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Assessment of the Energy Efficiency of Data Centers in Türkiye

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Abstract: Rapid developments in mobile and cloud technologies in particular are increasing the need for data storage today. This growing demand for data storage is leading to a rapid increase in the number of data centers. Data centers not only store organizations' digital information, but also process this data, play a role in its distribution, and assist in its management. In these centers, where numerous servers are housed together, security and sustainability are of critical importance to organizations, and any disruptions that may occur here can be extremely difficult to mitigate. Therefore, ensuring that data centers are designed to operate 24/7 and implementing the necessary precautions are essential requirements. The growing number of data centers has led to a significant increase in energy demand, both globally and in Türkiye. This situation poses serious problems for countries in terms of ensuring an energy supply and creating the necessary infrastructure. In recent years, the excessive energy consumption of data centers has become an area of intense research, and great efforts have been made to solve this problem. In this context, a new field of study called "Data Center Efficiency" has emerged. This study focuses on 18 data centers operating in Türkiye. Within the scope of the study, total facility power, IT equipment power, cooling capacity and total CO_2 amount data were collected from these data centers. Using this data, energy efficiency values and power utilization efficiencies of the data centers were calculated. Based on the values obtained, the efficiency of data centers was compared and classified. In addition, several recommendations are presented to improve the energy efficiency of data centers.

Keywords Data Centers, Energy Efficiency Values, Energy Sources, Total Facility Power,

1. Introduction

With the discovery of the internet, there have been major developments around the world. Humanity has become dependent on the internet, along with constantly evolving technology. Examples of this dependence include social media, online transactions, storage technologies, and telecommunications used today. Every photo we view on social media, every video we like, every money transfer and purchase we make—in short, every transaction we perform online—is a data sample. The transfer, processing, and storage of this data are carried out in data centers.

Energy has been a basic need for humanity for centuries. The consumption of energy plays a key role in meeting human needs and is increasing day by day (Akkurt & Özsan, 2025). Data centers are facilities that form the main infrastructure of information technologies in the digital world and consume large amounts of energy. Energy efficiency is critical to the sustainability of data centers, reducing operating costs and minimizing environmental impacts. Data center energy efficiency must be addressed from multiple perspectives, including energy management, energy savings, renewable energy integration, waste heat recovery, and energy performance methods.

The concept of energy efficiency generally refers to reducing energy consumption and using existing energy more efficiently without compromising production quality and quantity. This applies not only to the industrial and service sectors but also to data centers. Efforts are being made to increase energy efficiency in the industrial sector through measures such as preventing losses and leaks, recovering waste energy, and reducing energy costs. Waste heat recovery systems, thermal insulation, and energy management applications are similarly important measures used to enhance energy efficiency in data centers (Karanfil et al., 2020).

The rapidly increasing number of data centers in Türkiye and around the world is causing serious problems for ecosystems and electrical infrastructures due to their high electricity consumption. The increasing energy demand has significantly increased the need for sustainable, environmentally friendly energy sources (Akkoyunlu et al., 2024). This situation underscores the importance of companies that provide hardware to data centers, prioritizing the security, continuity, and energy efficiency of the sensitive devices they produce. In a typical data center, 55% of energy consumption is attributed to information technology (IT) components, 16% to energy losses in the power distribution system, and 29% to cooling systems used to maintain the data center's temperature (Şen, 2019).

The amount of energy used by information technologies, communication systems, and mobile devices has reached significant levels today. This level is the highest amount of energy ever used throughout history. This level is expected to be exceeded in the coming years. To meet this energy need, financial investments in new energy sources are increasing, particularly Türkiye's imports of energy from abroad (Hacıbeyoglu et al., 2023). If necessary, measures are not taken in the coming years, this issue will continue to be debated. A study conducted in 2012 revealed that the total electricity consumption of all data centers worldwide was 270 TWh. This figure represents 1.4% of the world's total electricity consumption (Koomey, 2007). According to a study, by 2030, the energy consumed by data centers is expected to account for 13% of the world's total energy consumption. These studies and estimates also indicate that if necessary measures are not taken and the required work is not done for data centers by 2030, data centers will cause significant energy problems (Van Heddeghem et al., 2014).

A review of the literature reveals similar studies on the efficiency of data centers. These studies generally focus on energy efficiency in data centers, including heating and cooling systems, energy management, and reducing energy costs. Examples of such studies are presented below.

Improving energy efficiency in cooling and climate control systems, which account for a large portion of energy consumption in data centers, is also an important issue. For example, a study found that when a recuperator was used, boiler thermal efficiency increased from 64.46% to 76.54%, and HVAC systems achieved 47% heat recovery efficiency (Akhan, 2023). Additionally, studies have been conducted on evaluating energy performance and creating energy performance certificates. The BEP-TR software was used to calculate the energy performance of buildings and served as the basis for issuing energy performance certificates (Akın & Kaplan, 2019). Efforts have also been made to develop data entry and calculation methods for accurately measuring energy performance and determining energy efficiency potential (Aydın & Canım, 2017). Furthermore, studies on energy efficiency have been conducted in energy-intensive sectors such as textiles, iron and steel, cement, and glass (Töre & Elitaş, 2022). An energy audit was conducted at a foundry, the energy saving potential and payback periods for the projects to be implemented were calculated, and the annual energy savings and monetary equivalent resulting from the projects were determined. The impact of energy efficiency on costs was also addressed (Akkurt & Taşdemir, 2021). Studies have also been conducted in data centers to reduce energy consumption and encourage conscious use, utilizing consumption rates and activity-based costing models (Kavrar & Yılmaz, 2019) (Telliel, 2022) (Kılıçarslan & Dumrul, 2019).

According to studies in literature, data centers are an important and indispensable concept for today's technology. Türkiye, in particular, is taking steps in this area and is constantly evolving. However, due to factors such as the absence of large-scale data centers in Türkiye and Turkish companies renting space for data centers abroad, the concept of data centers has not developed to the desired level in Türkiye. Additionally, due to the scarcity of experts and companies specializing in the design and establishment of data centers in Türkiye, the country has not been able to meet its domestic demand for data centers or achieve self-sufficiency in this area. However, it is clear that efforts in this field will play a significant role in the process of achieving the required capacities in the future. For this reason, this study focuses on the energy efficiency of data centers.

This study investigated the efficiency of data centers operating in Türkiye. First, data on total facility power, IT equipment power, cooling capacity, and total CO2 emissions were collected from 18 data centers operating in different cities across Türkiye (Istanbul, Ankara, Bursa, and Izmir). Using this data, data centers' power usage efficiency and carbon usage efficiency were calculated. This provides a comparative overview of the overall energy efficiency of data centers in Türkiye.

2. Materials

In this study, the energy efficiency values and Power Usage Effectiveness (PUE) of 18 data centers operating in different regions of Türkiye were calculated to determine their current status. In addition, the efficiency levels of the data centers were compared with each other. Based on the energy efficiency and power usage data obtained, the data centers were classified, and recommendations were made to improve their energy efficiency. Table 1 contains information about the institutions for which energy efficiency values will be calculated. Due to commercial concerns, data centers are referred to by codes rather than names. For example, "Data Center 1" is abbreviated as "DC-1.". For the purposes of this study, the following data were collected from the data centers: total facility power, IT equipment power, cooling capacity, and total CO_2 emissions. These data are presented in Table 1.

Table 1 Information received from data centers

Data Centers	Total Facility Power (ρ - kVA)	IT Equipment Power (ω - kW)	Cooling Capacity (kW)	Total CO_2 Amount (C - $kgCO_2/kWh$)
DC-1	2500	1440	1190	0.385
DC-2	4550	3500	2500	0.745
DC-3	4200	3000	2250	0.630
DC-4	3500	2000	1500	0.435
DC-5	4000	1500	1260	0.445
DC-6	2750	1300	1780	0.560
DC-7	2500	1500	1600	0.620
DC-8	1000	800	850	0.250
DC-9	1250	800	750	0.300
DC-10	2400	1900	1750	0.425
DC-11	3200	1500	1250	0.545
DC-12	3900	3000	2800	0.735
DC-13	2200	1000	850	0.540
DC-14	2500	900	800	0.450
DC-15	3100	2600	2500	0.550
DC-16	2400	1500	1250	0.375
DC-17	2200	1100	1000	0.525
DC-18	2800	1800	1500	0.485

3. Methods

The rapid growth of data centers has brought with it some significant problems. These can generally be described as data center energy efficiency and environmental sustainability. Objective and accepted metrics must be used to objectively evaluate these values. The Green Grid is a global association of corporations dedicated to improving energy efficiency in data centers and information technology ecosystems, comprising government agencies and educational institutions (Azevedo et al., 2010). PUE (Power Usage Effectiveness) is a metric proposed by Green Grid. PUE, the most fundamental metric used to measure data center efficiency, relates the total energy consumed in data centers to the amount of energy consumed by IT components (such as servers). Carbon Usage Effectiveness (CUE), on the other hand, focuses on carbon emissions, which are a natural consequence of PUE. In short, while PUE is related to energy efficiency in data centers, CUE is related to environmental sustainability.

3.1 Power Usage Effectiveness (PUE)

The PUE metric was proposed by The Green Grid; an association of IT experts committed to enhancing the energy efficiency of data centers. Power Usage Effectiveness (PUE) is a key metric used to evaluate the energy efficiency of data centers. This metric is described as the ratio of total facility power usage to power consumed by IT equipment (Equation 1). Conceptually, in an efficient scenario where all energy is transmitted to the IT load (servers, storage, and network infrastructure), PUE equals 1. However, in practice, this value often exceeds 1 due to factors such as cooling systems, lighting, power distribution losses, and auxiliary infrastructure. The PUE value serves as an important performance indicator for data center operators in terms of energy optimization, with lower PUE values indicating increased energy efficiency.

$$PUE = \frac{\rho}{\omega} \quad (1)$$

where, ρ is the total facility power in the data center and ω is the IT tools power in the data centers. This proportion explains how much additional energy is needed to protect the IT tool for every watt supplied to each piece of the tool in a data center. Below is a systematic classification of energy efficiency levels based on PUE values:

- **PUE = 1.2(Very Efficient):** This level represents near-optimal performance in energy usage. Energy expenditure for infrastructure outside of IT equipment (cooling, lighting, etc.) is at a minimum.

- **PUE = 1.5(Efficient):** This represents an acceptable level of efficiency. Energy losses are under control, and there is limited potential for improvement.

- **PUE = 2.0(Average):** This value is considered average according to industry standards. However, it indicates significant opportunities for improvement in cooling systems or power distribution.

- **PUE ≥ 2.5(Insufficient):** Indicates inefficient energy usage and requires urgent optimization. At this level, the energy expended on supporting infrastructure significantly exceeds the energy consumed by IT equipment.

3.2 Carbon Usage Effectiveness (CUE)

Carbon Utilization Efficiency (CUE) has been introduced as a complementary metric to PUE for assessing the environmental performance of data centers. This metric represents the ratio of carbon emissions from operational processes to the energy consumed by the IT infrastructure. The main difference from PUE is that it uses a unit scale (kg CO_2/kWh) and provides quantitative analysis of the carbon footprint. The denominator value in the CUE calculation uses IT energy consumption data obtained from the PUE analysis. The ideal value for this metric is zero (0.0), indicating no carbon emissions from operational activities. In practice, however, it takes positive values depending on the carbon intensity of energy sources. For example, a data center using coal-based electricity will have a significantly higher CUE value compared to a facility using renewable energy. The CUE and PUE metrics only cover direct impacts during the operational phase, excluding indirect emissions from equipment production, logistics, and disposal processes. This limitation highlights the need for additional methodologies in comprehensive environmental assessments requiring life cycle analysis (LCA).

$$CUE = \frac{C}{\omega} \quad (2)$$

where, C represents the total amount of CO_2 generated by the data center, while ω represents the power consumption of IT equipment in data centers. This metric plays a critical role in measuring the performance of renewable energy transition strategies, particularly due to its sensitivity to the carbon content of energy sources. Data center operators can use CUE monitoring to quantitatively assess the environmental impact of their energy procurement policies and take concrete steps toward their sustainability goals.

4. Analysis and Results

In this study, various operational parameters were collected to evaluate the energy efficiency and environmental impact of data centers. These operational parameters consist of total facility power, energy consumption power of IT equipment, cooling capacity of the facility, and total carbon emissions (in kg CO_2/kWh). The total facility power mentioned here represents the energy consumption of all systems in a data center. It includes not only IT equipment but also cooling systems, power conversion losses, lighting, and other supporting infrastructure components. The energy consumed by hardware that performs IT functions such as storage, network communication, and data processing is referred to as IT equipment power. Ventilation systems used to ensure that hardware operates in a suitable environment indicate the cooling capacity of the facility. Here, cooling capacity has not been used as a parameter in PUE and CUE calculations but has only been provided as additional information. It is also known that cooling systems have an indirect effect.

The PUE and CUE values for data centers were calculated using Equations 1 and 2 provided in the previous sections of this study. PUE calculations represent the ratio of total facility power to IT equipment power and help us determine how much energy consumption is allocated to computing activities. Here, CUE is used to determine the carbon footprint in this process. When we consider these two metrics together, they enable us to see both how efficient data centers are and how environmentally sustainable they are.

To better understand the calculations in this study, it would be useful to provide an example based on one of the data points in Table 3. This example shows how the calculations were performed and how they should be interpreted. For example, if the total facility power measured in a DC-1 data center is 2,500 kW, the IT equipment power is 1,440 kW, and the total carbon emissions are 0.385 CO_2, the PUE value is calculated as 1.74 according to Equation 1, and the CUE value is calculated as 2.674E-04 according to Equation 2. Such calculations are critical for understanding the current energy usage profile of data centers and developing improvement strategies. Additionally, the accuracy and currency of the parameters used in the calculations directly affect the reliability of the PUE and CUE values obtained.

These calculations were also performed for the other 17 data centers and are presented in Table 2 below.

Table 2 PUE & CUE efficiency level

Data Centers	PUE	CUE	City
DC-1	1,74	2,674E-04	İSTANBUL
DC-2	1,30	2,129E-04	İSTANBUL
DC-3	1,40	2,100E-04	İSTANBUL
DC-4	1,75	2,175E-04	BURSA
DC-5	2,67	2,967E-04	İSTANBUL
DC-6	2,12	4,308E-04	ANKARA
DC-7	1,67	4,133E-04	İSTANBUL
DC-8	1,25	3,125E-04	İZMİR
DC-9	1,56	3,750E-04	İSTANBUL
DC-10	1,26	2,237E-04	İSTANBUL
DC-11	2,13	3,633E-04	İSTANBUL
DC-12	1,30	2,450E-04	İSTANBUL
DC-13	2,20	5,400E-04	İSTANBUL
DC-14	2,78	5,000E-04	İSTANBUL
DC-15	1,19	2,115E-04	İSTANBUL
DC-16	1,60	2,5E-04	ANKARA
DC-17	2,00	4,772E-04	İSTANBUL
DC-18	1.55	2,694E-04	İZMİR

In addition, the PUE and CUE values obtained for all data centers are shown in Figure 1 below for general evaluation purposes.

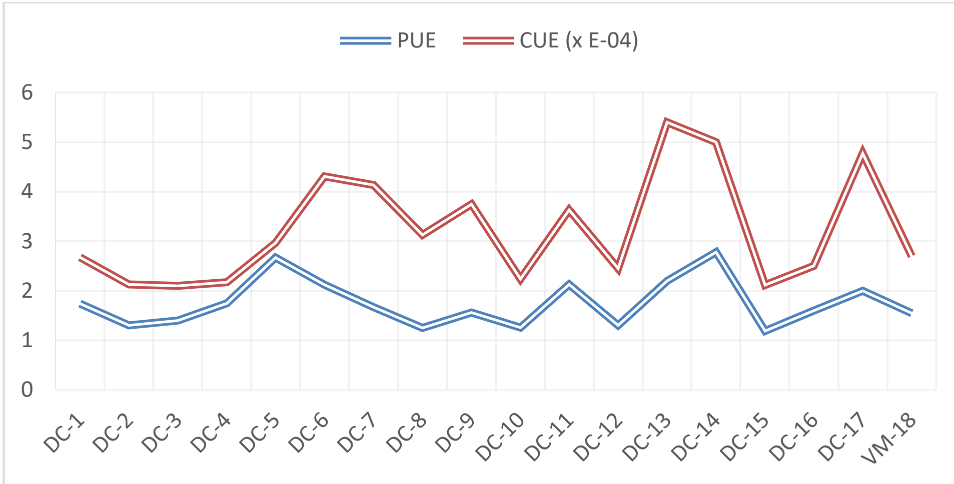

Figure 1 Graph of calculated PUE and CUE values

After calculating the PUE and CUE values for all data centers, the results were evaluated according to the data levels given in Table 3 above, and the data centers were grouped into four classes according to their efficiency:

• **Highly efficient:** This category includes 6 data centers with PUE values between 1.2 and 1.5 (DC-2, DC-3, DC-8, DC-10, DC-12, DC-15). These data centers are the closest to the ideal. Their energy efficiency is at a high level.

• **Efficient:** This class includes 6 data centers with a PUE value between 1.5 and 2 (DC-1, DC-4, DC-7, DC-9, DC-16, DC-18).

• **Average:** This class includes 4 data centers with a PUE value between 2 and 2.5 (DC-6, DC-11, DC-13, DC-17).

• **Insufficient:** This class includes two data centers with a PUE value greater than 2.5 (DC-5, DC-14). The PUE values that need to be improved for data centers are in this group.

Centers with low CUE values (e.g., DC-3, DC-4, DC-15) may be advantageous in terms of renewable energy use or low-carbon energy sources.

5. Conclusions

This study is an important piece of research on data centers, which have become indispensable and increasingly important in today's world. Data on Total Facility Power, IT Equipment Power, Cooling Capacity, and Total CO2 Amount were collected from 18 data centers located in different cities in Türkiye for the purposes of energy efficiency and environmental sustainability. These values were used to assess the data centers using the Power Usage Effectiveness (PUE) and Carbon Usage Effectiveness (CUE) metrics. Upon detailed analysis of the results, it was revealed that the energy efficiency levels of data centers vary significantly. Centers such as DC-15, with a PUE value of 1.19, are classified as "highly efficient," while centers such as DC-5 and DC-14, with PUE values of 2.67 and 2.78, respectively, are classified as "insufficient." CUE values reflect the impact of renewable energy use in centers with low carbon footprints (e.g., DC-3, DC-4).

The study highlights the importance of optimizing cooling systems and utilizing renewable energy sources to increase the efficiency of data centers. It also emphasizes that some of the data centers operating in Türkiye have low energy efficiency. These findings may serve as a guide for policymakers and industry stakeholders regarding the sustainability and energy efficiency of data centers in Türkiye. Recommendations and future work are provided in more detail in the following subsections.

5.1 Recommendations

The findings of this study indicate that data centers operating in Türkiye have specific areas for improvement in terms of energy efficiency. Cooling systems should be addressed first in data centers. The use of new-generation climate control approaches and artificial intelligence-based cooling control algorithms can provide advantages in both regional and changing conditions. However, the design of data centers should also be addressed. Modular and flexible structures should be preferred as much as possible for capacity expansion and energy savings. New generation and low-loss equipment should be used to prevent energy losses. Furthermore, continuous monitoring is required to meet international standards. Finally, renewable energy sources should be integrated into the facilities as a supporting element.

5.2 Future Work

Future research will benefit significantly from the development of the dataset used in this study and the examination of a larger number of data centers. In particular, a comparative analysis of data centers operating in different regions and under different climatic conditions will more clearly demonstrate the impact of cooling technologies on energy efficiency. In regions with high solar and wind energy potential, studies can be conducted on the integration and efficiency of renewable energy systems in data centers. In subsequent stages, the use of life cycle assessment (LCA) methods can provide a comprehensive analysis covering not only energy consumption during operation but also all processes from hardware production to disposal. Studies on energy efficiency can be conducted using approaches such as artificial intelligence-based forecasting. The effects of energy storage systems in data centers on energy efficiency and continuity can be investigated. Furthermore, data centers in different countries can be compared with those operating in Türkiye, and assessments can demonstrate the level of compliance of Turkish practices with global standards.

Declaration of Ethical Standards

As the authors of this study, we declare that he complies with all ethical standards.

Credit Authorship Contribution Statement

R. Çelik: Software, Investigation, Resources, Validation, Formal analysis, Writing -Original Draft, Visualization.

M.A. Şahman: Investigation, Writing, Review & Editing, Supervision.

A.O. Dündar: Writing, Review & Editing.

Declaration of Competing Interest

The authors declared that they have no conflict of interest.

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Data Availability

No datasets were generated or analyzed during the current study.

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