

ATILIM UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
DEPARTMENT OF BUSINESS ADMINISTRATION
BUSINESS ADMINISTRATION MASTER PROGRAMME

**EFFICIENCY EVALUATION OF ELECTRICITY DISTRIBUTION COMPANIES IN
TURKEY IN 2022 WITH DATA ENVELOPMENT ANALYSIS**

Master Thesis

Etkin Ekin KARADAĞ

Ankara-2024

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ACCEPTANCE AND APPROVAL

This is to certify that this thesis titled “Efficiency Evaluation of Electricity Distribution Companies in Turkey in 2022 with Data Envelopment Analysis” and prepared by Etkin Ekin KARADAĞ meets with the committee’s approval unanimously/by a majority vote as Master's Thesis in the field of Business Administration following the successful defense conducted on 16/01/2024



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ETHICAL STATEMENT

I accept and acknowledge that I have prepared this thesis study, prepared in line with the Thesis Writing Guidelines of Atılım University Graduate School of Social Sciences;

- within the framework of academic and ethical rules;
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- I have referenced each work from which I have benefited while preparing my thesis, and that
- I hereby present a unique study.

I hereby also understand that I shall accept any loss of rights on my behalf in cases otherwise.

Date and Signature

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Etkin Ekin KARADAĞ

Concept: Data envelopment and Electric

Topic: Data envelopment analysis on Electric distribution companies

Research Questions: Which aspects of Turkish Electric Distribution Companies are lacking and causing being less efficient regarding to other companies that also operate in Turkey for the year 2022?

Title: Efficiency Evaluation of Electric Distribution Companies in Turkey in 2022 with Data Envelopment Analysis.



ÖZ

KARADAG, Etkin Ekin. Veri Zarflama Analizi ile Türkiye’deki Elektrik Dağıtım Şirketlerinin 2022 yılı için Verimliliklerinin Değerlendirilmesi.

Elektrik tüketimi günden güne artmaktadır. Bu yüzden elektrik toplumun olağan yaşantısını devam ettirebilmesi için önemli bir hammadde halini almıştır. Günümüzde farklı tekniklerle elektrik üretimi sağlansa da, elektrik sınırlı bir kaynaktır. Bu yüzden bu hammaddenin üretimi tüketimi ve hatta iletimi büyük bir önem arz etmektedir. Bundan kaynaklı, elektrik tüketimin artması ile birlikte elektrik dağıtım şirketlerinin sorumlulukları artmaktadır. Bu tez çalışmasında, hali hazırda aktiflik gösteren bu dağıtım firmalarının mevcut pazardaki rollerini anlamak için etkinlikleri inceleyeceğiz ve verimli olup olmadıkları çıkarımlarda bulunacağız. Analizlerin gerçekleştirebilmesi için ilk olarak girdi ve çıktılar konusunda karar kılındı. Yüzölçümü, yatırım miktarı, toplam iletim hattı uzunluğu ve kadrolu eleman sayısı değerlerinin girdi olarak kullanılmasına karar verildi. Toplam tüketici sayısı ve dağıtımdan bağlı tüketicilerin tüketim miktarı ise çıktı olarak kullanılmasına karar verildi. Bu değerler kullanılarak faaliyet gösteren 21 firmanın 2022 yılı için göreceli verimlilikleri hesaplandı.

Anahtar Sözcükler: Veri Zarflama Analizi, Verimlilik, Elektrik Dağıtım Şirketleri, Yöneylem Araştırması, Lineer Programlama.

ABSTRACT

KARADAG, Etkin Ekin. Efficiency Evaluation of Electric Distribution Companies in Turkey in 2022 with Data Envelopment Analysis.

Electricity consumption is increasing day by day, making electricity a crucial resource to sustain the normal life of society. While various techniques are used for electricity generation today, electricity remains a finite resource. Therefore, the production, consumption, and even distribution of this resource has become of paramount importance. Consequently, as electricity consumption increases, the responsibilities of electricity distribution companies are also growing. In this thesis, we will examine the activities of the currently active distribution companies to understand their roles in the existing market and draw conclusions about their efficiency. To conduct the analyses, decisions were made regarding input and output. Input values such as land area, investment amount, total transmission line length, and the number of permanent employees were chosen. Total number of consumers, and Consumption of Consumers Connected to Distribution were chosen as output values. Using these values, the relative efficiencies of 21 operating companies were calculated for the year 2022.

Keywords: Data Envelopment Analysis, Efficiency, Electric Distribution Companies, Operational Research, Linear Programming.

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INDEX OF SYMBOLS and ABBREVIATIONS

LP	: Linear Programing
DEA	: Data Envelopment Analysis
DMU	: Decision Making-Units
EDC	: Electricity Distribution Companies
EPDK	: Enerji Piyasaları Düzenleme Kurumu
EMRA	: Energy Market Regulatory Authority
EDAŞ	: Elektrik Dağıtım A.Ş.
EDC	: Electric Distribution company
CRS	: Constant Return to Scale
VRS	: Variable Return to Scale
CCR	: Cooper, Charles, and Rhodes Model
CCR-O	: Output oriented CCR Model
CCR-I	: Input oriented CCR Model
BCC	: Banker, Charles, and Cooper Model
BCC-O	: Output Oriented BCC Model
BCC-I	: Input Oriented BCC Model

INTRODUCTION

Throughout human existence, the search for viable energy sources has marked pivotal milestones. Initially, fire revolutionized cooking and bolstered tool quality. Later, the harnessing of steam emerged. Over time, people melded age-old knowledge with novel techniques in pursuit of fresh energy prospects. Eventually, scientists unlocked a new frontier: electricity.

While electricity has seamlessly integrated into daily life, its excessive use bears detrimental effects. The unchecked consumption of fossil fuels, inherent to excessive electricity usage, exacts an ongoing toll on the planet. Even with the inevitability of fossil fuel depletion, the irreversible damage persists.

Local governments are highly alerted by the concerns over escalating electricity costs, primarily fueled by non-renewable energy sources. This concern draws from the realization that electricity consumption intertwines closely with both GDP (Gross Domestic Product) growth and population expansion. A 2019 study by Khalifa, Caporin, and Di Fonzo underscores this correlation, indicating that as the population increases, electricity demand follows suit.

In anticipation of the increasing demand for electricity, scientists actively pursue innovative and cost-effective solutions. Ongoing efforts focus on discovering more efficient methods to meet the evolving needs, particularly addressing challenges posed by the increasing population and the subsequent surge in electricity consumption. The collective aim is to ensure that our energy supply remains in step with future demands.

Facilitating the widespread distribution of electricity to specific zones, particularly for consumer use, are mediators known as electric distribution companies. These entities, responsible for the maintenance, repair, and management of electricity lines, play a crucial role in addressing malfunctions such as electric outages. Operating on a profit model derived from arbitrage—the variance between suppliers' and distributors' pricing—electric distribution companies are integral to the functioning of modern civilization. Despite this, occasional unprofitability arises due to managerial issues, impacting both companies and consumers alike.

According to data provided by the Energy Market Regulatory Authority (EMRA) in 2015, annual electricity consumption in Turkey amounted to 264,136,800 MWh. Within the same dataset, it was noted that imported electricity accounted for 411,100 MWh. To put this into perspective, 1 out of every 50 units of electricity used in Turkey that year was sourced from overseas suppliers. This indicates a delicate balance, suggesting that both supplier and distributor companies are operating at the edge of meeting the public's electricity demands (EPDK, 2016).

This research will delve into the efficiency status of electric distribution companies using data envelopment analysis (DEA) techniques. DEA, a data-based analysis intricately linked to the operational research subtopic of Linear Programming, will assess the performance of Decision-Making Units (DMUs). The DMUs will be transformed into multiple inputs and outputs for efficiency calculations, as outlined by Cooper et al. in 2011.

Data Envelopment Analysis (DEA) is a non-parametric, linear programming-based method with the primary objective of comparing similar decision-making units and establishing an efficiency frontier to describe the situations of these units. The fundamental strength of this analysis lies in its ability to present an efficiency ratio and identify areas that lack efficiency, offering insights into potential enhancements.

DEA serves as a powerful tool for improving decision-making units by pinpointing variables with mediocre performance. Addressing and enhancing these variables can propel decision-making units closer to the efficient frontier, signifying increased efficiency within the defined model. Notably, DEA does not necessitate the establishment of functional relations between variables. This distinctive feature allows for the inclusion of diverse and unrelated variables, such as operational expenditure and the number of customers holding graduate degrees, in the same model.

Crucially, DEA operates under the necessary assumption that all decision-making units are either on the efficiency frontier or below it. This foundational assumption enables the comparison and improvement of inefficient units by referencing them against efficient units on the efficiency frontier. Through this approach, inefficient units can be systematically enhanced until they reach a state of efficiency.

The escalating demand for electricity coupled with finite energy sources has prompted ongoing discussions about the effectiveness of electricity distribution companies. To optimize benefits for both consumers and suppliers, it is imperative for Turkey to devise new, more efficient policies for distribution that contribute to overall profitability. The formulation of such policies hinges on obtaining accurate and thoroughly examined data.

The utilization of Data Envelopment Analysis (DEA) proves instrumental in this context. DEA enables the comparison of different, functionally unrelated variables within a single model, offering a robust evaluation without the need for intricate mathematical differentiation. This approach strengthens the evaluation process by allowing for a comprehensive comparison of potential aspects of decision-making units with the realized outcomes they produce. Particularly in the Turkish context, where companies operate within distinct geopolitical and socio-cultural environments, this methodology proves valuable, as it underscores the shared goal despite varying operational landscapes.

While there is acknowledgment of the substantial potential held by electric distribution companies, the extent to which these companies fulfill their potential remains uncertain. Through a systematic evaluation, companies can be scrutinized concerning their effectiveness in serving their intended purpose. Additionally, this examination can pinpoint specific areas where companies may be lacking, allowing for targeted improvements. In instances where identified deficiencies prove challenging to address, companies can explore alternative areas for enhancement to mitigate these shortcomings.

The implementation of Data Envelopment Analysis (DEA) promises to furnish essential, accurate, and scrutinized data. Consequently, this research aims to employ DEA to evaluate the efficiency of electric distribution companies operating in Turkey for the year 2022. This analytical approach is poised to shed light on the companies' performance and potential areas for improvement, facilitating informed decision-making within the industry.

CHAPTER 1: LITERATURE REVIEW

The foundational work on Data Envelopment Analysis (DEA) was introduced and utilized by Charnes et al. in 1978. Its first application was in comparing the efficiency of public schools. Subsequently, DEA evolved to cover a diverse array of fields for evaluating productivity efficiency. Owing to its versatility, DEA has found application in various domains including finance, health, education, military, sports, and numerous other fields that are too extensive to enumerate comprehensively.

The first application of Data Envelopment Analysis (DEA) to evaluate Electricity Distribution occurred with the work of Hjalmarsson and Veiderpass in 1992. Their study utilized a DEA approach to assess the performance of Swedish Electricity Distribution Companies over a span of 17 years (1970 to 1986), involving a total of 289 electric distribution companies. The output data considered for evaluation included low voltage electricity received by customers, high voltage electricity received by customers, number of low voltage customers, and number of high voltage customers. Input data encompassed hours worked by employees, length of low voltage power lines, length of high voltage power lines, and total transformer capacity. Efficiency was evaluated using the Malmquist index, facilitating a comparison of various ownership types and service areas. The research findings indicated no significant differences in productivity growth among distinct types of ownership or economic organizations within the Swedish Electricity Distribution Companies during the specified period.

In 1996, Bagdadioglu et al. used a nonparametric methodology, specifically Data Envelopment Analysis (DEA), in their research. The primary objective of their study was to conduct DEA for efficiency assessment, comparing publicly operated organizations with their private counterparts in 1991. The dataset for this analysis included 71 cities and 76 retail distribution companies, comprising 72 publicly operated companies, 2 privately run companies, and 2 private generators. The output data used for evaluation consisted of the number of customers, amount of electricity supplied, maximum demand, and service areas. On the other hand, input data encompassed workforce, transformer capacity, network size, general expenses, and network losses. The outcomes of the research revealed that private counterparts exhibited superior efficiency scores compared to publicly operated organizations.

In their 2007 research, Bagdadioglu et al. scrutinized the Turkish Government's proposition to establish 21 new distribution companies, 18 of which involved merging existing entities. Utilizing the Bogetoft and Wang (2005) merger analysis, the researchers aimed to evaluate the potential efficiency gains from these mergers. The model proved instrumental in delineating the presence and extent of efficiency enhancements resulting from the proposed consolidations. The focus of their merger analysis included two key aspects: operational cost and savings, and potential production efficiency gains, spanning 1999 to 2003. However, it is crucial to note that the model employed did not precisely quantify potential gains; rather, it identified their plausibility. The calculations involved the use of various input factors, including the number of employees, number of transformers, transformer capacity (MVA), network length (km), and network losses (MWh). Output factors comprised the number of customers, electricity used (MWh), and service area (square kilometers). The research findings concluded that there existed substantial potential for efficiency gains through the proposed mergers, shedding light on the feasibility of enhancing operational efficiency in the distribution sector.

In Bagdadioglu's 2009 research paper, published in a university journal, the focus was on examining 21 companies operating in Turkey using Data Envelopment Analysis (DEA) in the year 2004. The chosen input parameters included total expenses, the number of outages, and hours of outages. For the output, the researcher considered the number of customers, distributed electricity (MWh), and the length of lines (km). The results of the analysis revealed that 13 out of the 21 companies were identified as underperforming based on the established constraints. Conversely, this implies that the remaining 8 companies were performing well within the given parameters, displaying a noteworthy disparity in the efficiency levels among the analyzed entities.

In Bagdadioglu and Senyucel's 2010 research, stochastic frontier analysis was employed. The chosen model input was the distance function, and the study focused on the examination of 20 Turkish electricity distribution companies spanning the years 2002 to 2009. The selected input variables comprised total expenditure along with the cost of losses and illegal electricity usage, as well as interruption time per customer. The environmental variable considered was customer density, and the output variables included the number of customers and energy supplied. The research findings underscored that incorporating service quality parameters in efficiency models

significantly impacted the performance-based electricity distribution regulation. This impact was observed irrespective of geographical circumstances or village density, emphasizing the relevance of considering service quality aspects in assessing the efficiency and performance of distribution companies.

In Celen's 2011 Master of Science thesis, an examination of efficiency scores for 21 electricity distribution companies in 2009 was conducted using stochastic frontier analysis. The chosen input variables included the number of employees, length of the distribution line, transformer capacity, outage hours per customer, and time. For output variables, electricity delivered, and the number of customers were selected. External factors were also considered, with customer density, customer structure, and time chosen as environmental variables. The research findings indicated that the inclusion of total quality of service factors had minimal impact on the estimates of efficiency scores. This suggests that, in the context of the studied electricity distribution companies, the consideration of service quality aspects did not significantly alter the efficiency assessments derived from the stochastic frontier analysis.

In Bagdadioglu's 2011 book chapter, an examination of 20 distribution companies in 2006 was undertaken. The inputs chosen for the analysis included operating expenses, network losses, and service quality measures. The output variable considered was customers per network line. The Data Envelopment Analysis (DEA) applied in the study revealed that, according to efficiency assessments, only 8 out of the 20 distribution companies were operating efficiently.

In their 2012 study, Celen and Yacin employed a comprehensive approach utilizing FAHP/TOPSIS/DEA methods to assess the Turkish electricity distribution market. The FAHP method was initially applied to establish the comparative significance levels of various quality indicators. Subsequently, the TOPSIS method was utilized to calculate the quality-of-service variable. During the analysis phase, these variables, along with quantity delivered, number of customers, and quality of services, were considered as outputs. The input data included the number of employees, length of distribution lines, and transformer capacities. A notable aspect of their study was the integration of multiple methods concurrently—FAHP, TOPSIS, and DEA. This multi-method approach allowed for the simultaneous consideration of diverse

quality measures, providing a more comprehensive and nuanced evaluation of the performance of electricity distribution utilities.

In Senyuçel's 2012 graduate thesis, stochastic frontier analysis was employed to calculate efficiency scores. The study focused on the examination of 20 distinct electricity distribution companies over a six-year period spanning from 2003 to 2008. The selected input variables included total expenses, total expenses combined with losses and theft costs, total minutes of outages, and minutes of outage and repair. For output, the number of customers and electricity used were chosen. The research findings led to the conclusion that when energy losses are not considered, the estimation results may be skewed, particularly in countries with high energy loss ratios, such as Turkey. This underscores the importance of accounting for energy losses in efficiency analyses of electricity distribution companies for a more accurate assessment of their performance.

In Celen's 2013 analysis, the performance of Electricity Distribution companies operating in Turkey between 2002 and 2009 was scrutinized. The research's main objective was to assess the efficiency changes in electricity distribution regions influenced by the 2005 mergers. The study employed a stochastic frontier analysis framework for efficiency analysis, utilizing a distance function that allows describing a multi-input, multi-output production technology without specifying a specific behavioral objective like cost-minimization or profit-maximization. For the calculation purposes, the researchers utilized the number of employees, length of the distribution line (km), transformer capacity (MVA), and the quality of electricity distribution (comprising technical quality such as service interruptions, voltage regularity, outages, and duration of outages, and quality of customer services including repairs and meeting customer needs) as inputs. A fifth input, the time trend, was introduced to observe technological changes or frontier shifts. Environmental variables included customer densities of regions and the proportion of sales in MWh to residential customers in total sales. Additionally, a dummy variable was incorporated to capture efficiency level differences post-mergers. Outputs consisted of electricity delivered (MWh) and the number of customers. The findings indicated that companies serving mostly residential customers exhibited higher efficiency. Notably, three main positive impacts were identified: a drop in residential customer efficiencies after

mergers, a decrease in customer density (though insignificant), and a decrease in efficiency post-mergers as sales to residents increased.

In Celen's 2013 study, a two-stage analysis was conducted to assess the efficiency of 21 Turkish Electricity Distribution Companies over a seven-year period from 2002 to 2009. The first stage involved applying Data Envelopment Analysis (DEA) to evaluate efficiency based on various variables. In the second stage, the Tobit model was employed to determine the effects of these variables, specifically considering environmental factors. For the DEA analysis, the input variables included the number of employees, length of distribution line, transformer capacity, outage hours per customer, and lost-theft ratio. Outputs comprised electricity used and the number of customers. Environmental variables encompassed customer density, customer structure, restructuring dummy, ownership dummy, and loss-theft ratio. The research findings indicated that customer density and ownership type positively affected efficiencies, suggesting that privatization could be a viable strategy to enhance efficiency levels in electricity distribution companies.

In their 2019 research, Petridis and colleagues employed the Network Data Envelopment Analysis (DEA) model, a two-stage model, to assess the profit efficiency of 20 Turkish Electric Distribution companies. The primary objective was to evaluate the efficiency of these companies while considering the expansion cost for additional energy supply. The chosen inputs for the analysis included the number of staff, net consumption (MWh), number of transformers, length of cables (km), and installed capacity (MVA). Intermediate output was identified as energy supply (MWh), while undesirable outputs comprised annual faults and interruptions and energy losses (MWh). The final outputs were the number of customers and the number of towns/villages served. The research findings suggested that the proposed Network DEA model provided more realistic results compared to the radial efficiency model commonly found in the literature. This underscores the model's effectiveness in capturing the complexities associated with the efficiency evaluation of electric distribution companies, especially when considering expansion costs for additional energy supply.

In Cayır's 2020 study, an evaluation of 21 electric distribution companies in Turkey was conducted. The results from the Data Envelopment Analysis (DEA) indicated that 7 out of the 21 companies were more efficient than the remaining 14.

Subsequently, researchers employed the Artificial Neural Network method on the initial DEA model to reevaluate the efficiency of each company. For this reevaluation, powerline length, transformer capacity, and loss ratio were utilized as input data, while the number of customers and delivered electricity served as output data. This two-step approach, combining DEA and Artificial Neural Network methods, provided a comprehensive analysis of the efficiency levels of electric distribution companies, considering various input and output factors.

Indeed, the research underscores the multitude of approaches available for determining and quantifying the efficiency of companies, businesses, or decision-making units. Within this landscape, data envelopment analysis emerges as a highly regarded and distinctive method for efficiency evaluation. The literature review conducted in this research affirms that data envelopment analysis possesses a significant potential to provide precise insights into the historical or status of decision-making units. These insights, derived from data envelopment analysis, offer valuable information that can be used to enhance efficiency. Furthermore, they serve as a foundation for ensuring the future improvement of decision-making units. The research thus underscores the robustness and utility of data envelopment analysis in the realm of efficiency evaluation, positioning it as a valuable tool for strategic decision-making and continuous improvement initiatives.

Through extensive exploration of literature, data envelopment analysis has immense applicability across various situations and fields. This method has proven to be versatile and can be effectively implemented in diverse contexts. In summary, data envelopment analysis stands out as a highly accurate and reputable approach for evaluating efficiency. The comprehensive literature review serves as a guide, enabling the standardization of research goals, inputs, outputs, methods, and expected outcomes. As the research progresses, the application of data envelopment analysis will reveal whether companies are operating in alignment with expectations and if the applied approach proves beneficial for them. The thorough literature review conducted thus far contributes to a well-informed and structured research approach, providing a solid foundation for evaluating the efficiency of electric distribution companies in Turkey using data envelopment analysis.

CHAPTER 2: THEORITICAL BACKGROUND

2.1. History of Electricity

Electricity is a form of energy stemming from the movements of electrons, neutrons, and protons in a free environment, a discovery credited to Benjamin Franklin in 1752. Franklin's iconic kite experiment, featuring a key, was pivotal in observing electric sparks. In the 1800s, Alessandro Volta's exploration revealed that chemical reactions had the potential to generate electricity, laying the foundations for the term "battery." The practical application of electricity in daily life began in 1879 with Thomas Edison. Numerous methods exist for generating electricity, encompassing chemical reactions, friction, wind power, thermal energy, among others. Presently, electric generators play a significant role in electricity generation. Fossil fuels are burned, converting them into heat, which, in turn, propels electric generators to produce electricity. Additionally, sustainable methods such as wind power and hydroelectricity rely on generator rotation for electricity production.

2.2. Efficiency

In performance management, three basic concepts consistently surface: efficiency, effectiveness, and productivity. Performance refers to the quantity and quality of outcomes derived from individuals or groups executing their assigned tasks (Baş & Artar, 1991). It signifies the realized potential with respect to responsibilities.

Efficiency pertains to the actions undertaken to attain the anticipated outcomes. To assess efficiency, the following formula can be mentioned:

$$efficiency = \frac{Outcome(Output)}{Entry(Input)}$$

which indicates the likelihood that the generated outcome will align with the expected outcome. Effectiveness, on the other hand, measures the extent to which predetermined outcomes are accomplished. The effectiveness can be calculated using the formula:

$$effectiveness = \frac{Realized Outcome (Output)}{Expected Outcome (Input)}$$

Productivity is often conflated with performance, although they represent distinct concepts. While performance refers to the efforts exerted to attain a desired goal (Karasoy, 2000), productivity is a composite measure that encompasses both

efficiency and effectiveness. Despite various methods available to evaluate efficiency, such as SFA and FOTH, this paper focuses on the use of Data Envelopment Analysis models for its calculations.

2.3. Data Envelopment Analysis

Due to the rapid globalization of the world, human needs are increasing daily, leading to the establishment of new companies and organizations to fulfill these needs. The number of such entities is growing continuously, giving rise to intense competition. Success in this competitive landscape is often determined by how well a company manages its resources compared to others. To assess and compare resource management, this paper employs the Data Envelopment Analysis technique (Tetik, 2003). Data envelopment analysis is a non-parametric, mathematical, linear programming method designed to measure the relative efficiency of Decision-Making Units (DMUs) by comparing similar entities with multiple inputs and outputs.

2.4 Decision Making Units Decisions

The first step in Data Envelopment Analysis is the selection of Decision-Making Units (DMUs). This decision requires precision, and the chosen units must align with the goals of the research. The selected DMUs should be homogeneous, meaning they share a common purpose, have similar input, and output variables, and respond similarly to external factors. Including enough DMUs is crucial, as it ensures diverse efficiency scores and prevents a single unit from having an advantage solely due to output-input ratios. This diversity improves the reliability of results. Therefore, the decision on which DMUs to include demands careful consideration and accuracy (Karasoy, 2006).

2.5. Input and output Variable Decisions

In Data Envelopment Analysis, the evaluation of relative efficiency is contingent on the careful selection of input and output variables. While there is flexibility in choosing these variables, decisions should prioritize expressing the research goals effectively to yield logical results. Input plays a crucial role in influencing output outcomes. Thus, the interchangeability of inputs and outputs based on the research's purpose should be considered. To begin, all potential variables should be identified. Subsequently, decisions about which variables to designate as inputs,

outputs, or excluded from the model should be made with the researcher's insights and aligned with the research objectives. This thoughtful selection ensures the model reflects the study's goals accurately.

An excess of input and output variables in data envelopment analysis can diminish its ability to differentiate effectively. To address this, options include reducing the number of variables or increasing the number of decision-making units. Excessive variables may compromise the homogeneity of decision-making units, necessitating a balance in their selection. Resolving these issues is crucial for the research, as improperly chosen inputs and outputs may fail to accurately represent the problem. Exploring various combinations through trial-and-error methods can lead to a more refined model, ensuring a healthier and more meaningful outcome. (Karasoy, 2006)

2.6. Efficiency Scores

Before delving into the analysis, it is essential to establish a model. Decision-making units, input and output variables have been determined, and the next step involves identifying a suitable model for the research. Once the model is chosen, it is then solved using linear programming methods, yielding efficiency scores ranging from 0 to 1 as the outcome. This step is pivotal in quantifying the relative efficiency of the decision-making units within the defined parameters.

2.7. Efficiency Groups

Upon examination of the scores, Decision Making Units (DMUs) achieving an efficiency score of 1.0 are deemed efficient, while others are classified as inefficient and ranked from the highest to the lowest scores. This comparative process involves scrutinizing both outputs and inputs, resulting in efficiency scores for each DMU. Following this evaluation, a distinct set of decision-making units emerges, comprising both efficient and inefficient entities. Inefficient units aspire to emulate the characteristics of efficient ones with the aim of transitioning into the efficient category. The set of efficient DMUs that inefficient ones strive to resemble is called the reference group. Analyzing the efficiency data thus provides insights into potential pathways for transforming inefficient units into efficient ones.

2.8. Discussion of Results

Following the generation of results, a thorough evaluation of each decision-making unit is essential. This involves a comprehensive analysis of the inputs and outputs, with the aim of presenting and interpreting the findings for each unit. The evaluation process provides insights into the efficiency performance of individual decision-making units, shedding light on specific areas of strength or weakness. This step contributes to a nuanced understanding of the factors influencing the efficiency scores and guides potential strategies for improvement.

2.9. History of Data Envelopment Analysis

The first mention and application of DEA occurred in an academic paper titled "Measuring the efficiency of decision-making units" in 1978 by Abraham Charnes, William W. Cooper, and Edwardo Rhodes. They drew inspiration from Michael J. Farrell's 1957 paper, "The measurement of productive efficiency" (Cooper et al., 2011). Over the years, DEA has found applications in various professional and non-professional domains, ranging from assessing the efficiency of foundation universities to hospitals and even factors influencing the performance of horses.

2.10. Usage of DEA

The DEA tools are versatile, allowing researchers to apply them across various fields involving efficiency calculations. To delve deeper into the understanding of DEA, the CCR model will be examined.

The CCR model is the most fundamental and basic model within DEA, often considered the cornerstone of the methodology. The name "CCR" is derived from the surnames of its creators—Charnes, Cooper, and Rhodes. This model operates under the assumption of constant returns to scale.

The BCC model, introduced by Banker, Charnes, and Cooper in 1984, represents a distinctive variant within the Data Envelopment Analysis (DEA). This model systematically evaluates the resource management efficiency of businesses or units. It ensures fairness by comparing units of similar size. A noteworthy characteristic of the BCC model is its consistent provision of efficiency scores, which are at minimum equivalent to those derived from the CCR model. Unlike the CCR model, the BCC model accommodates variable returns to scale, adding a layer

of flexibility to the assessment. Employing linear programming techniques, the BCC model computes optimal weights for inputs and outputs, with the aiming objective of maximizing efficiency under variable return to scale. In more straightforward terms. In simpler terms, it's a way to see how well a company is doing, and it's a bit more flexible than some of the other methods.

‘The solution of DEA requires that the weights for inputs and outputs of each unit be selected to maximize its efficiency under certain constraints. In other words, we allow each unit to pick the most favorable weights for its specific situation.’ (Pahwa et al., 2002)

2.11. Concept of Return to Scale

The concept of returns to scale in efficiency analysis revolves around two main points: constant returns to scale (CRS) and variable returns to scale (VRS). In constant returns to scale, the assumption is that increasing input quantities will result in a proportional increase in output quantities. On the other hand, in VRS, the increase in input quantities may lead to either a less than proportional or more than proportional increase in output quantities. Constant returns to scale are a more restrictive model than variable return to scale, resulting in fewer efficient units and lower efficiency scores for all Decision-Making Units (DMUs) because it assumes a fixed relationship between inputs and outputs (ALBASRI, 2021). It is also worth mentioning other types of return to scales, namely increasing returns to scale and non-increasing returns to scale.

2.12. CCR Model

Firstly, the mathematical formulation of efficiency will be examined. Efficiency is about avoiding the waste of primary sources while producing the intended outcome and fulfilling the desire of using available resources in the most efficient way. This explanation can be expressed mathematically as the ratio of the work done to the spent energy. In other words, efficiency is equal to the output source divided by the input source.

$$efficiency = \frac{Outcome(Output)}{Entry(Input)}$$

While this equation is optimal for one input and one output, businesses and organizations often deal with more complex scenarios involving multiple inputs and outputs throughout the production process. To optimize this basic question for multi-input and multi-output situations, the equations become:

$$Efficiency\ Rate(ER) = \frac{\sum_{r=1}^m Output}{\sum_{i=1}^n Input}$$

This equation represents the efficiency ratio of the total ‘m’ number of outputs to the total ‘n’ number of inputs

$$ER = \frac{\sum_{r=1}^m u_r \times y_{r0}}{\sum_{i=1}^n v_i \times x_{i0}}$$

In the next step, u_r and v_i are added to the equation. According to Ozden (2008), those terms are coefficients of the inputs and outputs. u_r is the weighting coefficient of y_r which outputs DMUs and v_i is the weighting coefficient of x_i which input DMUs. The result of those calculations can be less than or equal to one because of the limitations stated by Charnes and Cooper. and Rhodes; any result less than one means it is inefficient. If a group of DMUs from calculations wanted to be declared as ‘efficient,’ the result must be equal to one. So, the equation will be easily simplified;

$$\max \quad h_0(u, v) = \frac{\sum_{r=1}^m u_r \times y_{r0}}{\sum_{i=1}^n v_i \times x_{i0}}$$

Subject to,

$$\frac{\sum_{r=1}^m u_r \times y_{rj}}{\sum_{i=1}^n v_i \times x_{ij}} \leq 1 \text{ for } j = 1, \dots, n$$

$$u_r, v_i \geq 0 \text{ for all } i \text{ and } r.$$

So, the equation above-mentioned has infinite numbers of solutions. To handle this situation, Charnes, and Cooper (1962) developed a transformation model. For this transformation, $\sum_{i=1}^n v_i \times x_{i0}$ is assumed to be equal to 1. Transforming the previous equation with this assumption, (u, v) will also transform to (μ , v). As a result of this Charnes and Cooper transformation;

$$\max \quad z = \sum_{r=1}^s \mu_r \times y_{r0}$$

Subject to,

$$\sum_{r=1}^s \mu_r \times y_{rj} - \sum_{i=1}^m v_i \times x_{ij} \leq 0$$

$$\sum_{i=1}^m v_i \times x_{i0} = 1$$

$$\mu_r, v_i \geq \varepsilon$$

This model is Multiplier form of Input oriented CCR model. If the dual of this model is taken in linear programming, the envelopment model is obtained, which is;

$$\min z = \theta - \varepsilon \left(\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+ \right)$$

Subject to,

$$\sum_{j=1}^n x_{ij} \lambda_j + s_i^- = \theta x_{i0} \quad i = 1, 2, \dots, m$$

$$\sum_{j=1}^n y_{rj} \lambda_j - s_r^+ = y_{r0} \quad r = 1, 2, \dots, s$$

$$\lambda_j \geq 0 \quad j = 1, 2, \dots, n$$

So, this is the Envelopment model of the input oriented CCR model. If the model wanted to turn output oriented, there should be some basic changes in the equation. Instead of assuming $\sum_{i=1}^m v_i \times x_{i0} \leq 0$ should be $\sum_{r=1}^s \mu_r \times y_{r0}$ is equal to 1. So, the multiplier model can turn into;

$$\min \quad q = \sum_{i=1}^m v_i \times X_{i0}$$

Subject to,

$$\sum_{i=1}^m v_i \times x_{ij} - \sum_{r=1}^s \mu_r \times Y_{rj} \geq 0$$

$$\sum_{r=1}^s \mu_r \times y_{r0} = 1$$

$$\mu_r, v_i \geq \varepsilon$$

This would be the multiplier model of the Output-oriented CCR model. Taking the linear programming dual of this model, this model will obtain;

$$\max q = \varphi + \varepsilon \left(\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+ \right)$$

Subject to,

$$\sum_{j=1}^n x_{ij} \times \lambda_j + s_i^- = x_{i0} \quad i = 1, 2, \dots, m$$

$$\sum_{j=1}^n y_{rj} \times \lambda_j - s_r^+ = \varphi y_{r0} \quad r = 1, 2, \dots, s$$

$$\lambda_j \geq 0 \quad j = 1, 2, \dots, n$$

The difference between input-oriented models and output-oriented models lies in their goals. In input-oriented models, the aim is to identify the most efficient input variables, focusing on minimizing the inputs for a given level of output. On the other hand, in output-oriented models, the primary objective is to maximize the outputs for a given level of inputs.

3.13. BCC Model

At the beginning, BCC ratio form is like CCR ratio form except adding a new variable depending on input-oriented or output-oriented. Firstly, the input-oriented version will be examined. In this version, $\bar{u}_0$ variable needed to be added into equation;

$$\max \quad \frac{u Y_0 + \bar{u}_0}{v X_0}$$

Subject to,

$$\frac{u Y_j + \bar{u}_0}{v X_j} \leq 1, \quad j = 1, \dots, n$$

$$\frac{u}{v X_0} \geq \varepsilon \cdot \bar{1}$$

$$\frac{v}{v X_0} \geq \varepsilon \cdot \bar{1}$$

This equation is known as the input-oriented BBC ratio model.

$$\max \quad z = \sum_{r=1}^s \mu_r y_{ro} + u_o$$

Subject to,

$$\sum_{i=1}^m v_i x_{io} = 1$$

$$\sum_{r=1}^s \mu_r y_{rj} - \sum_{i=1}^m v_i x_{ij} + u_0 \leq 0 \quad j = 1, 2, \dots, n$$

$$v_i \geq \varepsilon, \quad \mu_r \geq \varepsilon, \quad u_0 \text{ free in sign.}$$

This equation is known as the Multiplier form of the input-oriented BCC model.

If this multiplier form transformed into envelopment form;

$$\min \quad z = \theta_o - \varepsilon \left(\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+ \right)$$

Subject to,

$$\theta_o x_{io} = \sum_{j=1}^n x_{ij} \lambda_j + s_i^- \quad i = 1, 2, \dots, m$$

$$y_{ro} = \sum_{j=1}^n y_{rj} \lambda_j - s_r^+ \quad r = 1, 2, \dots, s$$

$$\sum_{j=1}^n \lambda_j = 1$$

$$\lambda, s_r^+, s_i^- \geq 0$$

This is the envelope form of the input-oriented BCC model. For showing output-oriented version of BBC ratio model instead of input-oriented model, $\bar{v}_0$ variable should be added into the equation;

$$\max \quad \frac{v x_0 + \bar{v}_0}{u Y_0}$$

Subject to,

$$\frac{u x_j + \bar{v}_0}{u Y_j} \geq 1 \quad j = 1, \dots, n$$

$$\frac{u}{u Y_0} \geq \varepsilon \cdot \bar{1}$$

$$\frac{v}{u Y_0} \geq \varepsilon \cdot \bar{1}$$

Turning those equation into multiplier form;

$$\begin{aligned}
\max \quad & q = \sum_{r=1}^s \mu_r y_{ro} - u_o \\
\text{Subject to,} \quad & \\
& \sum_{i=1}^m v_i x_{io} = 1 \\
& \sum_{r=1}^s \mu_r y_{rj} - \sum_{i=1}^m v_i x_{ij} - u_0 \leq 0 \quad j = 1, 2, \dots, n \\
& v_i \geq \varepsilon, \quad u_r \geq \varepsilon, \quad u_0 \text{ free in sign.}
\end{aligned}$$

If the primal of this equation taken, the envelopment form of the output-oriented BCC model will be received, and which is;

$$\begin{aligned}
\min \quad & q = \phi_o + \varepsilon \left(\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+ \right) \\
\text{Subject to,} \quad & \\
\phi_o y_{ro} &= \sum_{j=1}^n y_{rj} \lambda_j - s_r^+ \quad r = 1, 2, \dots, s \\
x_{io} &= \sum_{j=1}^n x_{ij} \lambda_j + s_i^- \quad i = 1, 2, \dots, m \\
\sum_{j=1}^n \lambda_j &= 1 \\
\lambda, s_r^+, s_i^- &\geq 0
\end{aligned}$$

2.14. Strong and Weak Sides of Data Envelopment Analysis

2.14.1. Strong sides

Many of the upcoming strong sides of DEA are related to this analysis. When applied appropriately, the evaluation process using DEA proves to be an effective tool for making assumptions about the Decision-Making Units (DMUs). The strengths of DEA can be summarized as follows:

- This analysis can be used to reduce the multi-inputs and multi outputs into only one number. This is one of the strongest sides of DEA.

- Input and output do not have to be related which means two non-related or different variables can be compared. So, this provides much wider opportunities to do evaluations.
- Provides the opportunity of comparison of two different irrelevant units.
- DMUs can easily be compared with each other regarding efficiency scores. So, the comparison part will be easier and smoother.
- Gives insights about how to turn inefficient DMUs into efficient DMUs.

2.14.2. Weak sides

While the strengths have been outlined in the preceding section, it is crucial to acknowledge the potential drawbacks associated with DEA. The weaknesses of DEA can be categorized as follows:

- DEA is finding the extreme point of graphics. It is extremely sensitive to miss calculations. So, even the slightest dislocation causes tremendous errors in the model and can affect results.
- Results depend on the input and output variables. The input and output decisions must be made wisely. Otherwise, results can become unusable or uninterpretable.
- DEA separates the DMUs into two categories. Those two categories are efficient and inefficient. It compares the DMUs with each other. So, it cannot specify which of the DMUs is absolutely the most efficient one.
- It only compares the specific time frame of the DMUs. The results may not be acceptable for other periods.
- Due to setting up different LP models for each DMUs, it became not time efficient to solve those models. Luckily, computer programs make it faster for users.
- It is not sensitive to non-discretionary variables and categorical variables like ‘weather of the day.’ (Erken&Emirel,2002)
- Due to being a non-parametric method, DEA is hard to implement in hypothetical research. (Kıyıda & Karaşahin, 2006)

CHAPTER 3: METHODOLOGY

Quantitative research relies on empirical data, numerical analysis, and statistical methods to draw conclusions. It is a deductive approach that focuses on variables and produces numerical findings. Quantitative research often involves large datasets, and its results are generalizable. In the context of the efficiency analysis discussed in this report, quantitative research, particularly using techniques like Data Envelopment Analysis (DEA), provides a systematic and numerical framework for evaluating decision-making units. Quantitative research is well-suited for fields such as mathematics, economics, biology, physics, and more. Its emphasis on numerical data and statistical analysis allows for a rigorous examination of performance and efficiency, making it an appropriate choice for this study.

3.1. Method

The choice of the quantitative research method in this report is well-justified, especially considering the use of complex and primarily numerical data. The focus on hard data, which is numerical in form, aligns with the need for rigorous analysis and modeling using linear programming methods such as Data Envelopment Analysis (DEA). Additionally, the mention of large sample sizes emphasizes the need for a quantitative approach to handle and analyze the extensive data involved in the study. It is also noteworthy that the sampling elements were not aware of the specific data usage in the field during data collection, which further underscores the independence of the data from its original context. This separation allows the data to be repurposed for this report's goals, showing flexibility in the application of quantitative research methods.

Indeed, based on the information provided, this research can be classified as nonreactive, specifically falling under the category of secondary data analysis. Nonreactive research refers to research where the subjects are not aware that they are being studied, and their behavior is not influenced by the research activity itself. In the case of secondary data analysis, the researcher analyzes existing data collected by others for a purpose different from the original intent of data collection.

3.2. Sampling

The choice of non-random sampling, particularly the purposive sampling method, and within it, the Total Population Sampling approach, suggests a deliberate and targeted selection of electric distribution companies based on specific criteria. This approach can be effective when the researcher has a clear understanding of the characteristics or attributes they are looking for in the sampled companies. Total Population Sampling involves studying the entire population, and in this case, it implies that all electric distribution companies meeting the defined criteria will be included in the analysis. This method is suitable when the population size is small, as it is in this context.

The entire population of electric distribution companies in Turkey, consisting of 21 companies, will be the focus of this research. The decision to use total population sampling indicates that there is no intention to select a subset of the population for analysis; instead, all companies meeting the criteria will be included. Given the specific context of electric distribution companies and their limited number in Turkey, this approach seems justified. The use of purposive sampling within total population sampling implies a deliberate selection based on specific criteria, which aligns with the research's targeted examination of efficiency within the chosen companies. This sampling strategy should provide a comprehensive understanding of the efficiency landscape among electric distribution companies in Turkey, particularly those that meet the specified criteria.

3.3. Data Collection

This report relies on secondary data, as data collection was not necessary, given the availability of relevant information from governmental sources. The primary data source is the annual service report compiled by the Energy Market Regulatory Authority (EMRA, in Turkish known as EPDK). This report consolidates data from the annual reports of electric distribution companies, providing comprehensive insights into various service metrics. Key data points include the number of complaints, customer count, electricity distribution volumes, and more.

3.4. Model Selection

Burns et al. (2000) conducted studies that revealed how variable decisions and the choice between constant returns to scale (CRS) or variable returns to scale (VRS) models can impact the efficiency scores of Decision-Making Units (DMUs). These models assess various aspects of efficiency. The CRS model, known as CCR, evaluates technical efficiency without considering unit size, while the VRS model, or BCC, examines pure technical efficiency and determines the return to scale type (increasing, decreasing, or constant). Challenges may arise when choosing between CRS and VRS models. DMUs can be efficient in VRS but inefficient in CRS due to factors like genuine inefficiency or operating on an inefficiently large or small scale (Burns et al., 2000). According to Burns et al. (2000) and Pahwa et al. (2002), CRS models are often deemed more suitable than VRS models for electricity-related studies, particularly in an input-oriented context. Efficiency analysis in the electric distribution context typically falls into two categories: input-oriented models, where DMUs aim to achieve specific output quantities with the least possible input, and output-oriented models, where DMUs aim to maximize output with specific input quantities (Albasri, 2021). For this research, the input oriented CCR model will be employed, focusing on assessing the efficiency of Electric Distribution Companies (EDCs). It is noteworthy that EDCs lack the authority to select their customers, obliging them to serve all individuals in their assigned areas. Consequently, EDCs have limited control mechanisms over outcomes (Donmezcelik, 2014).

3.5. Input / Output Selection

Making input and output decisions in research is crucial, as on-the-spot decisions contribute to clear and easily interpretable situations. In this research, several variables need consideration for use in the analysis. Examples of these variables include:

- Domain area Measurement
- Number of Subscribers
- Number of inhabitants in the domain
- Investment amount
- Total length of lines
- Total length of underground lines

- Total length of aerial lines
- Number of permanent employees
- Number of subcontractor employees
- Loss/Leakage ratio
- Total minutes of outage
- Total minutes of pre-notified outage
- Total minutes of non-notified outages
- Number of transformers
- Capacity of transformers

Reducing the number of variables is crucial for DEA to maintain its differentiation capability. Increasing the count of variables would necessitate an increase in the count of DMUs to achieve suitable outcomes. If there are too many input and output variables in the equation, more DMUs than desired would be defined as efficient (Cook, Tone, and Zhu, 2013). Hence, using numerous variables in calculations is not preferred. While deciding which variables to use in the research, the 'Rule of Thumb' is considered first. This rule states that the number of DMUs should be at least twice the total number of input and output variables (Golany and Roll, 1989). On the other hand, Banker et al. (1989) mentioned that the number of DMUs should be at least three times the total number of input and output variables. In this research, the approach of Banker et al. (1989) is applied, with 21 DMUs, and the total number of four inputs and two outputs variables were chosen.

Table1. Potential Variables

	Area Measure ment	Investments	Total Length of Lines	Per man ent Em ploy ees	Num ber of sub scri bers	Loss/ Leak age Ratio	Total Out age	Non - per man ent emp loy ees	Cap acit y of tran sfor mers	Num ber of Tra nsfo rme rs	Total Len gth of Air Line s	Total Len gth of Und ergr ound Line s	Ann oun ced Out age	Un ann oun ced Out age	Pop ulation
ADM	33,3 02	1.66 5,5	76.8 81	775	2.21 1.39 1	5,58 %	1.80 6,3	2.10 1	9.54 5	23.9 04	61.5 05	15.3 76	1.18 6,8	619, 5	3,25 2,75 8
Akd eniz	36,5 14	1.23 0,0	71.1 3	310	2.37 9.31 5	7,00 %	2.10 9,0	2.33 3	8.96 6	20.6 25	52.2 88	18.8 42	780, 1	1.32 8,9	3,40 7,12 8
Ake daş	22,2 17	436, 3	27.8 46	917	771. 578	4,32 %	1.47 7,9	260	4.06	13.3 75	24.3 14	3.53 1	462, 3	1.01 5,6	1,81 2,60 5
Ana dolu Yak ası	1,92 6	1.39 2,4	59.1 83	591	1.12 9.27 7	19,3 1%	2.43 2,1	1.42 4	3.37	14.9 52	50.9 59	8.22 4	1.63 6,5	795, 6	5,64 9,75 1
Ara s	70,0 07	975, 8	136. 017	4.21 8	4.52 3.13 4	5,05 %	2.07 8,2	2.77 2	18.2 55	35.7 94	99.3 22	36.6 96	818, 0	1.26 0,2	2,15 4,74 8
Baş kent	61,1 61	2.29 3,2	54.0 38	679	5.39 0.00 7	5,75 %	1.09 4,0	3.83 5	19.3 15	15.7 05	15.5 71	38.4 67	267, 8	826, 2	7,67 7,13 1
Boğ aziçi	3,50 7.83	2.30 7,4	50.1 26	289	1.06 0.93 9	6,38 %	1.53 9,9	118 2	3.20 2	13.7 06	43.1 75	6.95 1	654, 5	885, 4	10,2 58,2 00
Ça mlı b el	51,3 12	570, 8	62.7 39	402	1.51 3.14 6	6,05 %	2.13 2,7	2.44 7	4.80 6	13.0 86	56.8 67	5.87 1	973, 3	1.15 9,4	1,64 9,82 0
Çor uh	29,2 11	769, 9	83.5 21	3.94 3	2.13 7.98 5	6,64 %	5.52 5,6	3.84 4	15.2 76	70.7 93	70.8 11	12.7 1	2.06 2,0	3.46 3,6	1,92 6,84 8
Diçl e	61,1 98	2.05 2,5	48.6 54	342	1.09 8.63 0	43,6 3%	1.48 3,7	1.67 9	3.60 9	13.8 36	41.4 02	7.25 2	632, 0	851, 7	6,36 8,77 1
Fira t	37,4 41	640, 2	70.0 25	960	3.74 4.69 2	8,91 %	1.57 6,8	3.27 2	17.1 31	35.7 09	50.9 73	19.0 52	991, 8	585, 1	1,77 0,99 9
GD Z	28,5 00	2.30 4,6	34.4 78	204 9	3.09 2.69 5	5,04 %	687, 5	949	9.63 4	8.08 2	11.9 89	22.4 89	339, 3	348, 2	5,93 0,33 5

Kay seri ve Çev resi	16,9 69	409, 2	28.6 3	731	818. 83	6,67 %	819, 0	197	2.98 2	8.87 1	19.7 47	8.88 4	448, 8	370, 1	1,44 1,52 3
Mer am	66,5 16	1.46 0,0	122. 903	750	2.34 8.61 3	6,17 %	1.25 0,1	1.55 9	14.0 58	63.8 69	97.2 54	25.6 49	635, 2	614, 9	3,91 0,18 9
Os man gazi	49,6 92	1.84 8,1	53.2 07	123 3	1.97 8.67 3	6,31 %	1.66 0,3	1.76 4	8.54 3	29.4 29	43.4 78	9.72 8	550, 4	1.11 0,0	2,83 9,00 0
Sak arya	19,5 00	1.22 4,7	64.5 68	165 1	2.09 1.26 8	5,75 %	1.98 0,4	1.02 2	9.10 2	18.5 74	44.6 54	19.9 14	704, 3	1.27 6,1	3,88 5,10 7
Tor osla r	46,5 96	2.60 5,9	147. 262	4.38 1	4.30 8.01 6	10,6 2%	4.45 8,0	3.77 6	18.7 22	47.6 91	119. 602	27.6 6	1.93 9,8	2.51 8,1	8,73 7,96 0
Tra kya	16,9 83	782, 1	30.1 85	829	1.25 1.27 2	5,48 %	1.06 0,4	313	5.93 1	12.4 25	23.8 05	6.38	570, 2	490, 2	1,92 6,51 2
Ulu dağ	35,5 01	483, 8	53.3 12	766	3.55 6.68 0	4,79 %	577, 3	171 7	11.8 37	28.0 04	39.4 23	13.8 89	267, 3	310, 1	5,30 8,02 6
Van gölü	40,9 20	967, 6	41.3 67	102 1	802. 776	35,6 4%	4.07 8,7	1.22 2	3.13 1	13.0 97	37.0 84	4.28 2	1.49 3,5	2.58 5,2	2,15 7,27 2
Yeşi lirm ak	39,9 28	920, 6	85.1 47	545	2.35 4.54 2	6,55 %	1.96 5,8	1.64 2	5.26 6	20.7 84	72.3 5	12.7 97	1.05 7,1	908, 7	3,21 4,87 4

Six different variables were selected as inputs and outputs for the analysis: domain area measurement, investments, total length of lines, and permanent employees as inputs, and the number of subscribers and consumption of consumers connected to distribution as outputs. The rationale behind these choices is grounded in the perception that domain area, investments, line length, and permanent employees represent the fundamental resources of the companies and should be treated as raw materials. Conversely, subscriber count and consumption of consumers connected to distribution are considered performance-dependent metrics, subject to variation based on how companies manage these situations.

Also, a judicious choice of variables is crucial in maintaining the differentiation capability of DEA. Too many variables may lead to an inflated number of DMUs defined as efficient, and it is not preferred. The 'Rule of Thumb' suggests that the

number of DMUs should be at least twice the total number of input and output variables (Golany and Roll, 1989). Alternatively, Banker et al. (1989) proposes that the number of DMUs should be at least three times the total number of input and output variables. In this research, the approach of Banker et al. (1989) is applied, resulting in the selection of six variables for analysis, given 21 DMUs and a total of six inputs and outputs.

3.6. Inputs

Domain Area Measurement: The domain area refers to the space in which business activities are conducted. Companies do not define this activity area; rather, it is determined through tenders. Consequently, it can be perceived as a raw material that has the potential to be processed into something more valuable. As the utilization of this parameter depends on the investments and improvement initiatives undertaken by the companies, it is considered a raw material. This rationale leads to the selection of Domain Area Measurement in square kilometers as an input variable.

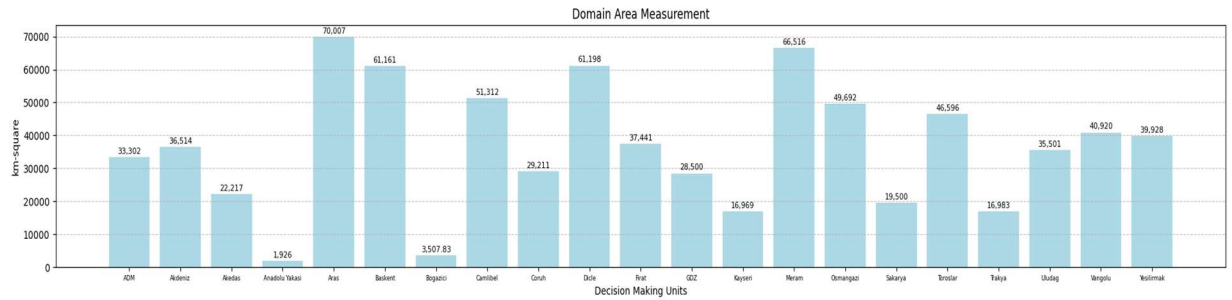


Figure 1. Area Measurement Graph of DMUs

Investments: The funds invested with the expectation of future profits are considered the primary resource of the distribution company. The amount of money invested can significantly influence future outcomes and is fundamental for the outputs to be addressed in the future. Therefore, it can be asserted that present investments directly impact future results. Consequently, the annual investment amount in millions of Turkish Lira is selected as an input variable.

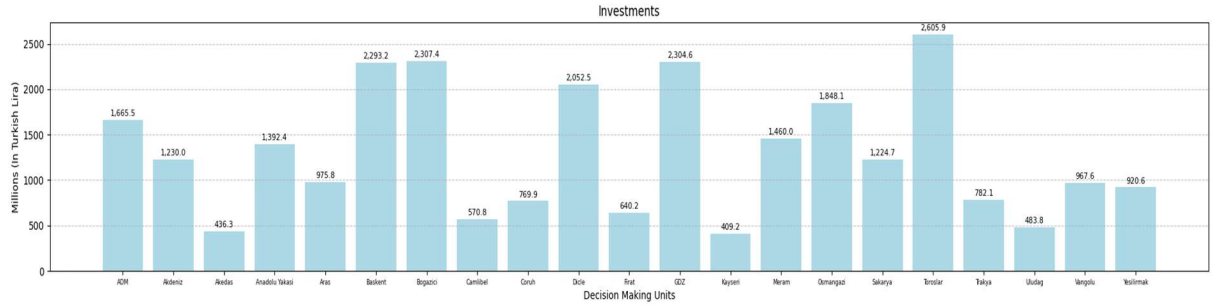


Figure 2. Investment Graph of DMUs

Total Length of Lines: The total length of lines, comprising both aerial and underground components, represents the entirety of the infrastructure transmitting electricity to customers. The length of these lines is directly associated with the coverage area of services provided. Moreover, the length of lines is linked to the quality of services, potentially influencing the amount of loss during transmission. Therefore, the total length of lines, combining aerial and underground segments in kilometers, is chosen as an input variable.

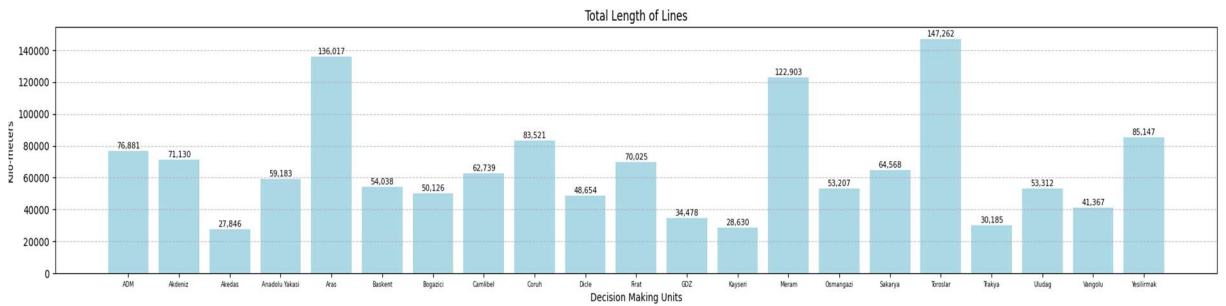


Figure 3. Length of Lines Graph of DMUs

Number of Permanent Employees: The total number of permanent employees represents the staff permanently employed by the companies. It is worth noting that when examining the numbers, a sizable portion of the workforce consists of outsourced employees, who typically focus on maintenance or installation tasks. As a result, most permanent staff members are responsible for operational functions. Therefore, the number of permanent employees is classified as an input variable.

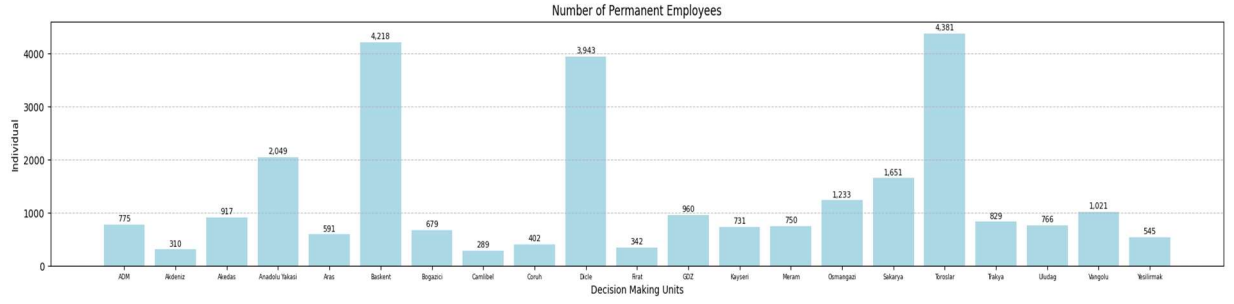


Figure 4. Permanent Employee Graph of DMUs

Table 2. Input Variables of DMUs

	Coded as	Area Measurement	Investment s	Total Length of Lines	Number of Permanent Employees
ADM	DMU1	33302	1665.50	76881.00	775.00
Akdeniz	DMU2	36514	1230.00	71130.00	310.00
Akdaş	DMU3	22217	436.30	27846.00	917.00
Anadolu Yakası	DMU4	1926	1392.40	59183.00	2049.00
Aras	DMU5	70007	975.80	136017.00	591.00
Başkent	DMU6	61161	2293.20	54038.00	4218.00
Boğaziçi	DMU7	3507.83	2307.40	50126.00	679.00
Çamlıbel	DMU8	51312	570.80	62739.00	289.00
Çoruh	DMU9	29211	769.90	83521.00	402.00
Dicle	DMU10	61198	2052.50	48654.00	3943.00
Fırat	DMU11	37441	640.20	70025.00	342.00
GDZ	DMU12	28500	2304.60	34478.00	960.00
Kayseri ve Çevresi	DMU13	16969	409.20	28630.00	731.00
Meram	DMU14	66516	1460.00	122903.00	750.00
Osmangazi	DMU15	49692	1848.10	53207.00	1233.00
Sakarya	DMU16	19500	1224.70	64568.00	1651.00
Toroslar	DMU17	46596	2605.90	147262.00	4381.00
Trakya	DMU18	16983	782.10	30185.00	829.00

Uludağ	DMU19	35501	483.80	53312.00	766.00
Vangölü	DMU20	40920	967.60	41367.00	1021.00
Yeşilirmak	DMU21	39928	920.60	85147.00	545.00

3.7. Outputs

Number of Subscribers: In this context, a subscriber refers to the endpoint of each line, representing a house, apartment, residence, or factory. The number of subscribers signifies the individual contracts established between the company and its customers. The total number of subscribers within the company's operational area reflects the effectiveness of its activities, including the extent of the network's reach to potential customers. Therefore, the total number of subscribers is chosen as an output variable.

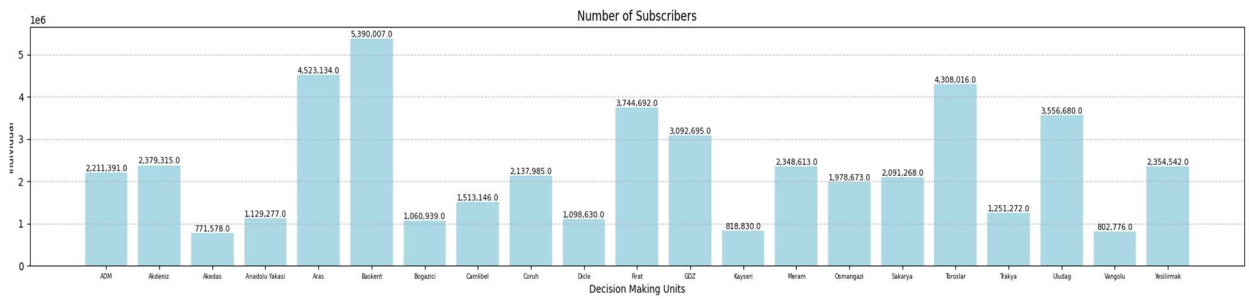


Figure 5. Number of Subscriber Graph of DMUs

Consumption of Consumers Connected to Distribution: Consumption of Consumers Connected to Distribution represents the electricity distributed through distribution line. This represents the total electricity supplied.

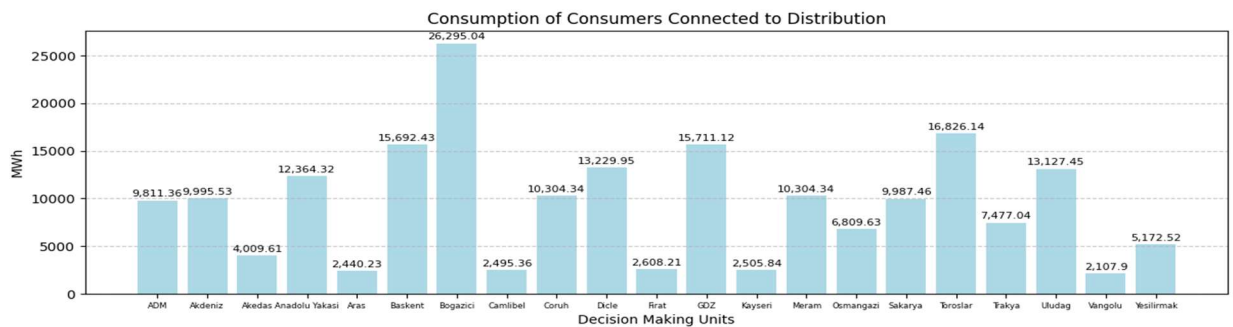


Figure 6. Consumption of Consumers Connected to Distribution Graph of DMUs

Table 3. Output Variables of DMUs

	Coded as	Number of Subscribers	Consumption of Consumers Connected to Distribution
ADM	DMU1	2211391	9811.36
Akdeniz	DMU2	2379315	9995.53
Akedaş	DMU3	771578	4009.61
Anadolu Yakası	DMU4	1129277	12364.32
Aras	DMU5	4523134	2440.23
Başkent	DMU6	5390007	15692.43
Boğaziçi	DMU7	1060939	26295.04
Çamlıbel	DMU8	1513146	2495.36
Çoruh	DMU9	2137985	10304.34
Dicle	DMU10	1098630	13229.95
Fırat	DMU11	3744692	2608.21
GDZ	DMU12	3092695	15711.12
Kayseri ve Çevresi	DMU13	818830	2505.84
Meram	DMU14	2348613	10304.34
Osmangazi	DMU15	1978673	6809.63
Sakarya	DMU16	2091268	9987.46
Toroslar	DMU17	4308016	16826.14
Trakya	DMU18	1251272	7477.04
Uludağ	DMU19	3556680	13127.45
Vangölü	DMU20	802776	2107.90
Yeşilırmak	DMU21	2354542	5172.52

CHAPTER 4: RESULTS

By following the criteria set for input and output selection and model choice, specifically the CCR-I (Input-oriented CCR model), the efficiency of 21 electric distribution companies was assessed. The entire evaluation process was conducted using MaxDEA Lite (v12.0) on the MacOS operating system. This section provides a concise overview of the analysis outcomes, highlighting the results of evaluations, efficiency scores, and the variations observed between the scores.

DMU1 holds the 13th position in the rankings with an efficiency score of 0.602621272, classifying it as an inefficient DMU. A closer look at the reference group of DMU1 reveals the presence of 4 DMUs within it. These DMUs, along with their respective weights, are as follows: DMU 7(0.273050557); DMU 11(0.308835184); DMU 12(0.038125181); DMU 19(0.181995235).

DMU2 secures first place with an efficiency score of 1.000, making it an efficient DMU. In the reference group check, only DMU2 itself is identified since it is already efficient.

DMU3 holds the 18th position with an efficiency score of 0.486630954, categorizing it as an inefficient DMU. Upon examination of the reference group of DMU3, there are 2 EDCs included: DMU 7(0.048229566); DMU 19(0.208830475)

DMU4 secures first place with an efficiency score of 1.000, making it an efficient DMU. In the reference group check, only DMU4 itself is identified since it is already efficient.

DMU5 occupies the 10th rank with an efficiency score of 0.778838191, marking it as an inefficient DMU. Upon examination of the reference group of DMU5, there are 2 EDCs included: DMU 11(1.106264918); DMU 19(0.106985338).

DMU6 secures the first place with an efficiency score of 1.000, classifying it as an efficient DMU. In the reference group check, only DMU6 itself is identified, indicating that this DMU is already efficient.

DMU7 also holds the first place with an efficiency score of 1.000, marking it as an efficient DMU. Upon checking the reference group, only one DMU is identified, and that is DMU7 itself, as it is already efficient.

DMU8 occupies the 15th rank with an efficiency score of 0.586919462, categorizing it as an inefficient DMU. Upon examination of the reference group of DMU8, there are 3 DMUs included: DMU 2(0.02314189); DMU 9(0.141627452); DMU 11(0.308513166).

DMU9 takes the first position with an efficiency score of 1.000, categorizing it as an efficient DMU. In the reference group check, only DMU9 itself is identified, indicating that this DMU is already efficient.

DMU10 secures the 16th rank with an efficiency score of 0.584597574, classifying it as an inefficient DMU. Upon examining the reference group of DMU10, two DMUs are identified: DMU 7(0.388590317); DMU 12(0.111412037); DMU 19(0.096099713).

DMU11 holds the first place with an efficiency score of 1.000, marking it as an efficient DMU. In the reference group check, only DMU11 itself is identified, as this DMU is already efficient.

DMU12 also takes the first position with an efficiency score of 1.000, categorizing it as an efficient DMU. In the reference group check, only DMU12 itself is identified, as this DMU is already efficient.

DMU13 holds the 20th rank with an efficiency score of 0.462506011, marking it as an inefficient DMU. Upon examining the reference group of DMU13, four DMUs were identified: DMU 4(0.029139657); DMU 12(0.022175969); DMU 19(0.20168802).

DMU14 is ranked 17th, the last position on the list, with an efficiency score of 0.563887238, categorizing it as an inefficient DMU. If the reference group of DMU14 is examined, four DMUs are identified: DMU 2(0.297233792); DMU 7(0.008212516); DMU 9(0.452202582); DMU 19(0.187220909).

DMU15 takes the 19th rank with an efficiency score of 0.477256266, marking it as an inefficient DMU. Upon examining the reference group of DMU15, 3 EDCs are identified: DMU 6(0.023702037); DMU 12(0.305688706); DMU 19(0.254596118).

DMU16 secures the 9th rank with an efficiency score of 0.820738274, categorizing it as an inefficient DMU. Upon examining the reference group of DMU16,

four DMUs are identified: DMU 4(0.488764969); DMU 7(0.035938733); DMU 12(0.019892932); DMU 19(0.404777879).

DMU17 holds the 11th rank with an efficiency score of 0.721525215, classifying it as an inefficient DMU. Upon examining the reference group of DMU17, 3 DMUs are identified: DMU 4(0.99546282); DMU 12(0.032407463); DMU 19(0.866998531).

DMU18 secures the 12th rank with an efficiency score of 0.718235159, marking it as an inefficient DMU. If the reference group of DMU18 is examined, four DMUs are identified: DMU 7(0.112678124); DMU 12(0.078450596); DMU 19(0.249981336).

DMU19 takes the first place with an efficiency score of 1.000, categorizing it as an efficient DMU. When the reference group is checked, only one DMU is found, and that is DMU19 itself, as it is already efficient.

DMU20 holds the 21st rank with an efficiency score of 0.259180898, marking it as an inefficient DMU. If the reference group of DMU20 is examined, 3 DMUs are identified: DMU 6(0.024749843); DMU 12(0.054660134); DMU 19(0.140672496).

DMU21 holds the 14th rank with an efficiency score of 0.590576909, marking it as an inefficient DMU. If the reference group of DMU21 is examined, 4 DMUs are identified: DMU 7(0.062186547); DMU 9(0.062320345); DMU 11(0.451254789); DMU 19(0.1308849).

In summary, 8 out of 21 companies are classified as efficient. DMU2, DMU4, DMU6, DMU7, DMU9, DMU11, DMU12, and DMU19 achieved an efficiency score of 1.000. On the other hand, 13 out of 21 companies are deemed inefficient as they did not meet the condition of having an efficiency score of 1.000. The inefficient companies include DMU1 with an efficiency score of 0.602621272, DMU3 with an efficiency score of 0.486631, DMU5 with an efficiency score of 0.778838, DMU8 with an efficiency score of 0.586919, DMU10 with an efficiency score of 0.584597574, DMU13 with an efficiency score of 0.462506011, DMU14 with an efficiency score of 0.563887238, DMU15 with an efficiency score of 0.477256, DMU16 with an efficiency score of 0.820738, DMU17 with an efficiency score of 0.721525, DMU18 with an efficiency score of 0.718235, DMU20 with an efficiency score of 0.259181, and DMU21 with an efficiency score of 0.590577.

Table 4. Result of Data Envelopment Analysis

DMU	Score	Rank	Benchmark(lambda)
DMU1	0.602621	13	DMU 7(0.273051); DMU 11(0.308835); DMU 12(0.038125); DMU 19(0.181995)
DMU2	1	1	DMU 2(1)
DMU3	0.486631	18	DMU 7(0.04823); DMU 19(0.20883)
DMU4	1	1	DMU 4(1)
DMU5	0.778838	10	DMU 11(1.106265); DMU 19(0.106985)
DMU6	1	1	DMU 6(1)
DMU7	1	1	DMU 7(1)
DMU8	0.586919	15	DMU 2(0.023142); DMU 9(0.141627); DMU 11(0.308513)
DMU9	1	1	DMU 9(1)
DMU10	0.584598	16	DMU 7(0.38859); DMU 12(0.111412); DMU 19(0.0961)
DMU11	1	1	DMU 11(1)
DMU12	1	1	DMU 12(1)
DMU13	0.462506	20	DMU 4(0.02914); DMU 12(0.022176); DMU 19(0.201688)
DMU14	0.563887	17	DMU 2(0.297234); DMU 7(0.008213); DMU 9(0.452203); DMU 19(0.187221)
DMU15	0.477256	19	DMU 6(0.023702); DMU 12(0.305689); DMU 19(0.254596)
DMU16	0.820738	9	DMU 4(0.488765); DMU 7(0.035939); DMU 12(0.019893); DMU 19(0.404778)
DMU17	0.721525	11	DMU 4(0.995463); DMU 12(0.032407); DMU 19(0.866999)
DMU18	0.718235	12	DMU 7(0.112678); DMU 12(0.078451); DMU 19(0.249981)
DMU19	1	1	DMU 19(1)
DMU20	0.259181	21	DMU 6(0.02475); DMU 12(0.05466); DMU 19(0.140672)
DMU21	0.590577	14	DMU 7(0.062187); DMU 9(0.06232); DMU 11(0.451255); DMU 19(0.130885)

Table 5. Efficient and Inefficient DMUs

Efficient DMUs	Inefficient DMUs
DMU2	DMU1
DMU4	DMU3
DMU6	DMU5
DMU7	DMU8
DMU9	DMU10
DMU11	DMU13
DMU12	DMU14
DMU19	DMU15
	DMU16
	DMU17
	DMU18
	DMU20
	DMU21

CHAPTER 5: DISCUSSION

In the initial section of the discussion, we will briefly examine the correlation among the variables. Correlation, a statistical measure, assesses the relationship between two or more variables. It reveals if there is a linear connection between the variables, and if present, it identifies the strength and direction of this relationship—whether it is positive or negative. Correlation analysis is particularly crucial for Data Envelopment Analysis (DEA). Therefore, the correlation analysis was conducted before the DEA, encompassing all input and output variables.

The input variables for the analysis included the domain area in square kilometers, investments in million Turkish liras, total length of lines in kilometers, and permanent staff. The output variables comprised the total number of subscribers, and consumption of consumers connected to distribution. To ensure meaningful results, a consideration of variable correlation is essential, as a higher correlation between variables is strongly preferred.

The correlation analysis was performed using the Python language in Jupyter Notebook. Upon examination of the correlation chart, it was observed that all variables are positively and highly correlated, aligning with the desired outcome. Additionally, the heat map of the correlation analysis was presented, emphasizing the importance of understanding the sensitivity of the heat map in interpreting the results.

Table 6. Correlation

	AD M	Ak den iz	Ak eda s	An ado luY aka si	Ar as	Bas ken t	Bo gaz ici	Ca mli bel	Co ruh	Dic le	Fir at	GD Z	Ka yse ri	Me ra m	Os ma nga zi	Sa kar ya	To ros lar	Tr aky a	Ulu dag	Va ngo lu	Yes ilir ma k			
A D M	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9			
		999	998	996	999	997	998	997	999	992	998	997	999	997	998	999	999	999	998	993	999			
		841	933	939	835	362	099	844	827	088	983	665	689	638	879	815	862	478	424	720	844			
		025	571	907	152	395	280	350	598	524	266	943	100	445	607	562	280	033	778	860	647			
		146	641	618	180	809	121	529	930	087	690	987	341	234	352	434	980	079	529	155	214			
		001	24	411	243	096	694	261	301	801	155	667	334	026	744	69	731	664	614	338	094			
A k d e ni z	0.9 999 841 025 146 001	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9			
			999	999	995	999	998	997	998	999	992	999	998	999	997	999	999	999	999	999	993	999		
			210	886	998	180	323	066	547	874	420	382	814	319	429	792	758	842	007	929	815			
			589	465	265	315	417	846	118	652	484	429	660	084	014	119	127	561	914	931	319			
			642	875	727	541	671	982	106	818	657	044	709	973	721	524	285	446	492	765	480			
		471	251	843	614	747	682	442	727	218	091	06	761	21	723	924	14	092	163	06				
A k e d as	0.9 998 933 571 641 24	0.9 999 210 589 642 471	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9			
				999	999	996	995	999	998	997	998	996	997	996	999	998	999	998	998	998	997	997	999	
				210	000	261	473	467	712	726	785	802	466	718	553	625	317	516	722	306	459	362		
				589	474	118	773	440	963	159	888	340	079	180	252	785	768	564	331	861	401	986		
				642	830	545	855	602	228	751	599	452	406	697	803	837	136	134	035	182	493	505		
		471	105	343	78	379	594	461	984	326	733	186	478	745	494	325	155	619	203	19				
A n a d ol u Y a k as i	0.9 996 939 907 618 411	0.9 995 886 465 875 251	0.9 994 000 474 830 105	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9			
					995	989	999	993	998	984	993	990	995	996	992	997	997	994	994	992	988	996		
					886	913	901	823	109	031	393	568	798	907	313	655	069	567	630	240	218	954		
					465	572	914	862	972	614	381	865	115	614	252	951	876	057	819	591	509	914		
					875	830	089	945	114	800	918	672	945	644	118	643	802	481	843	335	456	333	470	
		251	105	564	754	687	464	25	871	314	016	079	035	298	599	783	768	898	724	733				
A r as	0.9 999 835 152 180 243	0.9 999 998 261 118 572 843	0.9 999 261 118 572 343	0.9 995 913 572 089 564	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9			
						999	998	997	998	999	998	999	993	999	998	999	997	999	999	999	999	998	994	999
						835	108	338	151	563	025	371	307	843	424	443	777	758	821	948	075	838		
						152	857	894	574	554	453	915	508	746	831	237	842	143	558	868	054	481		
						180	090	120	739	657	799	416	471	465	904	877	045	271	898	684	456	072		
		843	564	32	095	703	751	622	677	356	231	307	299	177	671	485	135	013	97					
B as k	0.9 997 362 395	0.9 998 180 315	0.9 996 473 773	0.9 989 901 108 857	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9			
						992	994	996	989	999	999	997	991	998	997	997	999	999	997	999	998	996		
						338	273	089	028	580	964	152	403	302	790	175	076	845	678	842				
		395	773	914	857		296	108	749	911	458	694	583	835	902	996	662	621	246	116				

e	809	541	855	945	090		868	047	204	075	215	974	543	963	124	782	551	128	936	529	894
nt	096	614	78	754	32		083	815	667	72	873	131	678	606	655	706	18	575	865	433	554
B	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
o	998	997	995	999	997	992		994	998	986	995	993	997	996	994	998	998	996	994	989	998
g	099	323	467	823	338	338		421	906	185	476	115	214	847	539	295	651	348	354	434	084
a	280	417	440	862	894	004		327	431	488	392	805	371	678	252	775	213	604	020	550	331
zi	121	671	602	114	120	868		885	845	727	975	695	189	030	035	030	149	900	192	446	373
ci	694	747	379	687	095	083		08	715	063	58	274	498	133	117	202	855	728	524	842	406
C	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
a	997	998	999	993	998	994	994		997	998	995	994	999	999	998	996	997	997	995	998	998
m	844	066	712	109	151	273	421		853	082	937	219	027	039	798	898	302	244	284	834	572
li	350	846	963	972	574	296	327		745	523	082	737	332	223	024	450	561	221	128	756	520
b	529	982	228	800	739	047	885		460	348	640	105	874	134	852	591	383	967	326	466	572
el	261	682	594	464	703	815	08		459	186	917	409	113	43	791	573	008	6	082	014	805
C	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
o	999	999	998	998	999	996	998	997		991	998	996	999	998	998	999	999	998	997	993	999
r	827	547	726	031	563	089	906	853		909	189	485	579	363	268	666	865	928	441	893	864
u	598	118	159	614	554	108	431	745		203	590	175	069	852	611	954	148	430	269	287	976
h	930	106	751	918	657	204	845	460		357	543	026	089	212	086	422	114	125	200	761	999
	301	442	461	25	751	667	715	459		066	783	978	674	852	834	99	968	177	076	639	266
D	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
ic	992	992	996	984	993	989	986	998	991		990	988	994	995	995	990	991	991	989	999	993
le	088	874	785	393	025	028	185	082	909		157	526	663	602	548	493	054	948	645	422	482
	524	652	888	381	453	749	488	523	203		939	301	820	392	454	055	751	401	243	253	907
	087	818	599	672	799	075	727	348	357		088	803	671	373	597	269	153	611	400	642	135
	801	727	984	871	622	72	063	186	066		601	409	001	373	021	992	409	291	203	521	978
Fi	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
r	998	999	997	993	999	999	995	995	998	990		999	998	994	998	999	998	999	999	990	998
at	983	420	802	568	371	580	476	937	189	157		719	658	264	940	293	922	850	934	640	596
	266	484	340	865	915	911	392	082	590	939		301	483	144	136	591	183	505	032	211	466
	690	657	452	945	416	215	975	640	543	088		274	474	200	058	003	793	914	758	956	991
	155	218	326	314	677	873	58	917	783	601		754	216	975	369	928	705	704	401	722	395
G	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
D	997	998	996	990	998	999	993	994	996	988	999		997	991	998	998	997	999	999	988	997
Z	665	382	466	798	307	964	115	219	485	526	719		311	674	230	147	551	221	922	420	108
	943	429	079	115	508	458	805	737	175	301	301		639	585	362	034	875	630	308	426	761
	987	044	406	644	471	974	695	105	026	803	274		828	503	674	681	422	034	322	775	483
	667	091	733	016	356	131	274	409	978	409	754		318	713	85	4	659	338	765	119	656
K	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
a	999	999	999	995	999	997	997	999	999	994	998	997		998	999	999	999	999	998	995	999
ys	689	814	718	907	843	152	214	027	579	663	658	311		441	496	393	526	394	120	756	916
er	100	660	180	614	746	694	371	332	069	820	483	639		900	092	353	373	923	923	324	483
i	341	709	697	118	465	543	189	874	089	671	474	828		387	887	507	149	422	188	230	604
	334	06	186	079	231	678	498	113	674	001	216	318		983	643	957	501	015	384	004	296
M	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9
er	997	997	998	996	997	991	996	999	998	995	994	991	998		996	996	997	995	993	997	998

a	638	319	553	313	424	403	847	039	363	602	264	674	441		829	779	464	938	155	633	470
m	445	084	252	252	831	583	678	223	852	392	144	585	900		987	201	903	521	827	489	923
	234	973	803	643	904	963	030	134	212	373	200	503	387		964	198	138	211	060	382	977
	026	761	478	035	307	606	133	43	852	373	975	713	983		216	511	541	749	818	277	83
O	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9	0.9
s	998	999	999	992	999	998	994	998	998	995	998	998	999	996		998	998	999	998	995	999
m	879	429	625	655	443	302	539	798	268	548	940	230	496	829		549	478	418	733	685	063
a	607	014	785	951	237	835	252	024	611	454	136	362	092	987		332	227	088	216	198	076
n	352	721	837	802	877	124	035	852	086	597	058	674	887	964		344	336	215	452	519	547
g	744	21	745	298	299	655	117	791	834	021	369	85	643	216		598	903	952	829	417	383
a																					
zi																					
S	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9	0.9
a	999	999	998	997	999	997	998	996	999	990	999	998	999	996	998		999	999	998	992	999
k	815	792	317	069	777	790	295	898	666	493	293	147	393	779	549		950	621	799	002	643
a	562	119	768	876	842	902	775	450	954	055	591	034	353	201	332		502	149	449	639	845
r	434	524	136	481	045	782	030	591	422	269	003	681	507	198	344		822	715	559	650	538
y	69	723	494	599	177	706	202	573	99	992	928	4	957	511	598		992	003	674	239	204
a																					
T	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9
o	999	999	998	997	999	997	998	997	999	991	998	997	999	997	998	999		999	998	992	999
r	862	758	516	567	758	175	651	302	865	054	922	551	526	464	478	950		416	325	732	798
os	280	127	564	057	143	996	213	561	148	751	183	875	373	903	227	502		617	703	032	201
la	980	285	134	843	271	551	149	383	114	153	793	422	149	138	336	822		780	660	429	690
r	731	924	325	783	671	18	855	008	968	409	705	659	501	541	903	992		755	892	714	281
T	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9
r	999	999	998	994	999	999	996	997	998	991	999	999	999	995	999	999	999		999	992	999
a	478	842	722	630	821	076	348	244	928	948	850	221	394	938	418	621	416		630	595	324
k	033	561	331	819	558	662	604	221	430	401	505	630	923	521	088	149	617		681	388	790
y	079	446	035	335	898	128	900	967	125	611	914	034	422	211	215	715	780		151	658	214
a	664	14	155	768	485	575	728	6	177	291	704	338	015	749	952	003	755		461	869	179
U	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9
lu	998	999	997	992	998	999	994	995	997	989	999	999	998	993	998	998	998	999		989	997
d	424	007	306	240	948	845	354	284	441	645	934	922	120	155	733	799	325	630		812	972
a	778	914	861	591	868	621	020	128	269	243	032	308	923	827	216	449	703	681		521	497
g	529	492	182	456	684	936	192	326	200	400	758	322	188	060	452	559	660	151		639	643
	614	092	619	898	135	865	524	082	076	203	401	765	384	818	829	674	892	461		294	584
V	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9
a	993	993	997	988	994	988	989	998	993	999	990	988	995	997	995	992	992	992	989		994
n	720	929	459	218	075	678	434	834	893	422	640	420	756	633	685	002	732	595	812		942
g	860	931	401	509	054	246	550	756	287	253	211	426	324	489	198	639	032	388	521		099
ol	155	765	493	333	456	529	446	466	761	642	956	775	230	382	519	650	429	658	639		510
u	338	163	203	724	013	433	842	014	639	521	722	119	004	277	417	239	714	869	294		052
Y	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0
es	999	999	999	996	999	996	998	998	999	993	998	997	999	998	999	999	999	999	997	994	
ili	844	815	362	954	838	842	084	572	864	482	596	108	916	470	063	643	798	324	972	942	

r m a k	647	319	986	914	481	116	331	520	976	907	466	761	483	923	076	845	201	790	497	099	
	214	480	505	470	072	894	373	572	999	135	991	483	604	977	547	538	690	214	643	510	
	094	06	19	733	97	554	406	805	266	978	395	656	296	83	383	204	281	179	584	052	

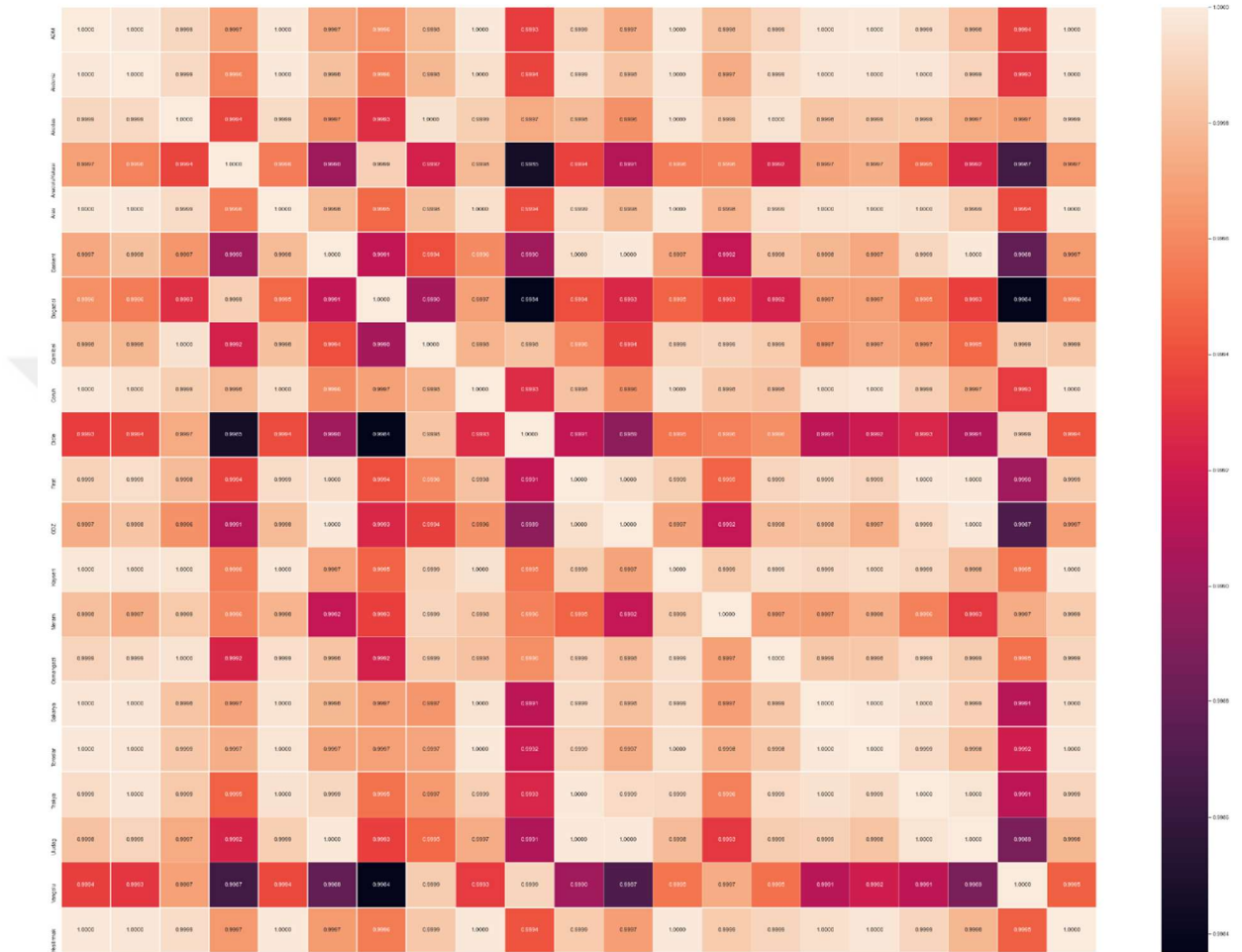


Figure 8. Heat Map

For DMU1, as mentioned earlier, four variables were chosen as input variables: Area Measurement (33,302 square kilometers), Investments (1,665.50 million Turkish Liras), Total length of Lines (76,882 kilometers), and Number of Permanent Employees (775). The other two variables, used as output variables in the model, are the Number of Subscribers (2,211,391) and Consumption of Consumers Connected to Distribution (9811.36). After the calculations, the efficiency score of DMU1 is determined to be 0.602621272, classifying this DMU as inefficient. Despite its inefficiency, there are potential ways to improve DMU1 and make it efficient. To explore these opportunities, the reference group needs to be examined. The reference group for DMU1 includes ' DMU7(0.273050557);

DMU11(0.308835184); DMU 12(0.038125181); DMU 19(0.181995235) '. The potential improvements for DMU1, based on its reference group, are presented in the table below.

Table 7. Reference Values of DMU1

		DMU1	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	33302	20068
	Investments (Million TL)	1665.50	1004
	Total Length of Lines (KM)	76881	46330
	Number of Permanent Employees	775	467

This DMU exhibits minimal changes. In terms of inputs, there are decreases in area measurement, investments, total length of lines, and permanent employees according to the reference group. Consequently, all inputs have decreased, indicating inefficiency in utilizing them. To transition this DMU to an efficient state, a focus should be placed on reducing input variables.

Table 8. Calculation of Reference Values of DMU1

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	$0.273050557 * 3507.83$ $+ 0.308835184 * 37441$ $+ 0.038125181 * 28500$ $+ 0.181995235 * 35501$	20068
	Investments (Million TL)	$0.273050557 * 2307.4$ $+ 0.308835184 * 640.2$ $+ 0.038125181 * 2304.6$ $+ 0.181995235 * 483.8$	1004
	Total Length of Lines (KM)	$0.273050557 * 50126 +$ $0.308835184 * 70025 +$ $0.038125181 * 34478 +$ $0.181995235 * 53312$	46330
	Number of Permanent Employees	$0.273050557 * 679 +$ $0.308835184 * 342 +$ $0.038125181 * 960 +$ $0.181995235 * 766$	467

For DMU2, as previously mentioned, four variables were chosen as input variables: Area Measurement (36,514 km²), Investments (1230 million Turkish Liras), Total length of Lines (71,130 km), and Number of Permanent Employees (310). The other two variables used as output variables are the number of subscribers (2,379,315) and total minutes of outage (2109). After the calculations, the efficiency score of DMU2 is declared as 1.000. So, this DMU can be classified as efficient. Due to being classified as an efficient DMU, this DMU does not have a reference group.

For DMU3, as previously mentioned, four variables were chosen as input variables. These variables are Area Measurement, which is 22,217 square kilometers; Investments, amounting to 436.3 million Turkish Liras; Total length of Lines, which is 27,846 kilometers; and the Number of Permanent Employees, totaling 917. The other two variables used as output variables in the model are the Number of Subscribers, reaching 771,578, and, lastly, Consumption of Consumers Connected to

Distribution, which amounts to 4009.61. After the calculations, the efficiency score of DMU3 is declared as 0.486630954. Thus, this DMU can be classified as inefficient. Even though this DMU is in an inefficient state, there are potential ways to improve and become efficient. For this purpose, the reference group needed to be examined. This DMU's reference group includes ' DMU 7(0.048229566); DMU 19(0.208830475).' According to the reference group of the DMU, its potential will be shown in the table below.

Table 9. Reference Values of DMU3

		DMU3	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	22217	7583
	Investments (Million TL)	436.30	212
	Total Length of Lines (KM)	27846	13551
	Number of Permanent Employees	917	193

Like the previous DMU, DMU3 changes in area measurement, investments, total length of lines, and the total number of permanent employees, with the only increase occurring in the loss and leakage ratio among the output variables. The decrease in input variables creates a significant gap for the loss and leakage ratio, allowing the DMU to compensate for larger amounts of loss and leakage after achieving efficiency.

Table 10. Calculation of Reference Values of DMU3

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	$0.048229566 * 3507.83$ $+ 0.208830475 * 35501$	7583
	Investments (Million TL)	$0.048229566 * 2307.4$ $+ 0.208830475 * 483.8$	212
	Total Length of Lines (KM)	$0.048229566 * 50126 +$ $0.208830475 * 53312$	13551
	Number of Permanent Employees	$0.048229566 * 679 +$ $0.208830475 * 766$	193

For DMU4, as previously mentioned, four variables were chosen as input variables: Area Measurement (1,926 in square kilometers), Investments (1,392.4 in million Turkish Liras), Total length of Lines (59,183 in kilometers), and Number of Permanent Employees (2,049). The output variables are the number of subscribers (1,129,277) and Consumption of Consumers Connected to Distribution (12364.32). After the calculations, the efficiency score of DMU4 is declared as 1.000. So, this DMU can be classified as efficient. Due to being classified as an efficient DMU, this DMU does not have a reference group.

For DMU5, as previously mentioned, four variables were chosen as input variables: Area Measurement (70,007 in square kilometers), Investments (975.8 in million Turkish Liras), Total length of Lines (136,017 in kilometers), and Number of Permanent Employees (591). The output variables are the number of subscribers (4,523,134) and Consumption of Consumers Connected to Distribution (2440.23). After the calculations, the efficiency score of DMU5 is declared as 0.778838191. So, this DMU can be classified as inefficient. Even though this DMU is in an inefficient state, there are potential ways to improve this DMU and become efficient. For this purpose, the reference group needed to be examined. This DMU's reference group is 'DMU 11(1.106264918); DMU 19(0.106985338).' According to the reference group of the DMU, this DMU's potential will be shown in the table below.

Table 11. Reference Values of DMU5

		DMU5	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	70007	45218
	Investments (Million TL)	975.80	760
	Total Length of Lines (KM)	136017	83170
	Number of Permanent Employees	591	460

Changes parallel the previous DMU, with decreases in area measurement, investments, total length of lines, and the total number of permanent employees.

Table 12. Calculation of Reference Values of DMU5

		Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)		$1.106264918 * 37441 + 0.106985338 * 35501$	45218
	Investments (Million TL)		$1.106264918 * 640.2 + 0.106985338 * 483.8$	760
	Total Length of Lines (KM)		$1.106264918 * 70025 + 0.106985338 * 53312$	83170
	Number of Permanent Employees		$1.106264918 * 342 + 0.106985338 * 766$	460

For DMU6, as previously mentioned, four variables were chosen as input variables: Area Measurement (61,161 km²), Investments (2293.2 million Turkish Liras), Total length of Lines (54,038 km), and Number of Permanent Employees (4218). The other two variables, the number of subscribers (5,390,007) and Consumption of Consumers Connected to Distribution (15692.43), are used as output variables in the model. After the calculations, the efficiency score of DMU6 is declared as 1.000. So, this DMU can be classified as efficient. Due to being classified as an efficient DMU, this DMU does not have a reference group.

For DMU7, as previously mentioned, four variables were chosen as input variables: Area Measurement (3,507.83 km²), Investments (2307.4 million Turkish

Liras), Total length of Lines (50,126 km), and Number of Permanent Employees (679). The other two variables, the number of subscribers (1,060,939) and Consumption of Consumers Connected to Distribution (26295.04), are used as output variables in the model. After the calculations, the efficiency score of DMU7 is declared as 1.000. So, this DMU can be classified as efficient. Due to being classified as an efficient DMU, this DMU does not have a reference group.

For DMU8, as previously mentioned, four variables were chosen as input variables: Area Measurement (51,312 km²), Investments (570.80 million Turkish Liras), Total length of Lines (62,739 km), and Number of Permanent Employees (289). The other two variables, the number of subscribers (1,513,146) and Consumption of Consumers Connected to Distribution (2495.36), are used as output variables in the model. After the calculations, the efficiency score of DMU8 is declared as 0.586919462. So, this DMU can be classified as inefficient. Even though this DMU is in an inefficient state, there are potential ways to improve this DMU and become efficient. For this purpose, the reference group needed to be examined. This DMU's reference group is 'DMU 2(0.02314189); DMU 9(0.141627452); DMU 11(0.308513166)'. According to the reference group of the DMU, this DMU's potential will be shown in the table below.

Table 13. Reference Values of DMU8

		DMU8	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	51312	16533
	Investments (Million TL)	570.80	335
	Total Length of Lines (KM)	62739	35079
	Number of Permanent Employees	289	170

Changes are confined to input variables, with decreases in area measurement, investments, total length of lines, and the number of permanent employees.

Table 14. Calculation of Reference Values of DMU8

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	0.02314189 * 36514 + 0.141627452 * 29211 + 0.308513166 * 37441	16533
	Investments (Million TL)	0.02314189 * 1230 + 0.141627452 * 769.9 + 0.308513166 * 640.2	335
	Total Length of Lines (KM)	0.02314189 * 71130 + 0.141627452 * 83521 + 0.308513166 * 70025	35079
	Number of Permanent Employees	0.02314189 * 310 + 0.141627452 * 402 + 0.308513166 * 342	170

For DMU9, as previously mentioned, four variables were chosen as input variables: Area Measurement (29,211 square kilometers), Investments (769.90 million Turkish Liras), Total length of Lines (83,521 kilometers), and Number of Permanent Employees (402). The other two variables, the number of subscribers (2,137,985) and Consumption of Consumers Connected to Distribution (10304.34), are used as output variables in the model. After the calculations, the efficiency score of DMU9 is declared as 1.000. Therefore, this DMU can be classified as an efficient DMU, and as such, it does not have a reference group.

For DMU10, as previously mentioned, four variables were chosen as input variables: Area Measurement (61,198 square kilometers), Investments (2,053.50 million Turkish Liras), Total length of Lines (48,654 kilometers), and Number of Permanent Employees (3,943). The other two variables, the number of subscribers (1,098,630) and Consumption of Consumers Connected to Distribution (13229.95), are used as output variables in the model. After the calculations, the efficiency score of DMU10 is declared as 0.584597574. Therefore, this DMU can be classified as inefficient. Even though this DMU is in an inefficient state, there are potential ways to improve it and become efficient. For this purpose, the reference group needed to be examined. This DMU's reference group is 'DMU 7(0.388590317); DMU

12(0.111412037); DMU 19(0.096099713)'. According to the reference group of the DMU, this DMU's potential will be shown in the table below.

Table 15. Reference Values of DMU10

		DMU10	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	61198	7950
	Investments (Million TL)	2052.5	1200
	Total Length of Lines (KM)	48654	28443
	Number of Permanent Employees	3943	444

Changes are confined to input variables, with decreases in area measurement, investments, total length of lines, and the number of permanent employees.

Table 16. Calculation of Reference Values of DMU10

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	0.388590317 * 3507.83 + 0.111412037 * 28500 + 0.096099713 * 35501	7950
	Investments (Million TL)	0.388590317 * 2307.4 + 0.111412037 * 2304.6 + 0.096099713 * 483.8	1200
	Total Length of Lines (KM)	0.388590317 * 50126 + 0.111412037 * 34478 + 0.096099713 * 53312	28443
	Number of Permanent Employees	0.388590317 * 679 + 0.111412037 * 960 + 0.096099713 * 766	444

For DMU11, four variables were selected as input parameters: Area Measurement (37,441 square kilometers), Investments (640.20 million Turkish Liras), Total length of Lines (70,025 kilometers), and Number of Permanent Employees (342). The other two variables, the number of subscribers (3,744,692) and Consumption of Consumers Connected to Distribution (2608.21), serve as output parameters in the model. After the calculations, the efficiency score of DMU11 is determined to be 1.000. Consequently, this DMU is classified as efficient, and as such, it does not have a reference group.

For DMU12, four variables were selected as input parameters: Area Measurement (28,500 square kilometers), Investments (2,304.60 million Turkish Liras), Total length of Lines (34,478 kilometers), and Number of Permanent Employees (960). The other two variables, the number of subscribers (3,092,695) and Consumption of Consumers Connected to Distribution (15711.12), serve as output parameters in the model. Following the calculations, the efficiency score of DMU12 is determined as 1.000. Consequently, this DMU is classified as efficient, and as such, it does not have a reference group.

For DMU13, four variables were selected as input parameters: Area Measurement (16,969 square kilometers), Investments (409.20 million Turkish Liras), Total length of Lines (28,630 kilometers), and Number of Permanent Employees (731). The other two variables, the number of subscribers (818,830) and Consumption of Consumers Connected to Distribution (2505.84), serve as output parameters in the model. Following the calculations, the efficiency score of DMU13 is determined as 0.462506011. Consequently, this DMU is classified as inefficient. Despite its current state, there are potential ways to improve efficiency for DMU13. To explore this, the reference group was examined, consisting of ' DMU 4(0.029139657); DMU 12(0.022175969); DMU 19(0.20168802).' The potential improvements for DMU13 based on its reference group are shown in the table below.

Table 17. Reference Values of DMU13

		DMU13	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	16969	7848
	Investments (Million TL)	409.20	189
	Total Length of Lines (KM)	28630	13242
	Number of Permanent Employees	731	235

Atypical alterations, in contrast to previous DMUs, include reductions in area measurement, investments, total length of lines, and the total number of permanent employees.

Table 18. Calculation of Reference Values of DMU13

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	$0.029139657 * 1926 + 0.022175969 * 28500 + 0.20168802 * 35501$	7848
	Investments (Million TL)	$0.029139657 * 1392.4 + 0.022175969 * 2304.6 + 0.20168802 * 483.8$	189
	Total Length of Lines (KM)	$0.029139657 * 59183 + 0.022175969 * 34478 + 0.20168802 * 53312$	13242
	Number of Permanent Employees	$0.029139657 * 2049 + 0.022175969 * 960 + 0.20168802 * 766$	235

For DMU14, as previously mentioned, four variables were chosen as input variables: Area Measurement (66,516 km²), Investments (1,460 million Turkish Liras), Total length of Lines (122,903 km), and Number of Permanent Employees (750). The other two variables, used as output variables, are the number of subscribers (2,348,613) and Consumption of Consumers Connected to Distribution (10304.34). After the

calculations, the efficiency score of DMU14 is declared as 0.563887238. Thus, this DMU is classified as inefficient. Despite its inefficient state, there are potential ways to improve DMU14 and make it efficient. To explore this, the reference group, including DMU 2(0.297233792); DMU 7(0.008212516); DMU 9(0.452202582); DMU 19(0.187220909), is examined. The potential improvements for DMU14 based on its reference group are presented in the table below.

Table 19. Reference Values of DMU14

		DMU14	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	66516	30738
	Investments (Million TL)	1460	823
	Total Length of Lines (KM)	122903	69303
	Number of Permanent Employees	750	423

This DMU witnesses fewer changes, with decreases in area measurement, investments, total length of lines, and the number of permanent employees.

Table 20. Calculation of Reference Values of DMU14

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	0.297233792 * 36514 + 0.008212516 * 3507.83 + 0.452202582 * 29211 + 0.187220909 * 35501	30738
	Investments (Million TL)	0.297233792 * 1230 + 0.008212516 * 2307.4 + 0.452202582 * 769.9 + 0.187220909 * 483.8	823
	Total Length of Lines (KM)	0.297233792 * 71130 + 0.008212516 * 50126 + 0.452202582 * 983521 + 0.187220909 * 53312	69303
	Number of Permanent Employees	0.297233792 * 310 + 0.008212516 * 679 + 0.452202582 * 402 + 0.187220909 * 766	423

For DMU15, as previously mentioned, four variables were chosen as input variables: Area Measurement (49,692 km²), Investments (1,848.10 million Turkish Liras), Total length of Lines (53,207 km), and Number of Permanent Employees (1,233). The other two variables, used as output variables, are the number of subscribers (1,978,673) and Consumption of Consumers Connected to Distribution (6809.63). After the calculations, the efficiency score of DMU15 is declared as 0.477256266. Thus, this DMU is classified as inefficient. Despite its inefficient state, there are potential ways to improve DMU15 and make it efficient. To explore this, the reference group, including DMU 6(0.023702037); DMU 12(0.305688706); DMU 19(0.254596118), is examined. The potential improvements for DMU15 based on its reference group are presented in the table below.

Table 21. Reference Values of DMU15

		DMU15	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	49692	19200
	Investments (Million TL)	1848.10	882
	Total Length of Lines (KM)	53207	25393
	Number of Permanent Employees	1233	588

Changes mirror those of previous EDCs, with decreases in area measurement, investments, total length of lines, and the total number of permanent employees, albeit at a smaller scale compared to other DMUs.

Table 22. Calculation of Reference Values of DMU15

		Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)		$0.023702037 * 61161 + 0.305688706 * 28500 + 0.254596118 * 35501$	19200
	Investments (Million TL)		$0.023702037 * 2293.20 + 0.305688706 * 2304.60 + 0.254596118 * 483.8$	882
	Total Length of Lines (KM)		$0.023702037 * 54038 + 0.305688706 * 34478 + 0.254596118 * 53312$	25393
	Number of Permanent Employees		$0.023702037 * 4218 + 0.305688706 * 960 + 0.254596118 * 766$	588

For DMU16, as previously outlined, four variables were chosen as input variables: Area Measurement (19,500 km²), Investments (1,224.70 million Turkish Liras), Total length of Lines (64,568 km), and Number of Permanent Employees (1,651). The other two variables, used as output variables, are the number of

subscribers (2,091,268) and Consumption of Consumers Connected to Distribution (9987.46). After the calculations, the efficiency score of DMU16 is declared as 0.820738274. Consequently, this DMU is classified as inefficient. Despite its inefficient state, there are potential ways to improve DMU16 and make it efficient. To explore this, the reference group, including DMU 4(0.488764969); DMU 7(0.035938733); DMU 12(0.019892932); DMU 19(0.404777879), is examined. The potential improvements for DMU16 based on its reference group are presented in the table below.

Table 23. Reference Values of DMU16

		DMU16	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	19500	16004
	Investments (Million TL)	1224.70	1005
	Total Length of Lines (KM)	64568	1651
	Number of Permanent Employees	1651	1355

Like previous DMUs, DMU16 undergoes changes with decreases in area measurement, investments, total length of lines, and the total number of permanent employees, albeit at a smaller scale compared to other DMUs.

Table 24. Calculation of Reference Values of DMU16

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	$0.488764969 * 1926 +$ $0.035938733 * 3507.83$ $+ 0.019892932 * 28500$ $+ 0.404777879 * 35501$	16004
	Investments (Million TL)	$0.488764969 * 1392.40$ $+ 0.035938733 *$ $2307.4 + 0.019892932$ $* 2304.60 +$ $0.404777879 * 483.8$	1005
	Total Length of Lines (KM)	$0.488764969 * 59183 +$ $0.035938733 * 50126 +$ $0.019892932 * 34478 +$ $0.404777879 * 53312$	1651
	Number of Permanent Employees	$0.488764969 * 2049 +$ $0.035938733 * 679 +$ $0.019892932 * 960 +$ $0.404777879 * 766$	1355

For DMU17, the chosen input variables include Area Measurement (46,596 km²), Investments (2,605.90 million Turkish Liras), Total length of Lines (147,262 km), and Number of Permanent Employees (4,381). The output variables are the number of subscribers (4,308,016) and Consumption of Consumers Connected to Distribution (16826.14). After calculations, the efficiency score of DMU17 is determined as 0.721525215, classifying it as inefficient. Despite being in an inefficient state, potential improvements can be explored. The reference group for DMU17 includes ' DMU 4(0.99546282); DMU 12(0.032407463); DMU 19(0.866998531).'

Further details are presented in the table below.

Table 25. Reference Values of DMU17

		DMU17	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	46596	33620
	Investments (Million TL)	2605.90	1880
	Total Length of Lines (KM)	147262	106253
	Number of Permanent Employees	4381	2735

Parallel to previous DMUs, changes involve decreases in area measurement, investments, total length of lines, and the total number of permanent employees, but the decreases are smaller compared to other DMUs.

Table 26. Calculation of Reference Values of DMU17

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	$0.99546282 * 1926 + 0.032407463 * 28500 + 866998531 * 35501$	33620
	Investments (Million TL)	$0.99546282 * 1392.4 + 0.032407463 * 2304.6 + 866998531 * 483.8$	1880
	Total Length of Lines (KM)	$0.99546282 * 59183 + 0.032407463 * 34478 + 866998531 * 53312$	106253
	Number of Permanent Employees	$0.99546282 * 2049 + 0.032407463 * 960 + 866998531 * 766$	2735

For DMU18, the chosen input variables include Area Measurement (16,983 km²), Investments (782.10 million Turkish Liras), Total length of Lines (30,185 km), and Number of Permanent Employees (829). The output variables are the number of subscribers (1,251,272) and Consumption of Consumers Connected to Distribution (7477.04). After the calculations, the efficiency score of DMU18 is determined as 0.718235159, categorizing it as inefficient. Despite its current state, there are potential

ways for DMU18 to improve and become efficient. To explore this, the reference group for DMU18, including ' DMU 7(0.112678124); DMU 12(0.078450596); DMU 19(0.249981336) ', is examined. The details of DMU18's potential within this reference group are presented in the table below.

Table 27. Reference Values of DMU18

		DMU18	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	16983	11506
	Investments (Million TL)	782.10	562
	Total Length of Lines (KM)	30185	21680
	Number of Permanent Employees	829	3443

Fewer changes are observed in DMU18, with decreases in area measurement, investments, total length of lines, and the number of permanent employees. However, these decreases are smaller compared to other DMUs.

Table 28. Calculation of Reference Values of DMU18

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	$0.112678124) * 3507.83 + 0.078450596$ $* 28500 + 0.249981336$ $* 35501$	11506
	Investments (Million TL)	$0.112678124) * 2307.4$ $+ 0.078450596 *$ $2304.6 + 0.249981336$ $* 483.8$	562
	Total Length of Lines (KM)	$0.112678124) * 50126$ $+ 0.078450596 * 34478$ $+ 0.249981336 * 53312$	21680
	Number of Permanent Employees	$0.112678124) * 679 +$ $0.078450596 * 960 +$ $0.249981336 * 766$	3443

For DMU19, the selected input variables include Area Measurement (35,501 km²), Investments (483.80 million Turkish Liras), Total length of Lines (53,312 km), and Number of Permanent Employees (766). The output variables are the number of subscribers (3,092,695) and Consumption of Consumers Connected to Distribution (13127.45). After the calculations, the efficiency score of DMU19 is declared as 1.000. Therefore, this DMU can be classified as efficient, and it does not have a reference group.

For DMU20, the selected input variables include Area Measurement (40,920 km²), Investments (967.60 million Turkish Liras), Total length of Lines (41,367 km), and Number of Permanent Employees (1,021). The output variables are the number of subscribers (802,776) and Consumption of Consumers Connected to Distribution (2107.90). After the calculations, the efficiency score of DMU20 is determined as 0.259180898, categorizing it as inefficient. Despite its current state, there are potential ways for DMU20 to improve and become efficient. To explore this, the reference group for DMU20, including 'DMU6 (0.028277022), DMU9 (0.158024147), DMU12 (0.176618042), DMU19 (0.060387683)', is examined. The details of DMU18's potential within this reference group are presented in the table below.

Table 29. Reference Values of DMU20

		DMU20	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	40920	8066
	Investments (Million TL)	967.6	251
	Total Length of Lines (KM)	41367	10722
	Number of Permanent Employees	1021	265

Fewer changes are observed in DMU20, with decreases in area measurement, investments, total length of lines, and the number of permanent employees.

Table 30. Calculation of Reference Values of DMU20

		Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)		$0.028277022 * 61161 + 0.158024147 * 29211 + 0.176618042 * 28500 + 0.060387683 * 35501$	8066
	Investments (Million TL)		$0.028277022 * 2293.2 + 0.158024147 * 769.9 + 0.176618042 * 2304.6 + 0.060387683 * 483.8$	251
	Total Length of Lines (KM)		$0.028277022 * 54038 + 0.158024147 * 83521 + 0.176618042 * 34478 + 0.060387683 * 53312$	10722
	Number of Permanent Employees		$0.028277022 * 4218 + 0.158024147 * 402 + 0.176618042 * 960 + 0.060387683 * 766$	265

For DMU21, the selected input variables include Area Measurement (39,928 km²), Investments (920.60 million Turkish Liras), Total length of Lines (85,147 km), and Number of Permanent Employees (545). The output variables are the number of subscribers (2,354,542) and Consumption of Consumers Connected to Distribution (5172.52). After the calculations, the efficiency score of DMU21 is declared as 0.590576909. Therefore, this DMU can be classified as inefficient. Even though this DMU is in an inefficient state, there are potential ways to improve its efficiency. For this purpose, the reference group needs to be examined. The reference group for DMU21 is 'DMU 7(0.062186547); DMU 9(0.062320345); DMU 11(0.451254789); DMU 19(0.1308849).' According to the reference group of the DMU, its potential will be shown in the table below.

Table 31. Reference Values of DMU21

		DMU21	
		Original Values	Reference Values
Inputs	Area Measurement (KM ²)	39928	23581
	Investments (Million TL)	920.60	544
	Total Length of Lines (KM)	85147	46899
	Number of Permanent Employees	545	322

This DMU undergoes fewer alterations, marked by substantial decreases in area measurement, investments, total length of lines, and the number of permanent employees. However, these changes are proportionally significant.

Table 32. Calculation of Reference Values of DMU21

	Variables	Calculation	Reference Value
Inputs	Area Measurement (KM ²)	$0.062186547 * 3507.83$ $+ 0.062320345 * 29211$ $+ 0.451254789 * 37441$ $+ 0.1308849 * 35501$	23581
	Investments (Million TL)	$0.062186547 * 2307.4$ $+ 0.062320345 * 769.9$ $+ 0.451254789 * 640.2$ $+ 0.1308849 * 483.8$	544
	Total Length of Lines (KM)	$0.062186547 * 50126 +$ $0.062320345 * 83521 +$ $0.451254789 * 70025 +$ $0.1308849 * 53312$	46899
	Number of Permanent Employees	$0.062186547 * 679 +$ $0.062320345 * 402 +$ $0.451254789 * 342 +$ $0.1308849 * 766$	322

CONCLUSION

Energy is a fundamental force that can exist as potential or kinetic, driving various processes or enabling work to be accomplished. It manifests in different forms and plays a vital role in human life, influencing survival, industry, economy, heating, lighting, transportation, and technology. The effective and sustainable use of energy is crucial for both economic prosperity and environmental well-being. Energy policies should prioritize the transition to renewable sources, energy security, and environmental protection.

Electricity, a form of energy, stands out as a primary energy source for modern societies, playing a vital role in numerous essential areas. From powering home and industrial appliances to facilitating light, transportation, communication, medical advancements, and entertainment, electricity has become integral to modern life. However, it is imperative to address environmental and sustainability concerns associated with energy consumption and electricity production. Key considerations include leveraging renewable energy sources and enhancing energy efficiency to ensure the sustainable use of electricity. Optimizing the systems within which these processes occur represents a fundamental step in this direction.

Optimization is a crucial factor in the realm of energy and electricity. It has the potential to enhance efficiency, ensuring that finite resources are utilized in a more sustainable manner. In this context, the impact of optimization is particularly pronounced in the following fields:

1. Energy Efficiency
2. Cost-Cut
3. System Performance
4. Decreasing the environmental Factors
5. Improving Electrical Networks

Optimization stands as a critical tool in attaining key objectives such as sustainability, economic efficiency, and system reliability within the energy and electricity sectors. Its significance lies in the efficient utilization of resources, leading to cost reduction, effective energy usage, optimal system performance, mitigating

external impacts, enhancing electrical grids, and facilitating the integration of renewable energy sources.

The optimization process should commence at the initial stage of harvesting energy sources, extending to the optimization of production. This holds immense importance not only for producers but also for consumers. By optimizing the entire process, the cost of energy transmitted to consumers can be streamlined to a level of abundance.

Electricity is a ubiquitous energy source in our daily lives, making the optimization of its production and transmission a pivotal means to enhance community well-being. Countries aspiring for a future of abundance must prioritize the optimization of electricity, with electric distribution companies serving as key intermediaries. These companies play a crucial role in minimizing operational expenses, shaping the current landscape, and formulating plans. In this research, an efficiency analysis was conducted on electric distribution companies operating in Turkey in 2020, employing data envelopment analysis (DEA) through the MaxDEA Lite program.

The chosen model for the analysis was the input oriented CCR model (Charles, Cooper, and Banks). Input-oriented models were preferred as the selected outputs were directly influenced by external factors, with the results not solely stemming from operational efficiency but also impacted by external causes. The model incorporated area measurement (km^2), investment amount (in million-TL), total length of lines (in KMs), and the total number of permanent employees as inputs. The outputs considered were the number of subscribers, and consumption of consumers connected to distribution (in MWh).

Following the calculations, 8 out of 21 DMUs were identified as efficient, while the remaining 13 were deemed inefficient. In line with the expectations of the input-oriented model, all inputs exhibited a decrease. Notably, area measurement, investment amount, total length of lines, and the number of permanent employees all decreased. This suggests that inefficient companies should consider downsizing, dividing their operational areas into smaller segments. This may lead to the emergence of new distribution companies. Another potential solution, though less feasible, is to integrate downsized operational areas into efficient companies to achieve a balance.

The decrease in the investment amount indicates that the allocated funds for investments may not be utilized productively. It underscores the importance of strategic investment decisions and the need for higher management to prioritize business efficiency when deploying resources. The reduction in the total length of lines implies that operational areas should be streamlined. The decrease in the number of permanent employees suggests a downsizing in company size.

In conclusion, for the identified inefficient companies, downsizing is recommended across various aspects, including operational areas and expenditures. This strategic move can benefit both companies and customers. By focusing on smaller percentages, management can enhance the impact of their efforts in these areas. This downsizing approach enables companies to better navigate challenges posed by external factors and potentially offset losses. Considering these findings, companies are encouraged to adopt a proactive stance in their short- and long-term planning to optimize their operations and improve efficiency.

All the findings align with the conclusions drawn from the literature review, highlighting that companies operating in areas with higher socio-economic, socio-cultural, and education levels tend to exhibit greater efficiency. Conversely, a decrease in the levels of socio-economic, socio-cultural, and education is associated with reduced efficiency in distribution companies. This underscores the impact of external factors, emphasizing that companies operating in regions with higher education levels tend to optimize their operations more effectively.

In summary, this research reveals that more than half of the companies studied operate inefficiently. The recommendation for these inefficient companies is to consider downsizing, coupled with the adoption of other practices to enhance efficiency. Exploring innovative approaches to minimize factors such as loss, leakage, outage, operational expenditure, and capital expenditure is essential for long-term benefits, even if complete elimination is not feasible.

However, some constraints were encountered during the research process. The lack of standardized technical reporting across companies posed challenges. Yearly activity reports lacked a consistent layout or template, making them difficult to utilize. Additionally, while the Energy Market Regulatory Authority (EPDK) provides yearly and monthly sector reports, these are not detailed enough for in-depth analysis. Future

studies would benefit from an increase in technical reports, ensuring cleaner, more understandable, and applicable data for comprehensive analysis.

The second constraint encountered during the research was the limited number of DMUs (Decision Making Units). The scarcity of companies operating in Turkey restricted the scope of efficiency analysis practices, making it challenging to have a sufficient pool of businesses for comparison. To address this limitation, future studies could explore comparisons not only between companies but also across consecutive years or timelines before and after specific events.

The current state of Turkey is characterized by unpredictability, emphasizing the need to maximize the utilization of all available resources. Optimization emerges as a key action step in achieving this goal. Furthermore, optimization should be implemented comprehensively, encompassing every step and aspect of the process. The most impactful measure for the public is the optimization of distribution companies, as even small improvements, such as cost reductions, can significantly enhance the quality of life for people.

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TURNITIN REPORT

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