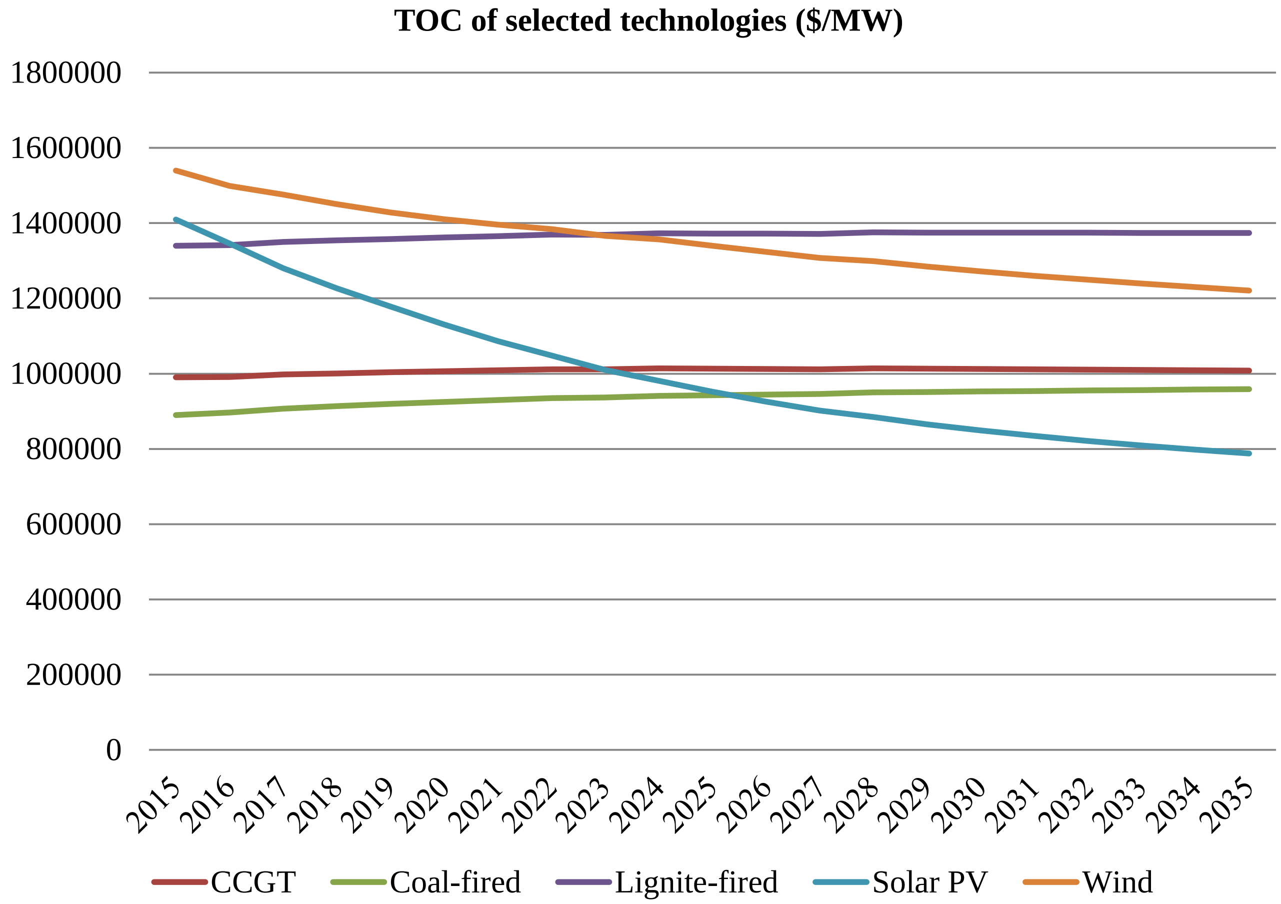

Figure 10. TOC projections according to current policies scenario

Considering the presented TOC results in Table 43 TOC of CCGT, coal, lignite, solar PV and wind is 1,007 $M/MW, 0,958 $M/MW, 1,374 $M/MW, 0,788 $M/MW and 1,22 $M/MW, respectively in 2035. TOC of CCGT, coal and lignite increases by 1,8%, 7,7% and 2,5%, respectively, while TOC of Solar PV decreases by 44% and TOC of wind decreases by 23% from 2015 to 2035.

Table 43. TOC results according to current policies scenario

TOC of selected technologies [M$]	2015	2020	2025	2030	2035
CCGT	990.000	1.006.421	1.013.007	1.012.126	1.007.970
Coal-fired	890.000	925.107	942.838	952.636	958.875
Lignite-fired	1.340.000	1.361.691	1.372.414	1.374.757	1.374.084
Solar PV	1.410.000	1.130.937	952.016	848.974	788.177
Wind	1.540.000	1.410.580	1.340.284	1.272.061	1.220.895

Compared to base scenario, TOC of the CCGT and lignite-fired falls down by 5 k$/MW, and 9,6 k$/MW respectively prices of wind power increases by 44,5 k$/MW in 2035. It can be observed that, increase in the deployed capacity yields in decrease in TOC and decrease in deployed capacity results in increase in TOC.

5.3.PV with External Costs

As it is mentioned in the Solar PV data list section, initial investment figures of PV systems do not include the contribution margins to be paid to transmission system operator. The logic behind the contribution margin is; if there is more than 1 project applied to the same region with a limited capacity, a tender is held between the applicants. Tender is subjected to a rate named as contribution margin which is determined as Turkish Lira/MW and expected to be paid to transmission system operator in 3 years. In the latest tenders held, with the contribution margins taken into account TOC was calculated as 1,61 M$/MW with minimum contribution margin (MinCM), 1.95 M$/MW with the median contribution margin (MedCM), 2,31 M$/MW with the maximum contribution margin (MaxCM) whereas data used in the previous models was 1,41 M$/MW for solar PV excluding the margins paid.

However, as it can be observed from the data presented above, contribution margins can be considered as Owner's Costs and affects the TOC directly. Therefore this section of results chapter is prepared for the presentation of TOC and LCOE results of PV power plants with minimum, median, maximum and zero contribution margins included.

5.3.1. LCOE Results

Analyzing the results of cost projection model, maximum contribution margin (MaxCM) project starts at 131,8 $/MWh in 2015 and results at 73,68 $/MWh in 2035 while the zero contribution margin (ZeroCM) project starts at 86,07 $/MWh in 2015 and results at 48,11 $/MWh in 2035. Looking at the percentage changes in LCOE rates, ZeroCM is exposed to

44% decrease, MinCM is exposed to 49% decrease, MedCM is exposed to 58% decrease and MaxCM is exposed to 68% decrease in LCOE rates. This implies that, LCOE rates converge to each other towards the year 2035.

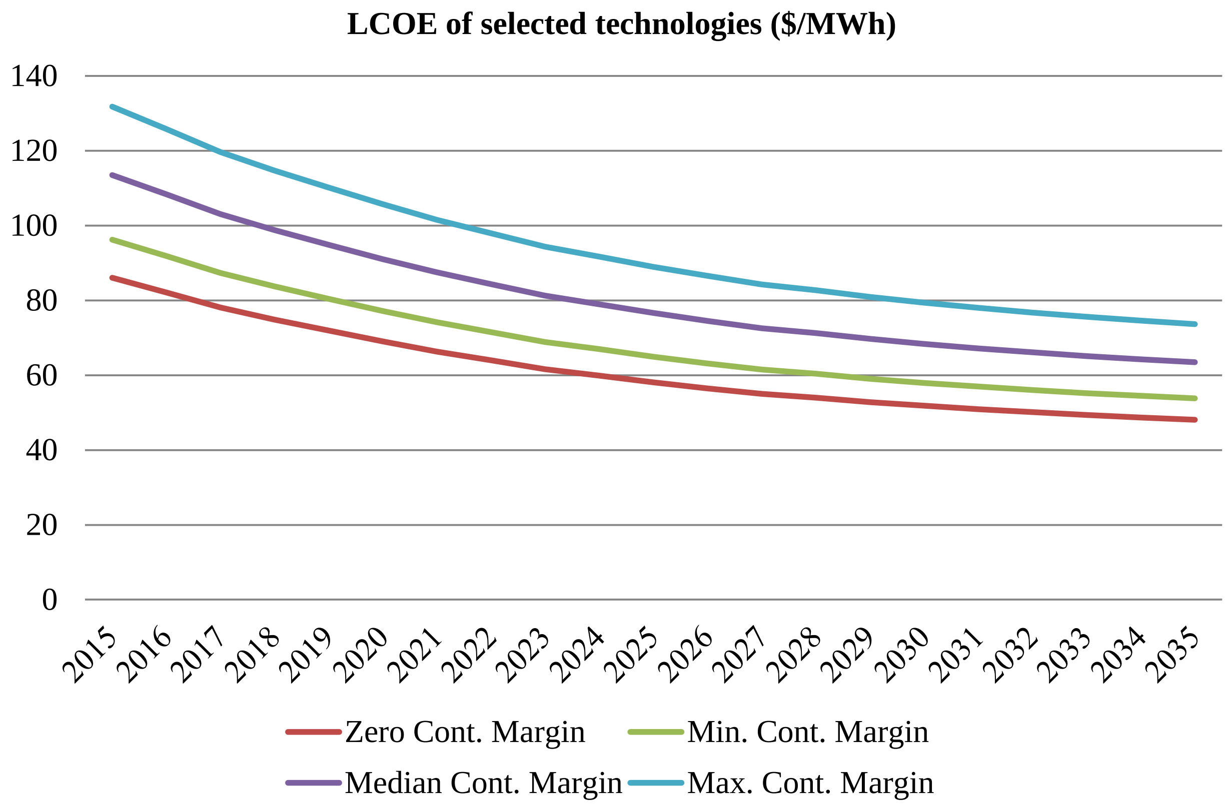

Figure 11. LCOE projections according to PV projects with external costs

Table 44. LCOE results of PV with external costs

LCOE selected technologies [$/MWh]	2015	2020	2025	2030	2035
Zero Cont. Margin	86,07	69,03	58,11	51,82	48,11
Min. Cont. Margin	96,23	77,18	64,97	57,94	53,79
Median Cont. Margin	113,51	91,04	76,64	68,34	63,45
Max. Cont. Margin	131,80	105,72	88,99	79,36	73,68

5.3.2. TOC Results

Looking at the TOC results, TOC figure of the project with MaxCM declined from 2,31 M$/MW in 2015 to 1,29 $M/MW in 2035 while TOC of the project with ZeroCM declined from 1,41 M$/MW in 2015 to 0,79 M$/MW in 2035. Compared to LCOE, percentage change in TOC rates are equal in every case resulting at 44%. Thus, it can be concluded that TOC figures do not converge to each other as opposed to LCOE figures.

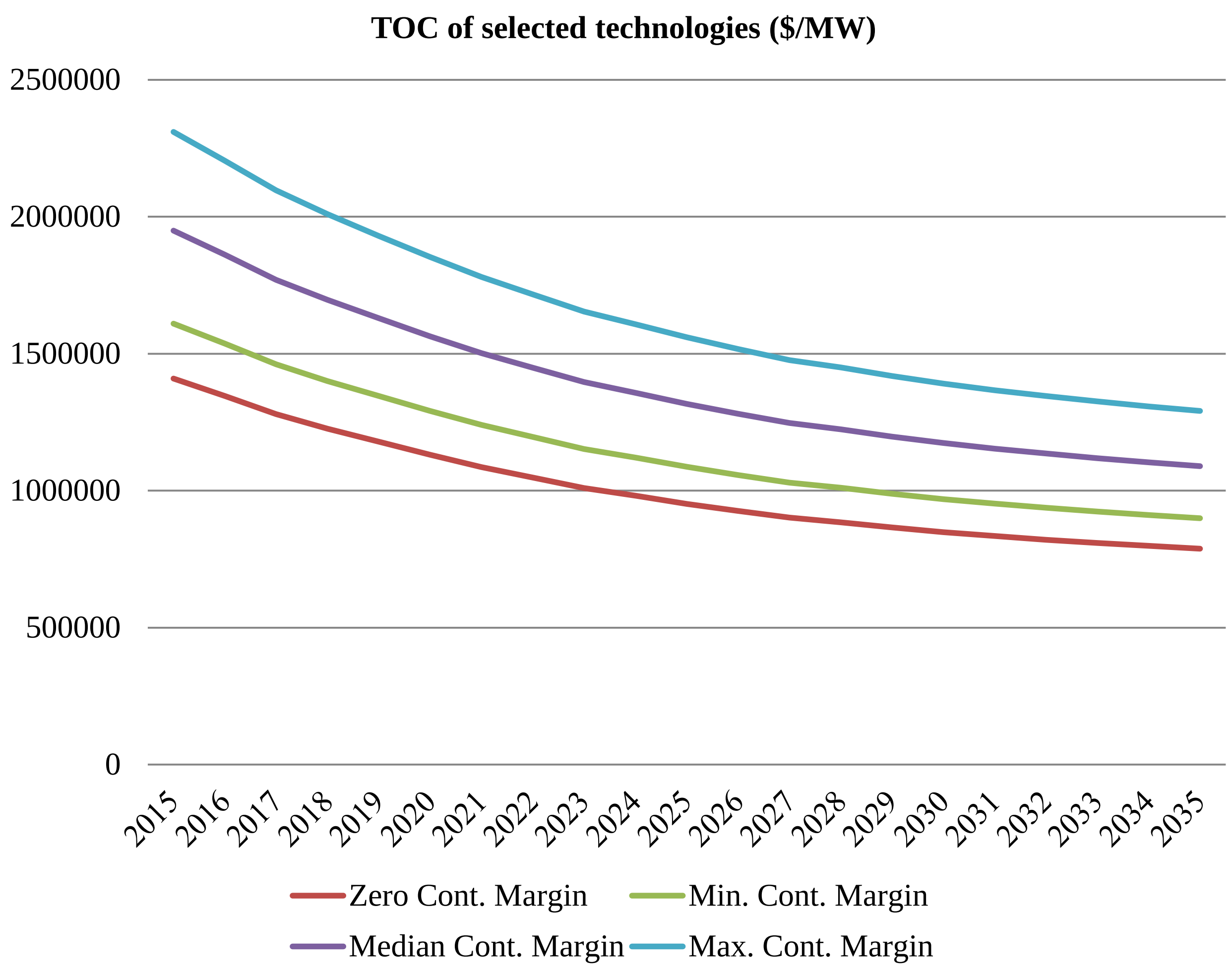

Figure 12. TOC projections according to PV projects with external costs

Table 45. TOC results of PV with external costs

TOC of selected technologies [M$]	2015	2020	2025	2030	2035
Zero Cont. Margin	1.410.000	1.130.937	952.016	848.974	788.177
Min. Cont. Margin	1.610.000	1.291.354	1.087.053	969.395	899.975
Median Cont. Margin	1.950.000	1.564.062	1.316.617	1.174.112	1.090.032
Max. Cont. Margin	2.310.000	1.852.812	1.559.685	1.390.871	1.291.269

6. CONCLUSION

Throughout the thesis study conducted, TOC and LCOE projections of CCGT, coal-fired, gas-fired, solar PV and wind power technologies were analyzed from 2015 to 2035. With the current market conditions in Turkey and under either base scenario that is structured on the state plans and projections, or current policies scenario which is based on the current applications for licenses, solar PV has lower LCOE and TOC figures and wind power has lower LCOE figures in 2035 compared to thermal power technologies. This implies that, for solar PV not only electricity generation will be more profitable under renewable power generation but also less capital will be required for 1 MW of renewable energy technology compared to thermal power technologies. Regarding to results observed, LCOE of renewable technologies constantly fall down, increasing their competitive advantage to thermal power technologies which has increasing LCOE figures overtime. However, these rates were calculated based on the average figures from plant database. Thus, calculated LCOE rates should be analyzed over the average values to be observed. Actual figures can vary with the subjected technology.

Constant decrease on the renewable power technology LCOE is directly related with the learning rates they are exposed to. 20% learning rate for solar PV and 17% for wind is considerably high compared to thermal technologies, but increase in both global and local capacity deployment of renewable energy systems and massive R&D studies to increase efficiencies of PV modules are all considered in the learning rates of renewable energy technologies with the addition of global policies on reducing CO_2 emissions.

Despite the renewable power technology favoring results obtained in this study, a comparison between various studies conducted on LCOE projections should be considered. Among the studies investigated through the literature review, EUSUSTEL, VGB, EPIA, NREL, EWEA and Fraunhofer ISE provide projections for future. Table 46 presents the results obtained from these studies.

Table 46. Comparison of LCOE results of reviewed literature

Name of the Study	Year Conducted	Focus Country	Projection Year	CCGT ($/MWh)	Coal-fired ($/MWh)	Lignite-fired ($/MWh)	Solar PV ($/MWh)	Wind ($/MWh)
EUSUSTEL	2007	EU-25	2030	70-73	28-52	x	44-118	26-89
EPIA	2011	Global	2020	x	x	x	104	x
NREL	2010	U.S.	2030	53	53	x	211	56
EWEA	2010	Global	2030	53	61	x	x	86
Fraunhofer ISE	2013	Germany	2030	112-162	100-137	62-100	61-125	50-125
EIA	2014	U.S.	2040	81,2	87	x	101,3	73,1
Thesis	2015	Turkey	2030	88,85	56,4	58,96	51,82	52,24

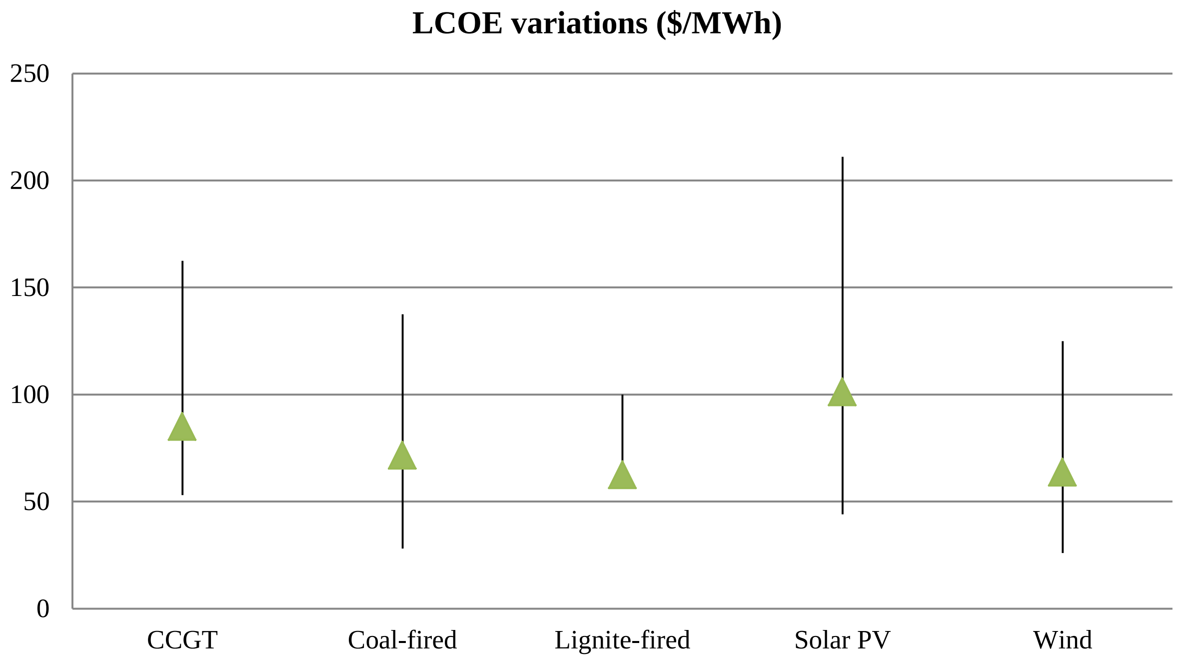

Figure 13. LCOE variations from the reviewed literature

According to the comparison, wind power increases its competitiveness compared to thermal technologies in all cases. However, solar PV does not gain enough competitive advantage over thermal power compared to wind power. Resulting variations among LCOE figures mainly caused from different learning rate assumptions, locality in the input database –expensive in Europe, cheaper in Asia, CO_2 prices against thermal power LCOE figures and external costs which are determined over impact on human and environment.

In the light of the conclusions of this thesis study, there are certain challenges for authorities to shift market according to the base scenario rather than current policies scenario. Increasing the share of domestic resource usage, lignite for this case, can be viewed logical under economic conditions. However from the environment and human health point of view, reliance on renewable energy technologies should keep their priority. But there are numerous challenges in front of renewable energy utilization in Turkey. First of all, since 2005, when renewable energy law was put in commission, there are several bureaucratic processes tied to each other for the case of license applications, license acquisition, construction and operation. Since the first capacity auctions of wind power, these conditions had put so much pressure not only on the investors but also on the regulatory authority and the ministry. Softening these processes will definitely be a supportive measure for a more stable and smooth licensing, constructing and operation periods. Secondly, current market structure does not enable households to participate in the solar PV market freely. Again regarding to the bureaucratic complexity, household consumers are drawing themselves off from roof-top PV systems. Third, financial institutions such as banks, funds and etc. should definitely adapt project financing techniques to provide better financial solutions for investors which are applied in numerous countries. Thus, rather than bringing foreign financing solutions, e.g. loans from Chinese institutions to build a lignite-fired power plant in Manisa, local institutions will gain importance. Finally, although the presence of policies on increasing the share of domestic lignite fired power plants, current applications and market development suggests that share of import coal fired power plants is increasing rapidly compared to lignite fired ones. While encouraging domestic resource usage and decreasing the dependency on imported resources, there should be certain measures to slowdown and stabilize the import coal fired power plant investments. Without considering these challenges, it seems unlikely to reach base scenario projections.

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