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A market based electricity capacity mechanism model for Turkey

Türkiye için piyasa tabanlı bir kapasite mekanizması modeli

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A Market Based Electricity Capacity Mechanism Model for Turkey

Highlights

- *The "Missing Money Problem" results resource adequacy where occurs loss of loads.*
- *Capacity mechanisms are commonly preferred by liberalized markets as supplementary tools to meet resource adequacy in addition to energy-only pools.*
- *This stıdy aims to propose a novel capacity auction model for Turkish electrcity system to provide system reliablity considering security and adequacy.*

Graphical Abstract

A robust and fair Capacity Auction mechanism is proposed for Turkish electricity market where Capacity Payments method has been already implemented. Forecasts and sensitivity analysis proved that a Capacity Auction is more efficient than current scheme.

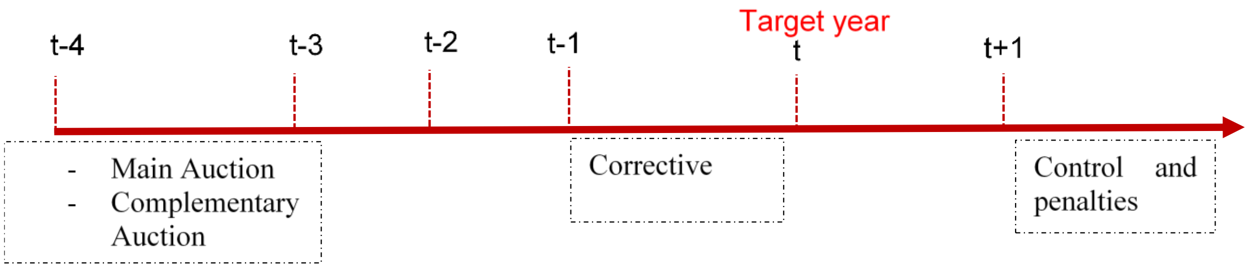

Figure. Proposed auction process for capacity

Aim

Discussion of capacity remuneration mechanisms and proposal of a new auction based capacity mechanism for Turkish electricity market.

Design & Methodology

Designed capacity acution model was processed with two models as linear estimation model and Monte-Carlo method and results are discussed.

Originality

In terms of capacity mechanisms, the study is the first design propal for Turkish electricty market and it has a pioneering role.

Findings

Model resulted a more competitive capacity market with decreasing costs to the system while securing system reliability.

Conclusion

Results of modelling and sensitivity analysis shows that, other than existing capacity payment scheme, suggested auction mechanism prevents all renewable sources, which have very low marginal costs and benefit from renewable energy incentives, where base power plants and balancing service providers having relatively high-capacity factors are supported, facilitating the required market signal for potential new entrants/investments.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

A Market Based Electricity Capacity Mechanism Model for Turkey

Research Article / Araştırma Makalesi

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ABSTRACT

Market players in a liberalized electricity sector are subject to trading energy through bilateral agreements or organized platforms. Energy-only trading through those venues might fall short in providing the required conditions for system reliability due to the well-known phenomenon of "missing money problem". In order to avoid unintended loss of load, additional market mechanisms were developed in time. Several markets utilized capacity remuneration mechanisms to secure the system reliability through market-based or non-market-based models. Specifically, in Turkish electricity market, the regulator has implemented "direct payment" approach where generators fulfilling pre-determined conditions receive remunerations based on their installed capacities. This mechanism can be considered as a "quasi-market-based" model due to links to the market price formation. However, in principle, it should be categorized as a non-market-based model due to direct payments based on installed capacity levels. In this study, existing capacity remuneration mechanism in Turkey is analysed, an alternative market-based auctions model is developed and its results are simulated via Monte Carlo analysis. The study also elaborates on comparative advantages of the proposed market-based model over the existing approach and why it is a better option to preserve system reliability while being fully compliant with the electricity market reform goals.

Keywords: Electricity markets, capacity mechanisms, reliability, adequacy, auctions, monte carlo simulation.

Türkiye için Piyasa Tabanlı Bir Kapasite Mekanizması Modeli

ÖZ

Liberal bir elektrik sektöründeki piyasa oyuncuları, ikili anlaşmalar veya organize platformlar yoluyla enerji ticaretine tabidir. Bu platformlar aracılığıyla yalın-enerji ticareti, meşhur "kayıp para problemi" olgusu nedeniyle sistem güvenilirliği için gerekli koşulları sağlamada yetersiz kalabilir. Arzu edilmeyen yük kaybını önlemek için zamanla ilave piyasa mekanizmaları geliştirilmiştir. Bazı piyasalar, piyasa bazlı veya piyasa bazlı olmayan modeller aracılığıyla sistem güvenilirliğini güvence altına almak için kapasite fiyatlandırma mekanizmalarını geliştirmiştir. Spesifik olarak, Türkiye elektrik piyasasında düzenleyici otorite, önceden belirlenmiş koşulları yerine getiren üreticilerin kurulu kapasitelerine göre ücret aldığı "doğrudan ödeme" yaklaşımını uygulamıştır. Bu mekanizma, piyasa fiyatı oluşumuyla ilişkisi nedeniyle "yarı-piyasa temelli" bir model olarak düşünülebilir. Ancak bu model prensip olarak, kurulu güç miktarına dayalı doğrudan ödeme yapısına sahip olması nedeniyle piyasa bazlı olmayan bir model olarak kategorize edilmelidir. Bu çalışmada, Türkiye'deki mevcut kapasite fiyatlandırma mekanizması incelenmiş, alternatif bir piyasa bazlı ihale modeli geliştirilmiş ve sonuçları Monte Carlo analizi ile benzetime tabi tutulmuştur. Çalışma ayrıca, önerilen piyasa temelli modelin mevcut yaklaşıma göre karşılaştırmalı avantajlarını gösterirken önerilen modelin elektrik piyasası reform hedefleriyle tamamen uyumlu bir şekilde sistem güvenilirliğini koruma açısından mevcut duruma göre neden daha iyi bir seçenek olduğunu açıklamayı hedeflemektedir.

Anahtar Kelimeler: Elektrik piyasaları, kapasite mekanizmaları, güvenilirlik, yeterlilik, ihaleler, monte carlo benzetimi.

1. INTRODUCTION

In energy markets with vertically integrated structures, electricity is produced, transported and delivered to the final consumer as a commercial commodity through a single entity. On the other hand, in liberalized markets, generation, transmission, distribution activities, being mostly the physical activities, and the market activities such as wholesale and retail sales, having mostly commercial aspects are performed by different legal entities. Simultaneous supply and demand balance, in other words, assurance of sufficient generation to meet the demand for electrical consumption instantly is designated as a duty of legal entities called "System Operators". While this task was given to an independent institution or company in some countries, in some others it was entrusted to the transmission system operator as in Turkey. Turkish Electricity Transmission Corp. (TEİAŞ) is in charge of provision of supply-demand balance among Turkish interconnected system as a system operator and keeping the system frequency at nominal values.

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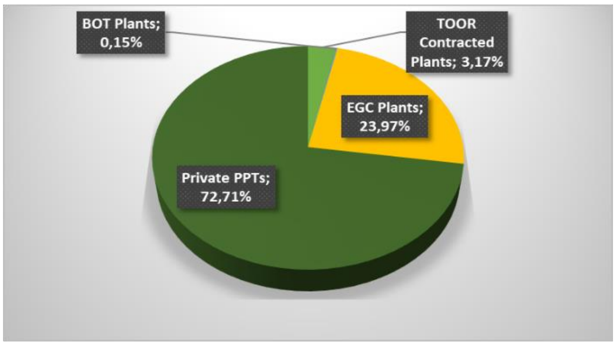
Figure 1 shows the ownership status of existing power plants in Turkey. By the end of 2020, more than 70% of power plants are privately owned. In this context, although TEİAŞ is tasked with the above-mentioned duties, the liberalized market is expected to provide the financial conditions that will allow investors to decide on the investments required for the system.



TOOR: Transfer of Operational Rights, BOT: Build-Operate-Transfer, EGC: Electricity Generation Company (Public), PPT: Power Plant.

Figure 1. Distribution of Licensed Electrical Installed Capacity by organizations as of the end of January 2021 [1]

In addition to provision of investment capital of power plants by returns, the annual stranded fixed and variable costs during production must be covered through the income from energy sales. In this context, revenues from bilateral agreements, over-the-counter markets or energy exchange directly affect the investment decisions.

In order to make the necessary plant investments to ensure capacity adequacy in the grid, energy-only markets where energy is bought and sold in kWh might not able to provide sufficient incentive, leading to the well-known "Missing Money Problem (MMP)". At this point, it is observed that "Capacity Mechanisms" are implemented in addition to energy-only markets. Specifically in Turkey, a "Capacity Payments" application has been in force since 2018 and monthly payments have been made to the plants participating in the mechanism.

This study examines the Turkish experience following the discussion of different capacity mechanisms, and then proposes an alternative approach together with the simulation results for the model proposed. The main objective is to contribute to a more functional and investment-oriented electricity market by establishing a mechanism which is cost-effective and supporting security of supply. In this context, first of all, necessity of capacity mechanism is discussed around MMP. Then, some European and U.S. practices are explained by providing examples of capacity mechanism/market requirements and methods. Thirdly, current capacity mechanism scheme of Turkey is presented and the principles of existing implementation are discussed. In the last part of the study, proposed market-based Capacity Mechanism and expected results are presented via simulations based on the proposed mechanism.

2. LITERATURE REVIEW

2.1. The "Missing Money Problem"

In organized and liberal electricity markets, especially with the high penetration of renewable energy, it is seen that there is a noticeable decrease in the energy prices in the market. This situation, which becomes more pronounced with the high supply, creates the MMP for producers who provide the required flexibility to the system but cannot cover their costs through the market due to the price ceilings as they work less hours throughout the year.

In cases where supply cannot meet or barely meet the demand, all plants in the system will be able to produce in a way that meets their operational fixed and variable costs (when even the power plant with the highest marginal cost could compensate its costs at the market price identified in the system). In this case, the demand side will move to increase prices until all the demand is met. This behavior may actually be marked as the main incentive for all energy markets [2-3].

Regulators are preferring the "price ceiling" method to ensure that prices do not rise too high at any time of the year [4]. A bidding upper limit is set for the buying or selling option in the organized wholesale market. Some peak load generators will be unable to meet their operational fixed costs as there will be no purchase or sale more than a ceiling price set by the regulator. This situation reveals the MMP, which is the revenue that cannot be obtained from market.

2.2. Contributions of subsidies on MMP

The price ceilings are not the only problem for generators with high production costs. Especially in systems that subsidies are built with a direct proportion to the energy produced, such as Turkey's renewable energy support mechanism that is based on a feed-in-premium model, it is seen that settlement price of the system (e.g. Market Clearing Price/MCP for Turkey) is suppressed downward (see Figure 2). The generators who prepare proposals for the acceptance of the entire production bid in the direction of injection to the grid are positioned within the market by bidding around "0 TL/MWh" just to position within the merit order list. Similar to Turkey, where prices seem to be going down in this direction, [4] showed that the system price (the price generated by the Spanish Market Operator OMEL) has been degraded for years along with renewable incentives for the Spanish electricity market and that the price will move further downwards as renewable penetration increases [5].

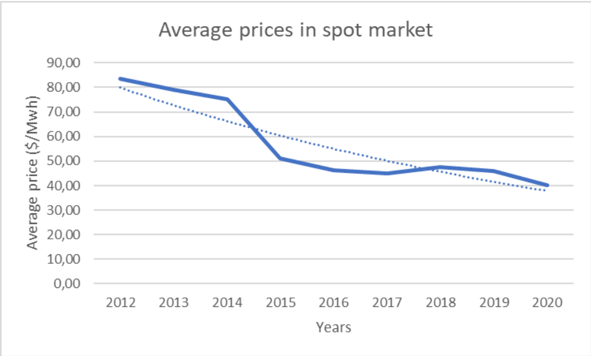


Figure 2. Average pool prices in Turkish Electricity Market (2012-2020)

Prices suppressed by renewable penetration, similar to the “price limit”, raise the problem that some power producers cannot afford their costs. This problem might cause some plants that are important for security of supply to loose money in the short term and exit the system in the medium term.

2.3. Resource Adequacy and Capacity Mechanism Requirement

Interconnected systems play a crucial role in control of supply-demand and frequency instantly and they enable participation of all generators to the energy system. In terms of management of the grid in the interconnectedness, there is a need to manage the network through system constraints with instantaneous flow of energy, control of system frequency and voltage. System Reliability is an important criterion for the management of the electricity network. By definition, reliability can be expressed as a performance measure of the system's ability to deliver energy to consumers with acceptable standards and at desired amounts.

Reliability basically consists of two elements: (i) Security, (ii) Adequacy [6]. System Security can be expressed as the durability of the network to sudden disruptive effects or fluctuations. Provision of this feature requires short-term operations and services covered by “ancillary services”. Voltage control, congestion management, operating reserves, grid backups etc. could be counted as ancillary services. System security may also be called short-term reliability according to [7]. The concept of Adequacy is related to the ability of the system to meet the total demand for electrical energy at any time. This feature, which is related to long-term planning, can be controlled by mechanisms such as amount of installed capacity, operational capacity, available capacity.

For a pre-defined period (e.g. a year), when all hourly-load occurrences are in descending order, a curve is obtained which is called Load Duration Curve (LDC). When the demand is higher than a maximum level of available capacity Cmax (Figure 3), there would be lack of resource adequacy. In the case that might occur in a short while during a year/years, there could happen a loss of load.

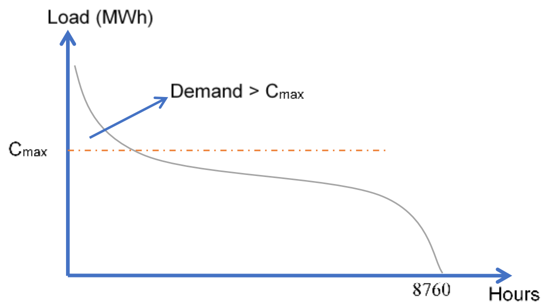


Figure 3. Example LDC for a year

In the absence of peaking power plants as they leave the system and/or new investment decisions due to the MMP, the system operator will be forced to shed loads during the period of high demand. Therefore, capacity mechanisms come to the play to complement the energy-only based market.

3. EXISTING CAPACITY RENUMERATION MECHANISMS

In addition to energy-only markets, five known capacity mechanism methods are used in practice [8]:

(i) Mandatory capacity method
(ii) Capacity tender
(iii) Capacity payments
(iv) Strategic reserve
(v) Reliability option

Mandatory method (capacity obligation): At this method, which is not a centralized approach, energy trading market participants are obliged to define their consumers’ load profile and make agreements with the power producers regarding these profiles for capacity allocation. Participants who fall into imbalance due to insufficient capacity allocation are subjected to sanctions for the lack amount.

Capacity auction: This method is based on allocation of available generation capacity to load entities through a centralized and regulated auction. Certified (licensed) generators participate in and bid on the capacity auction, and the participants of the demand side are obliged to buy capacity certificates from the auction winners. Demand side could be represented by a single side like Independent System Operator or a balancing responsible party.

Capacity payments: In capacity payments method, which is a price-based approach, a premium is directly paid to the producers in addition to the energy price (kWh). Capacity payments are to be realized according to the installed capacity or available capacity of the generator.

Strategic reserve: Some generators are selected through a bidding process and they keep redundant capacity as strategic reserve for emergency management. Currently, countries like Germany, Sweden and Finland have opted for this method [9-10].

Reliability option: In this method, capacity providers (generators) could earn the difference between the marginal price generated in the market and the predetermined reference price. The reference price is calculated so that generators can obtain more stable revenues.

4. TURKISH CASE: CAPACITY PAYMENTS

The regulation on capacity remuneration, "Electricity Market Capacity Mechanism Regulation" was published in the Official Gazette dated 20.01.2018 and numbered 30307 and amended four times by 2021 [11]. Following sections describe fundamental rules of the mechanism in that regulation.

4.1. Participants of the mechanism

Article 6 of the Regulation defines criteria for market players **who are not able to** participate in capacity mechanism. In other words, whether a generator has one of the following properties that generator/market player is forbidden to utilize capacity payments:

- *Power plants where the public share exceeds 50 %*
- *Plants that have a build-operate and build-operate-transfer agreement*
- *Privatized old public generators*
- *Nuclear power generation plants*
- *Generators take part in renewable support scheme*
- *The plants scheduled for privatization after publish of the Regulation*
- *Power plants with electricity installed power below 50 MW_e for local resources and less than 100 MW_e for other resources*
- *Non-domestic plants with an efficiency rate below 50%*
- *Wind and solar power plants which are not able to generate uninterruptedly*

Facilities included in the mechanism have to apply to the System Operator (TEİAŞ), by mid-October of the previous year. An annual budget is determined by TEİAŞ and approved by Energy Market Regulatory Authority (EMRA[1]) for supply and system security and capacity payments are paid to the power plants who are eligible to participate in the previous application year according to the priority order. Payments are carried out in such a way as not to exceed the budget ascertained by TEİAŞ and approved by the EMRA Board (Article 5 and Article 6 of the Regulation).

4.2. Payment method and realizations

The amount of payment to be made is formulated in Article 8 of the Regulation for capacity mechanism (CM). According to this article, the ratio for amount of payment to be paid to resource type *i* during the invoice period *f* is $CAR_{i,f}$

$$CAR_{i,f} = \frac{FCC_{i,f} \times IC_{i,f} \times CF_i}{\sum_{i=1}^{m} FCC_{i,f} \times IC_{i,f} \times CF_i} \quad (1)$$

where,

$FCC_{i,f}$ is fixed cost component for resource type *i* for period *f*

$IC_{i,f}$ is total installed capacity for resource type *i* for period *f*

CF_i is capacity factor for resource type *i*

m is number of all resource types participating in CM.

For a specific generator ***p*** producing by use of resource type *i*, the amount of payment $CP_{i,p,f}$ is calculated with following formula for invoice period *f*:

$$CP_{i,p,f} = CAR_{i,f} \times BUD_f \times \frac{IC_{i,p,f}}{IC_{i,f}} \quad (2)$$

Here $IC_{i,p,f}$ is installed capacity of generator *p* and BUD_f is the budget allocated by TEİAŞ for period *f*.

Since beginning of 2018, TEİAŞ distributed capacity payments to generators according to the Regulation. The corresponding budget that is allocated through the transmission tariffs regularly increased every year and total payments are expected to exceed 8 billion TL by end of 2021 (Figure 4).

[1] EPDK in Turkish.

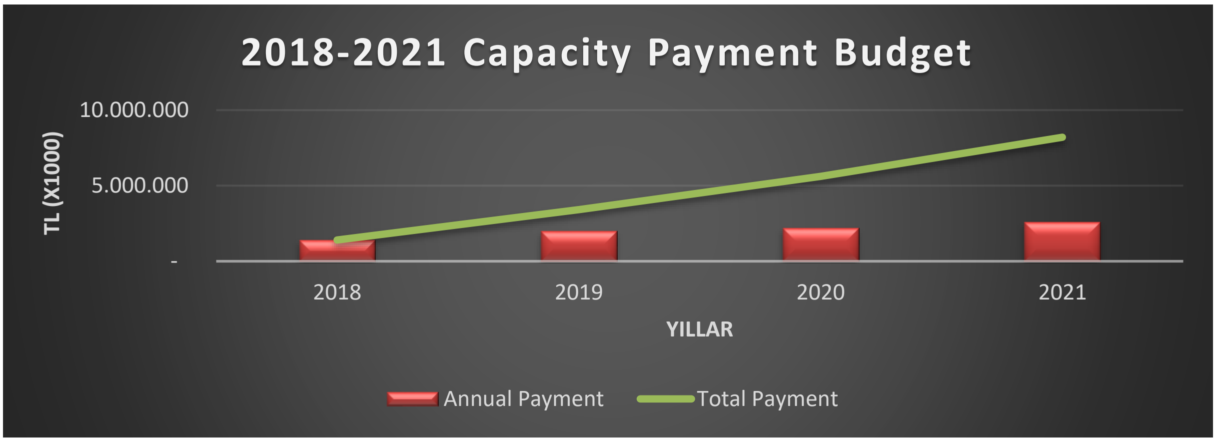


Figure 4. Capacity payments in Turkey (2018-2021), [12].

5. ALTERNATIVE CAPACITY REMUNERATION METHOD: AUCTIONING MODEL PROPOSAL

For the Turkish case, a model for capacity mechanism is developed as a capacity auction which has traces from Italian model and PJM/US approach. In the Italian electricity market, a market-based mechanism was established, which was approved by the European Commission's decision on 7 February 2018 for compliance with the rules of "state aid" [13].

The capacity mechanism in Italy is based on a tender system that sorts prices in a descending order. In this system, the ISO participates as the demand side and offers a price (€/MW/year) for the amount of capacity it needs (in MW). Capacity providers are also submitting their bids for the amount of capacity they can provide as sale bids [14]. Auction is consisted of multiple rounds: In the first round all sale side participants give their first bids. Through following rounds, the prices of the participants who bid for the sale are reduced until provision of intersection of supply and demand curves. When the marginal price and allocated capacity become stable, the tender is terminated. The auction process consists of maximum of 26 rounds [14].

The transmission system operator considers Loss of Load Probability (LOLP) calculations when creating the demand curve for auction. An exemplary demand curve in Figure 5 shows a curve with 4 points specified as A, B, C and D. Points A and B indicate the price ceiling (point B corresponds to the final capacity that ISO will receive from the peak price), point C indicates the cost of a new plant in the system (CONE), and point D indicates where the price is equal to "0". Values shown on the vertical axis in the figure are calculated first when the auction begins, renewed in each round due to abatements in the auction process [15].

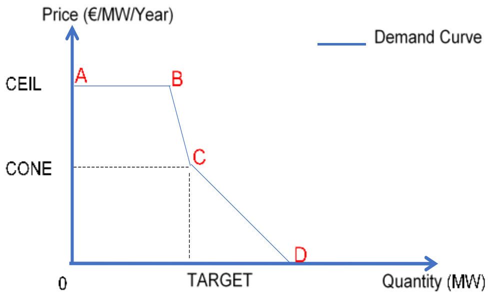


Figure 5. Four-point demand curve (Italian Capacity Auction)

Auction process, which consists of four main phases in total, begins with the year 4 years before the year T. Through the main tender held once a year, a large part of the capacity is traded. In the second phase, which is called "complementary auction", contracts made every four years but for shorter periods are bought/sold in order to ensure full supply adequacy. The third stage, the "Adjustment auction", is used to set up requirements of the responsible capacity providers and/or ISO as the delivery time approaches. The "secondary market", which can be considered as a weekly market, has a complementary market feature that operates with market logic and where offers are accepted according to the priority of the offer [15].

Ensuring resource adequacy in electricity in the United States comes across as three different models [16]: (i) Traditional planned markets, which are fully regulated, (ii) Energy-only markets, where only the price of energy is signaling for investments, (iii) Regions with a separate platform that provides an open or closed revenue stream for capacity.

In the third option, there are models where capacity payments are made through the bilateral resource adequacy requirements (BRAR) as well as in the regions where the Centralized Capacity Market (CCM) is established. In US, the CCM model is implemented in regions operated by system operators such as PJM, MISO, ISO-NE and NYISO [17].

Auction method is applied in addition to bilateral agreements in PJM market. In the application based on Reliability Pricing Model (RPM), a structure has been established in which the signal produced within the market determines whether regulatory intervention is required. In the RPM model, capacity is defined as an annual product; there is a system in which all capacity is obligatory to be offered and purchased for the whole load, and the link between energy and capacity markets is established through performance indices and a net income difference. The RPM design has a three-year supply process based on a demand curve with designated bending (breaking) points. Local market definition and market power degradation rules for the market are also defined [18].

All Load Serving Entities (LSEs) are required to participate in the RPM model. The exception is made up of participants who prefer the Fixed Resource Requirement Alternative, and LSEs who would have capacity plans approved to PJM with this alternative also do not have to participate in the RPM system [19].

The demand curve plays an important role in demonstrating the need for capacity. Similar to the Italian approach, there are reliability thresholds based on the Net CONE of a sample peaking power plant. Net CONE simply points out the difference between the gross cost of the energy to be produced and the possible revenue instreams [18]. A sample demand curve used in PJM tenders is illustrated in Figure 6 [19].

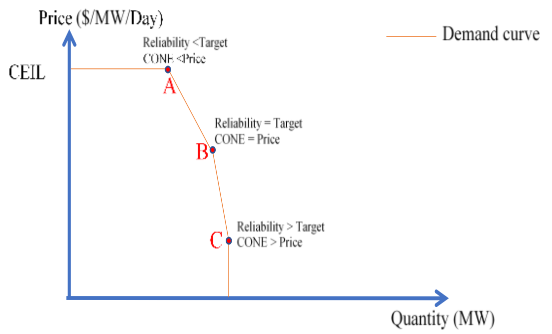


Figure 6. An exemplary demand curve in PJM’s capacity mechanism)

When determining the demand curve, it is important to determine a balanced capacity price that will ensure the desired level of reliability. According to the PJM implementation guide [19], the highest price on the curve, also accepted as the Variable Resource Requirement Curve (VRRC), is divided into a coefficient that will regard the average interruption index of the whole system, with 1.5 times the amount of “CONE - Energy and Ancillary Services Revenue Threshold” (which corresponds to the flat curve up to point A). The coefficient at the second breakdown value was taken as 0.75, and the 2020 guide did not include a third breakdown and landed directly at $0/MW [2] [19].

Obligations of LSEs to maintain capacity are met directly by their own provision or by participating in market by bilateral agreements or the capacity market. Installed capacities are checked by converting them into excepting interruptions capacity obligations (unforced), considering the impact of fault sources such as periodic maintenance, etc. These obligations are fulfilled by LSEs by submitting successful proposals within the capacity mechanism. A penalty of $170 per MW/Day applies to liabilities not fulfilled by the System Operator [20].

6. PROPOSED MODEL FOR TURKISH MARKET AND ANALYSIS

6.1. Capacity auction

Similar to auction models in other markets, a stepwise approach for Turkish market is suggested: Main Auction, Complementary Auction and Corrective Auction.

Main Auction: If the capacity requirement to be determined for the target year is below the current capacity requirement, auctions will be activated for the capacity needed. Existing facilities and facilities that will be commissioned by the target year other than renewable energy sources will be able to bid in the auction based on their installed capacity. A minimum of 5 round of a descending clock type auction is considered. When there is no price difference between the **n+1**st and the **n**th round, results of the **n**th round will be registered as official price and capacity. Furthermore, as it is in Italian market, a maximum number for rounds could also be determined prior to the auctions.

Complementary Auction: If capacity supply cannot cover the demand to ensure sufficient capacity for the target year, a new auction is held. Auction call shall be created for the amount of capacity that cannot be matched. Other facilities other than the bids (capacities) accepted in the Main Auction will be able to bid in this tender.

Corrective Auction: In the year before the target year, a position correction auction shall be organized for the capacity adjustment. Market participants who will not be able to provide the committed amount of capacity can

[2] CONE is based on the cost of a gas turbine, and as energy revenue, the average annual earnings per MW of the reference unit in PJM and an estimated value of $/MW.year as the revenue with the ancillary service are determined in $/MW units.

participate in this type of auction to close their positions in order not to face possible penalties. In this spot market-like tender, where price levels will not be determined, the transfer of liabilities and final settlement will be ensured.

The processes and workflow algorithm of the auctions to be carried out by the network (system) operator are illustrated in Figure 7.

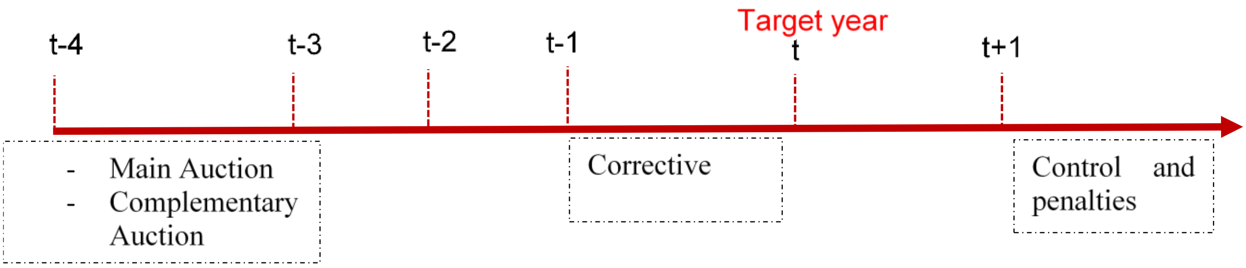


Figure 7. Proposed auction process

Very first step for designing a model, accurate need assessment for resource adequacy is crucial.

6.2. Resource adequacy for Turkish system

In terms of system adequacy, it is thought that existing plants will remain active in the grid to meet the demand, as well as the generation capacity will expand to meet the increase in demand in the coming years. Currently, in order to meet the demand, available dispatchable capacity has to be sufficient to meet instantaneous consumption. Figure 8 depicts the LDC formed by the hourly distribution of consumption of year 2020 and ordering of consumption from high to low. As can be seen from the graph, maximum consumption per hour is around 45 GWh and the minimum amount is around 15 GWh. The peak value of consumption was recorded as 45,301.59 MWh.

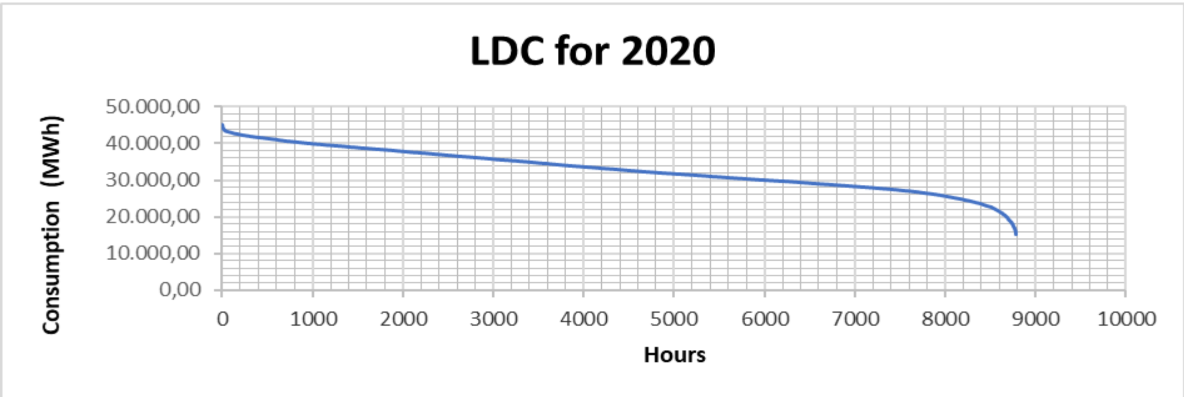


Figure 8. Annual consumption curve for 2020

When the available installed capacity and consumption amounts are examined during 2020, it is inferred that the generation capacity in Turkey already seems to be sufficient to meet the demand (Table 1). Moreover, during the year it is seen that the minimum level of the available capacity was 50,312.8 MW, which is at a level that meets the maximum demand.

Table 1. Available Installed Capacity (AIC) on a resource basis (End of 2020)

	Natural Gas	Wind	Lignite	Hard Coal	Exported Coal	Fuel- Oil	**Total**
Average AIC (MW)	13,310.44	7,730.04	4,177.03	132.30	6,952.66	219.48	**58,100.62**
Minimum AIC (MW)	8,939.23	6,934.26	2,841.00	-	1,945.50	110.60	**50,312.83**
Maximum AIC (MW)	15,993.68	8,644.77	5,937.45	290.00	8,142.00	276.65	**63,211.16**
	Geothermal	Dams (hydro)	Naphta	Biomass	Run-of-the-river	Others	
Average AIC (MW)	1,254.33	16,390.90	9.05	635.00	6,689.77	466.64	
Minimum AIC (MW)	1,016.91	12,560.69	-	485.41	5,704.38	218.44	
Maximum AIC (MW)	1,366.31	18,551.72	12.14	846.21	7,315.51	649.15	

Under the proposed mechanism, plants based on renewable energy sources with very low marginal costs will be excluded from the mechanism and the focus will be on the plants which are high in variable costs and could also be considered as peaking power plants. In this context, when determining the capacities to be used, it is appropriate to consider the amount of energy that cannot be met by renewable energy within the maximum consumption. The relevant statistics are presented in Table 2.

Table 2. Maximum consumptions and renewable production statistics

YEAR 2020	
Peak Demand (MWh)	45,301.59
Hourly Renewable Generation-Avg. (MWh)	13,157.70
Hourly Renewable Generation- Median (MWh)	13,461.16
Hourly Renewable Generation-Max. (MWh)	23,330.07
Hourly Renewable Generation-Min. (MWh)	3,147.03

By deducting the average amount of renewable energy generation from the peak demand, the amount of demand that is to be met from non-renewable sources shall be found. With a Capacity Factor (CF) of 0.8, the necessary non-renewable source installed capacity also shall be estimated for year 2020:

$$Demand\ met\ by\ non_{ren} = 45{,}301.59 - 13{,}157.70 = 32{,}143.89\ MWh \quad (3)$$

$$ICAPnonren = \frac{32.143.89}{0.8} = 40{,}179.89\ MW \quad (4)$$

6.3. Predictive analysis

For observation of an auction type mechanism's reflections, a capacity requirement model for Turkish case is formed. A capacity requirement curve is prepared with current data and projected up to year 2025. After preparation of the requirement curve, possible bid proposal sets are established by considering costs of typical generators. Then, iterative analyses are performed with several sensitivity trials.

6.3.1. Capacity Requirement Curve

Cost of New Entry, CONE, required for the requirement (demand) curve to be created when setting up the auction system will be taken into account. Similar to the PJM model, a natural gas power plant's tendency to enter the market or remaining of existing plants in the system is reference for the curve construction. In this context, it is thought that investment costs in IEA 2020's study [21] could be based on the installation cost per MWh (Levelized Cost of Electricity) of CCGT (combined-cycle gas turbine) type generation facilities. This value will be converted to TL/MW per year and will evolve into CONE. Details for calculation of CONE and steps for fix and variable parts are shown in *Annex A1*.

6.3.2. Net CONE

Similar to the mechanism in PJM, finding the exact necessary revenue stream for survival of existing plants or provision of new entries is important to set the upper limit for the revenue curve. Therefore, Net CONE can be determined by deducting possible revenues coming from energy sales (bilateral contracts, spot market etc.) and ancillary services. So Net CONE could be founded as,

$$Net\ CONE = CONE - (Net\ ER + ASR) \quad (5)$$

Where Net ER is energy revenue calculated by subtraction of variable cost of typical power plant (natural gas power plant for this study) from spot market price. For conversion of Net EG to an average revenue per MW for year 2020, following formula also can be used.

$$Net\ ER = \frac{(\text{Gross Energy Revenue for 2020} - \text{Variable Costs for 2020})}{Average\ Installed\ Capacity\ for\ 2020} \quad (6)$$

For an exemplary natural gas power plant (NGPP) Net EG is found as 104,8 TL/kW.Year. Details are given in Table 3.

Table 3. Net EG Calculation

Average IC (kW)	Total Production by NGPPs (2020)	Variable Cost (MWh/TL)*	Revenue for 2020 (TL/YIL)**	Net EG per kW (TL/kW.YIL)
25,681.925	68,072,555.14	263.17	20,604,914,508.44	104.8

* $CONE_{var}$ is used. **Calculated by aggregation of hourly generation multiplied by hourly MCPs.

ASR, potential ancillary service revenue also could be estimated by historical accruals to NGPPs. While the annual ASR per kW of the sample power plant is found, the potential ancillary services revenues coming from ASR are calculated. The annual total ASR is computed by multiplying the hourly capacity payment prices resulting from the auction results for both PFC and SFC services, and hourly reserve amounts. Then, ASR is obtained on the basis of resources by proportioning them with the resource-based reserve capacities. The potential ASR per kW is calculated by dividing the natural gas revenues by the average installed capacity from these values. Finally, for year 2020, ASR is found as 29.1 TL/kW.Year.

According to equation Net CONE is calculated[3] with data from 2020 as,

$$Net\ CONE = 886.7 - (104.8 + 29.1) = 752.8 \frac{TL}{kW}.Year \quad (7)$$

6.3.3. Sample Requirement Curve for 2020

As a result of the calculations described above, capacity requirement curve is prepared with three breaking points. Similar to [14], first breaking point is designed to meet all the demand, second breaking point is designed to withstand the possibility of a three-hour interruption and third breaking point is based on the possibility of a six-hour interruption.

In this context, according to LDC shown in Figure 8, 4th highest demand value (for 3 hours of LOLP) and 7th highest demand value (for 6 hours of LOLP) during all year are found as:

For t=4, Hourly Demand= 44,975 MWh

For t=7, Hourly Demand = 44,641 MWh

Each point in Figure 9 could be determined by following breaking points:

- 1st Breaking point (A)
  - Price: Net CONE[4]
  - Capacity: (39,354)[5] MW
- 2nd Breaking point (B)
  - Price: **Ω[6]** x Net CONE
  - Capacity: (39,772)[7] MW
- Intersection point at X-axis (C): 40,180[8]

[3] For CONE, see Appendix A.1.
[4] Net CONE calculated via Equation (13).
[5] Calculated for t=4.
[6] Coefficient for 2nd breakeven point which is directly linked to Value of Loss Load (VOLL).
[7] Calculated for t=7.
[8] The value found at Equation (4).

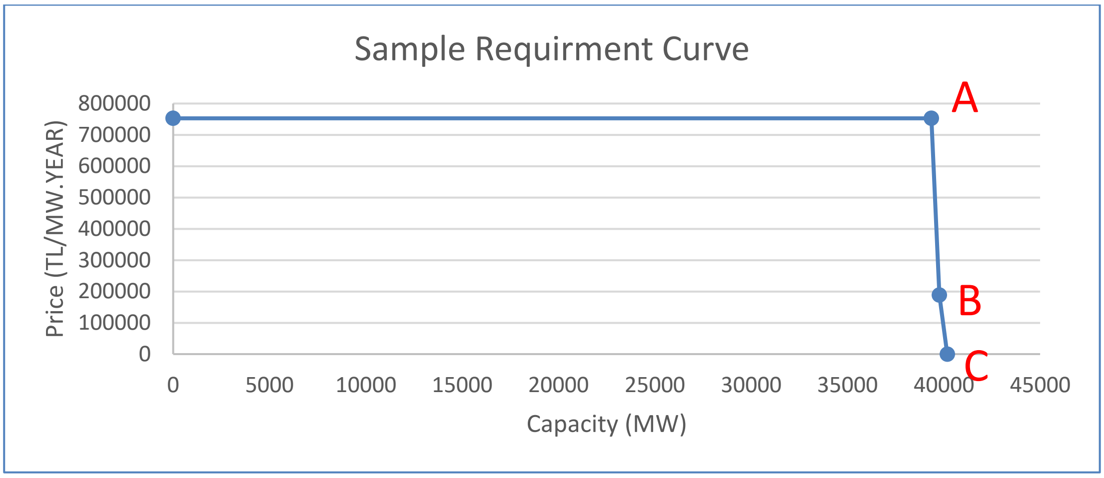


Figure 9. Annual consumption curve for 2020

6.4. Estimation of Requirement Curves for leading years (2021-2025)

6.4.1. Linear estimation

According to TEİAŞ's "10-Year Demand Forecast Report 2021-2030", the base scenario for demand increase is around 3.6 % per year [22]. Following this assumption; maximum, the 4th and 7th highest (3-hour and 6-hour LOLP) demand forecast is predicted as stated in Table 4. For requirement curve computation, using values in Table 4 results threshold values for breaking points in Table 5. With a stable Net CONE and Ω=0.25, requirement curves shall be drawn as illustrated in Figure 10.

Table 4. Linear escalation for demand (2021-2025)

	2020	**2021**	**2022**	**2023**	**2024**	**2025**
Maximum (MWh)	45,302	46,933	48,622	50,373	52,186	54,065
4th Highest (MWh)	44,975	46,594	48,271	50,009	51,810	53,675
7th Highest (MWh)	44,641	46,248	47,913	49,638	51,425	53,276

Table 5. Threshold capacities (2021-2025)

	2020	**2021**	**2022**	**2023**	**2024**	**2025**
CAPACITY FOR A (MW)	39,257	40,670	42,134	43,651	45,222	46,850
CAPACITY FOR B (MW)	39,740	41,171	42,653	44,189	45,779	47,428
CAPACITY FOR C (MW)	40,180	41,627	43,125	44,678	46,286	47,953

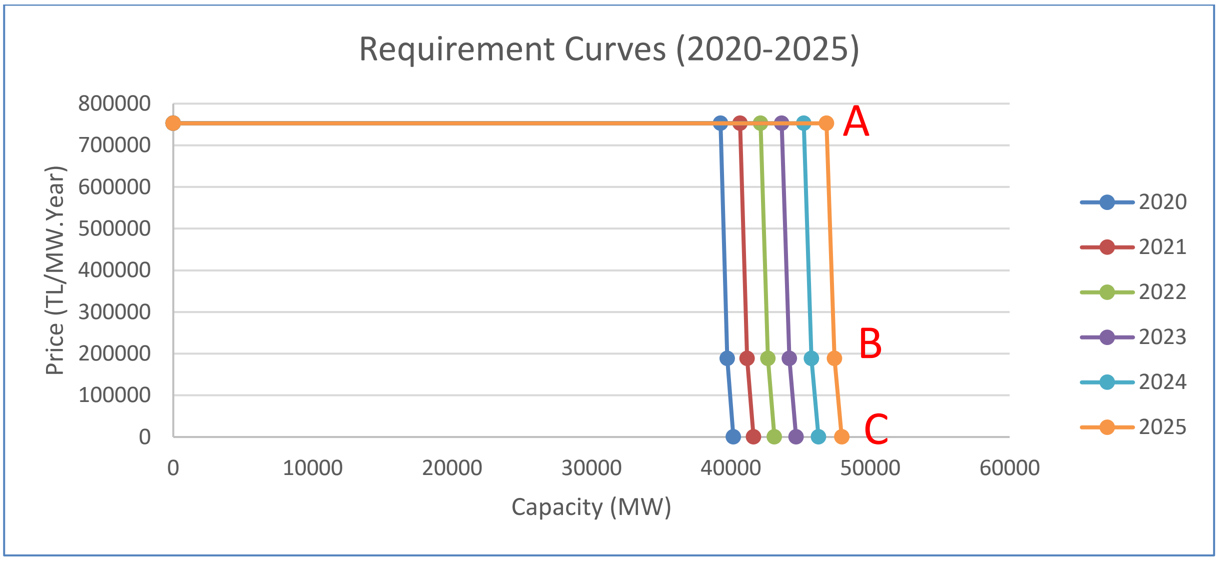


Figure 10. Requirement curves by linear escalation (2020-2025)

6.4.2. Estimation with Monte Carlo method

According to the [23], Monte Carlo method which is also called stochastic simulation [24], defined as a model where a problem's solution is lean on hypothetical population. In the created model, a sample of population is reproduced by random number generation and after that relevant parameter is estimated using the model. This method, which is used for sampling, estimation and optimization, is often used in fields such as industrial engineering and operations research, physical structures and processes, the creation of random graphs, numerical statistics, economics and finance [25].

In addition to linear model, Monte Carlo method is also applied for future forecast of demand. When hourly consumption amounts are assessed, probability distribution is seemed to converge Normal (Gaussian) distribution. Probability distribution parameters of historical consumption series are found as follows with 95 % confidence interval by using Matlab *fitdist()* function:

Normal (Gaussian) distribution

μ = 33120.4   [33005.5, 33235.4]

σ = 5497.2   [5417.1, 5579.72]

According to these parameters, cumulative distribution function for hourly consumptions of 2020 is sketched as Figure 11.

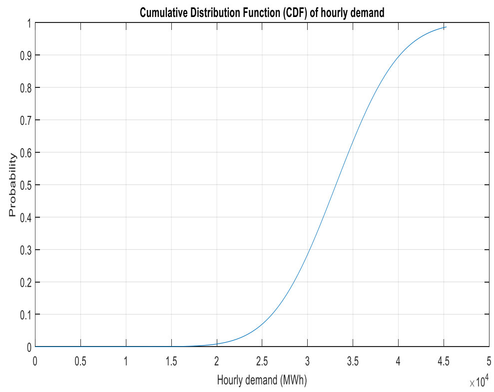


Figure 11. CDF of hourly demand of year 2020

For hourly consumptions having such probability distribution, a random number generation "between 0 and 1" is processed for probability possibility; and this is repeated 8760 times for a yearly mapping. From obtained PDF for relevant year, with respect to α=0,005 margin, detected highest value is accepted peak demand of that year. In other words, 99 % of maximum value of randomly predicted demands is accepted as hourly peak of ruling year (Figure 12). Following that, annual maximum consumption, 4th highest and 7th highest consumption predictions are randomly forecasted and listed in Table 6.

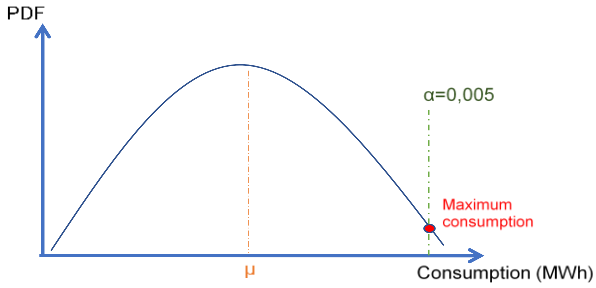


Figure 12. PDF of hourly demand and selection of yearly maximum

With a constant Net CONE, requirement curves for each year of 2020-2025 is drawn by using following steps detailed in previous section. The breaking points are listed in Table 7 and requirement curves are sketched in Figure 13.

Table 6. Annual demand forecast by MC Method (2021-2025)

	2020	2021	2022	2023	2024	2025
Maximum (MWh)	47,189	48,474	50,471	52,763	54,855	47,189
4th Highest (MWh)	47,008	48,438	50,385	52,463	54,620	47,008
7th Highest (MWh)	46,890	48,195	50,282	52,397	54,558	46,890

Table 7. Threshold capacities with MC method (2021-2025)

	2020	2021	2022	2023	2024	2025
CAPACITY FOR A (MW)	39,257	41,574	42,592	44,565	46,550	48,568
CAPACITY FOR B (MW)	39,740	41,721	42,895	44,693	46,632	48,647
CAPACITY FOR C (MW)	40,180	41,948	42,940	44,801	47,007	48,940

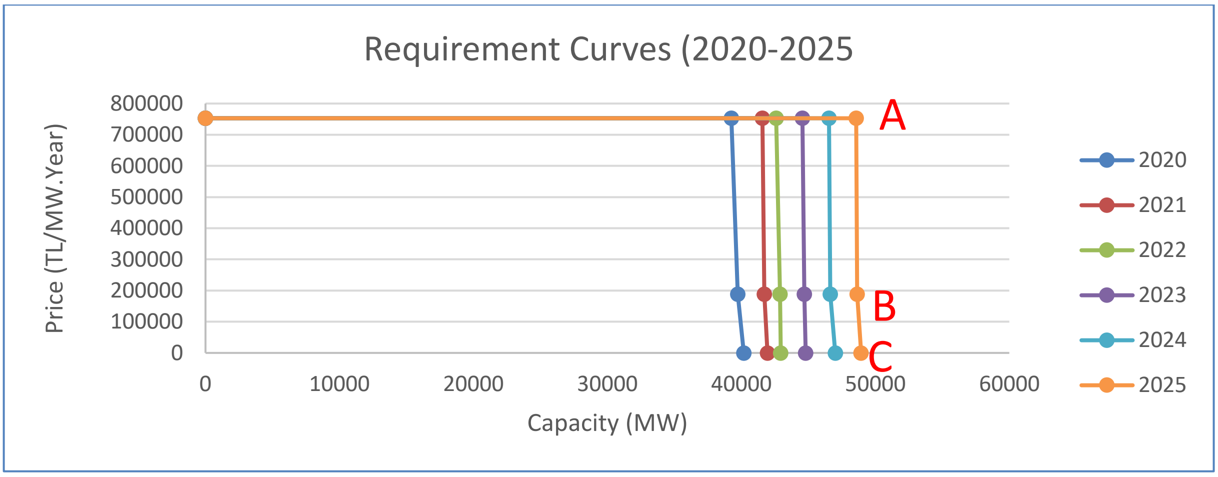


Figure 13. Requirement curves by MC method (2020-2025)

Up until to year 2024, existing installed capacity other than renewables looks sufficient to meet all demand considering that non-renewable installed capacity is around 46280 MW.

6.5. Prices and possible auction result

When energy-only market clearing price meets a generator's marginal cost, for each case, generators participating in capacity mechanisms will maintain their willingness to stay in the market. In this context, theoretical surplus revenues in addition to their potential revenue coming from spot market will contribute to compensation of their long-term marginal costs. Moreover, for the year 2024, new investments could be attracted according to the assumptions above; additional potential revenue coming from capacity auctions will directly affect investment decisions.

An analysis for possible auction results is also performed with a hypothetical bidding set. A two main source model (natural gas and coal) is developed with respect to costs and existing generators' tendency to recover their variable costs as well as fixed costs (excluding investment and decommissioning costs). Also, it is assumed that **generators are going to bid the margin between annual fixed and variable costs and their potential earnings from energy-only market and ancillary services market**.

Costs for natural gas generators are shown in part 6.3 in details. Cost elements for generators using coal as fuel, is summarized in Table 8. Cost calculation is performed following similar steps at 6.3; additional revenue to cover annual costs is found around - 100,000 TL/MW.Year which leads that current energy-only market and ancillary services market's contribution to revenue streams of coal fired power plants sustains presence of them. Therefore, the bidding price is accepted as "0 TL/MW.Year" for power plants using coal (hard coal, lignite, imported coal etc.) as fuel.

Table 8. Cost parameters for coal-fired power plant [21, 26]

Currency (TL/USD)	7
Construction period (Years)	4
Operation period (Years)	40
Investment Cost (USD/kW)	1785
Percentage for Fixed O&M Cost	1,70 %
Fixed network cost (TL/kW.Year)	54.65
Fuel Cost (USD/MWh)*	23.50
Variable network cost (TL/MWh)	15.477
Variable O&M Cost (US/MWh)	5.42

* Median value of coal price in IEA report.

With the parameters assumed in 6.3, for the natural gas power plants, the price is settled almost at breakeven point where additional necessary amount for sustainability of power plants occurs at 284.6 TL/MW.Year. For these values, probable auction match is illustrated in Figure 14 for year 2025. From the figure, the price is settled at 21,625 TL/MW.Year.

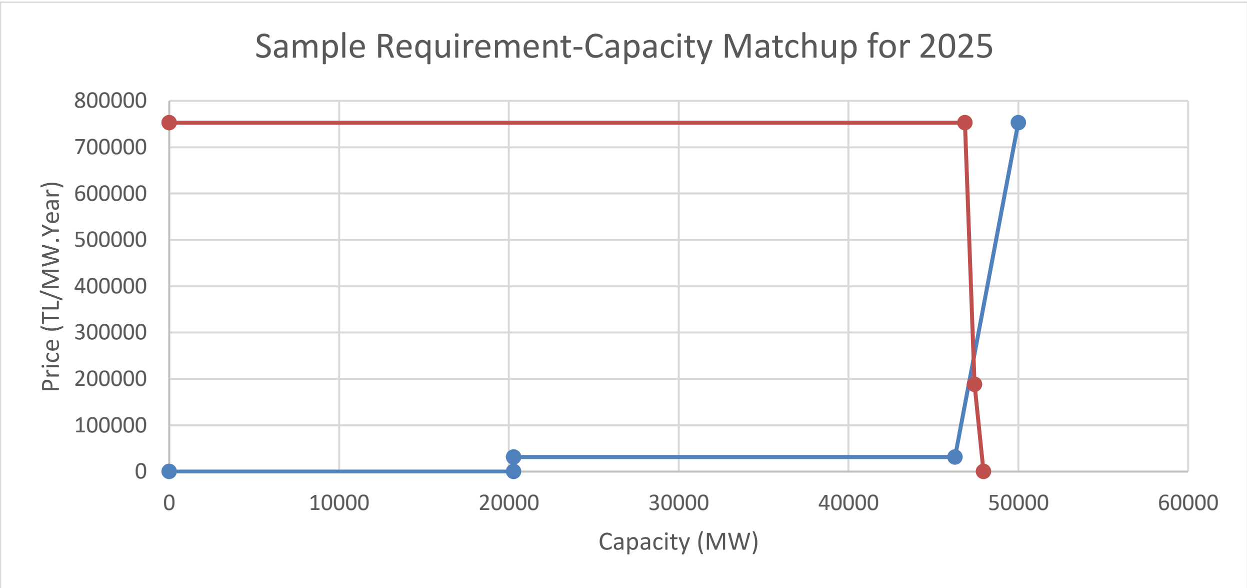


Figure 14. Sample auction for year 2025

6.6. Sensitivity Analysis

Parameters could vary because of fluctuations in international commodity markets, Turkish economy and energy related markets. Therefore, some extension analyses were also performed to cover possible scenarios. The sensitivity analysis results for $CONE_{fix}$, $CONE_{var}$ and Ω are shown in Table 9 (a), (b) and (c) where other parameters are kept unchanged.

Table 9- (a), (b) & (c). Sensitivity results for $CONE_{fix}$, $CONE_{var}$ and Ω

	Auction result (TL/MW. Year)
Minimum	216,390
Maximum	240,036
Mean	229,066
Median	229,309

(a) $CONE_{fix}$ varies between 5,369 TL/kW.Year and 6,860 TL/kW.Year

Table 9- (a), (b) & (c) (continued). Sensitivity results for $CONE_{fix}$, $CONE_{var}$ and Ω

	Auction result (TL/MW. Year)
Minimum	212,382
Maximum	225,397
Mean	219,121
Median	219,240

(b) $CONE_{var}$ *varies between 250 TL/MWh and 300 TL/MWh*

	Auction result (TL/MW. Year)
Minimum	140,206
Maximum	272,897
Mean	229,630
Median	239,971

(c) Ω *varies between 0.1 and 0.6*

Process structured above is based on a unique CF with 0.8. Reflections of change in only CF assumption directly effects requirement curve and results of possible auctions. Results of a varying CF for both sources and necessity for auction for specific year are listed in Table 10.

Table 10. Effect of CF on auction results

NG CF	COAL CF	PRICE, 2024 (TL/MW.Year)	PRICE, 2025 (TL/MW.Year)
0.85	0.85	**NO AUCTION**	**NO AUCTION**
0.85	0.8	**NO AUCTION**	38,989
0.85	0.75	27,426	83,445
0.85	0.7	74,835	122,687
0.8	0.85	**NO AUCTION**	51,375
0.8	0.8	40,666	94,347
0.8	0.75	86,415	132,358
0.8	0.7	126,640	166,220
0.75	0.85	53,431	104,901
0.75	0.8	97,605	141,737
0.75	0.75	136,531	174,610
0.75	0.7	171,091	204,127

7. CONCLUSION

Ensuring supply-side resource adequacy in the electricity market is of great importance in terms of ensuring the continuity of supply for end users. In order to maintain the resource adequacy, the income of power plants operating in the energy-only markets might not be sufficient at all times, leading to the MMP. In this case, which is caused by regulations such as additional support mechanisms (e.g., for renewables) in energy markets or the implementation of price limits, the market mechanism does not cover the operating and investment costs of the power plants. Accordingly, this complicates the conditions for new market entrants, especially for new investors. Consequently, this leads problems with maintaining the supply security, especially for countries with increasing demand.

When different country market applications are examined, it is seen that different mechanisms are created to supplement the energy-only markets for resource adequacy. In addition to market-based methods, there are models where direct “capacity payments” are paid to identified participants. In the Turkish case, there approach initiated in 2018 was implemented through capacity payments. The allocated budget, which is determined annually by EMRA and TEİAŞ considering the mechanism implemented within the framework of the Electricity Market Capacity Mechanism Regulation, is distributed monthly to the power plants listed in the regulation according to their installed capacities and resource types. Figure 4 depicts annual capacity mechanism budgets since beginning of 2018. As it mentioned before total payments will reach more than 8 billion TL by end of 2021.

In this study, an auction model as a capacity remuneration approach is developed and simulated for Turkey, against the capacity payment method which is currently applied. Within the scope of the proposed mechanism, two scenarios are assessed: (i) the base scenario linear demand forecast and (ii) random estimation by the Monte Carlo approach. The aim here was creation of the supply-demand curve to encompass demand expectations, according to the modeling. As a result, it was concluded that it would not be necessary to hold auctions for years before 2024 considering the current distribution of installed capacity and resources in the system. After this year it was suggested that the requirement curve and price levels should be created according to the expected load.

Results of modelling and sensitivity analysis questions the necessity of capacity payments and points out actual adequacy requirements. Moreover, other than existing capacity payment scheme, suggested auction mechanism prevents all renewable sources, which have very low marginal costs and benefit from renewable energy incentives, to participate in the capacity mechanism. Hence, fair allocation of available budget is ensured. Accordingly, base power plants and balancing service providers having relatively high-capacity factors are supported, facilitating the required market signal for potential new entrants/investments.

APPENDIX

A.1. CONE calculations

A.1.1. Calculation of fixed part of CONE.

CONE has a fixed term shall be called $CONE_{fix}$, where that could be calculated by annualized fixed costs. According to [27] annual fixed costs may include those items:

- Labor costs
- Fixed maintenance and repair costs
- Insurance and asset management costs
- Taxes and levies
- Transaction and control costs
- Annual fixed costs to compensate the underlying demand for DSR
- Fuel supply service contracts (excluding the fuel costs)
- Fixed electricity transmission and distribution charges
- Other annual costs including environmental compensation costs, local resident compensation costs etc.

Within this study for Turkish case; a structure that considers annual fixed workforce costs, fixed maintenance/repair costs and fixed grid costs. After calculation of equalized annual fixed costs (EAC), $CONE_{fix}$ is determined through dividing EAC by Capacity Factor (CF) [24].

$$CONE_{fix} = \frac{EAC}{CF} \quad (A.1)$$

Where *EAC* could be formulated as follows:

$$EAC = \left[\sum_{i=1}^{X} \frac{IC(i)}{(1+WACC)^i} + \sum_{i=X+1}^{X+Y} \frac{AFC(i)}{(1+WACC)^i}\right] . \frac{WACC\ .\ (1+WACC)^{X+Y}}{(1+WACC)^Y - 1} \quad (A.2)$$

i	Each year during construction and operation
X	Construction period (in years)
Y	Economic lifetime (in years)
IC	Investment costs which shall be spent for each construction year
AFC	Annual fixed costs during operation
WACC	Weighted Average Cost of Capital for power plant.

IC

Investment Costs are considered as the costs of a Combined OCGT type power plants overnight cost which is stated at IEA, [21]. Median value of the cost is 668 €/ kWe; with a 3 year construction period, annual IC is 223 $/kWe.year.

AFC

According to World Bank report, annual fixed operation and maintenance cost for combined natural gas power cycle plants amounts to 1.7% of the total investment cost [26]. O&M cost part of AFC for the accepted median value of IC in this case is then,

$$O\&M\ Cost = 668 \times 0.017 = 11.356\ \$/\ kWe.year \quad (A.3)$$

For grid costs, the fixed part of transmission costs for Turkish electricity grid could be calculated as average value of system use and operation fees for all tariff zones where Turkish transmission grid has 14 tariff zones for the year 2020. Therefore, average fixed grid cost is calculated as 54,646 TL/MW.Year according to transmission tariffs of 2021 [28].

WACC

An analysis is done with respect to market conditions in Turkey and made assumptions for risks. After sensitivity analysis WACC (real) is calculated within the interval between 8.1 % and 12.2 %.

Accepting economic lifetime of the plant as 25 years (X=3, Y=25), the currency of TL/$ as “7”, and WACC by 11 %; the Equation 6 results as follows:

$$EAC = \left[\sum_{i=1}^{3} \frac{1561}{(1+0.11)^i} + \sum_{i=4}^{28} \frac{133.87}{(1+0.11)^i}\right] . \frac{0.11\ x\ (1+0.11)^{28}}{(1+0.11)^{25}-1} = 753.61 \frac{TL}{MW}.year \quad (A.4)$$

For CF=0.85;

$$CONE_{fix} = \frac{753.61}{0.85} = 886.60 \frac{TL}{MW}.year \quad (A.5)$$

Sensitivity analysis could be held by altering input parameters. For instance, changing the annual IC from \$200 to \$250 and Annual O&M Cost ratio from 1% to 2% of the total investment cost, reflects a differentiation from 767 TL/kW.Year and 979.8 TL/kW.Year for $CONE_{fix}$. Similarly, as a result of the sensitivity analysis for WACC, by keeping other parameters constant and stepping WACC between 10 % and 13 %, it is seen that $CONE_{fix}$ varies between 827.31 TL/kW.Year and 1048.68 TL/kW.Year.

A.1.2. Calculation of variable part of CONE

In order to cover the long-term costs of plant investments, i.e. to maintain the plants' operation, variable costs of a power plant shall be obtained through the revenues from production. As a variable cost for a natural gas plant, variable parts of the fuel cost and the transmission fee are to be considered. In addition to them, for calculation of variable part of CONE, which is $CONE_{var}$, variable operating and maintenance costs are also considered.

BOTAŞ, the natural gas transmission corporation of Turkey, announces fuel price for natural gas generators. The announced price is considered [29] and converted to a variable fuel cost for per MWh by a hypothetic thermal efficiency of 60 % and with a higher heating calorific value of 9,155 $KCal/sm^3$; and fuel cost for the power plant is found as 224.94 TL/MWh.

As a variable cost, which is in TL/MWh, the variable grid cost should also be considered. For year 2021 the variable transmission cost is around 15.48 TL/MWh[9]. Variable O&M costs could be accepted as 3.25 $/MWh in alliance with [26].

Then, final variable $CONE_{var}$ shall be calculated as follows:

$$CONE_{var} = 224.94 + 15.48 + 22.75 = 263.17 \frac{TL}{MWh} \quad (A.6)$$

A.2. Abbreviations list

ACER	The European Union Agency for the Cooperation of Energy Regulators
AFC	Annual Fixed Cost
AIC	Available Installed Capacity
ASR	Ancillary Service Revenue
BOT	Build Operate Transfer
BOTAŞ	Petroleum Pipeline Corporation
BRAR	Bilateral Resource Adequacy Requirements
CCM	Centralized Capacity Market
CDF	Cumulative Disribution Function
CF	Capacity Factor
CM	Capacity Mechanism
CONE	Cost of New Entry
EAC	Equalized Annual Fixed Costs
EGC	Electricity Generation Company
EMRA	Energy Market Regulatory Authority
IC	Installed Capacity
IEA	International Energy Agency
ISO	Independent System Operator
LDC	Load Duration Curve
LOLP	Loss of Load Probability
LSE	Load Serving Entity
MCP	Market Clearing Price
MMP	Missing Money Problem
NGPP	Natural Gas Power Plant
PDC	Price Duration Curve
PDF	Probability Disribution Function
PFC	Primary Frequency Control
PPT	Power Plant
RPM	Reliability Pricing Model
SFC	Secondary Frequency Control
TEİAŞ	Turkish Electricity Transmission Corp.
TOOR	Transfer of Operational Rights
VRRC	Variable Resource Requirement Curve
WACC	Weighted Average Cost of Capital

[9] It includes a variable cost for system usage & operation and additional fee which is 0.5% of variable fee.

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mehmet Ali KÖLMEK: Developed and designed the proposed model and discussed sensitivity anlaysis results

Tayfun MENLİK: Contributed to literature review, discussed sensitivity anlaysis results and revised the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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