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Quantitative Evaluation of Data Centers' Participation in Demand Side Management

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ABSTRACT In recent years, the rapid increase in the number of internet users and widespread usage of internet applications have obliged large servers and networking equipment to manage large data stack and optimize the instantaneous transmission of digital information. The COVID-19 Pandemic has also caused an increase in data exchanges and digital information generation. In order to manage large-scale data, there is a need for gigantic data centers (DCs) which are tremendous energy consumers and have relatively flexible loads that are easier to control by means of shifting in time and space. Therefore, DCs can be regarded as dispatchable loads and are considered good candidates for participating in demand side management (DSM) programs for power curve smoothing and compensation of power fluctuation in electrical power systems. In this paper, the question of why DCs should participate in DSM has been investigated rather than the technical methods used in DSM. The amount of DCs' participation energy is used by peak shaving/shifting method for power curve smoothing using actual data. The possible environmental and financial effects of it for Turkey and all the world have been carried out. The study results show that DCs' participation in DSM for Turkey decreases peak load by up to 2.18%, defers up to 34% of the installed power plants launched in 2019, and improves load and loss factors by up to 2.2% and 4.3% respectively. Additionally, global DC's participation in DSM decreases the peak point by up to 0.77% and reduces CO_2 emission by 0.03%.

INDEX TERMS Demand side management, electricity market, data center, energy efficiency, peak shaving, CO_2 emission reduction.

I. INTRODUCTION

Over the past twenty years, demand for internet service providers and cloud services, use of information and communication devices have reached a significant level. Thus, the size of generated and processed data has been dramatically increased. In 2018, the number of global internet users was 3.9 billion and it is projected to reach 5.3 billion users by 2023 [1]. Also, the number of devices connected to the internet has been estimated to be 29.3 billion by 2023 [1]. According to the white paper of Seagate [2], the amount of generated digital information was 33 zettabytes (ZB) in 2018 and it is projected to reach 175 ZB by 2025. These large data are needed to be stored and processed in data centers (DCs) which include a large number of high-performance servers and have the ability to remote access.

Digital transformation has already been taking place for many years, yet the COVID-19 pandemic exacerbates it dramatically. Especially with most companies enabling employers to work from home, the demand for internet and online video conferencing software such as *Google Meet, Zoom, Microsoft Teams* has skyrocketed. Isolation duration has also affected the habits of people at home [3]. The ratio of video call communication with friends and relatives, the time spent on social media, and the usage of streaming audio and video services like *Netflix, HBO Now, Spotify* have increased so quickly. A survey which has been performed with 2200 adults between March 24 to March 26, 2020, in the U.S., shows that 37% of adults preferred to do online shopping more than before the Pandemic, 41% of adults and 57% of the age 18-29 preferred streaming movies more than before and the 18% of the age 18-29 used *FaceTime* or *Zoom* for the first time with the pandemic [4]. According to [5], the demand for *Google Meet* has reached 60% after the COVID-19 and

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the mean daily usage is declared as 2 billion minutes per day. Likewise, the usage rate of *Zoom* has 10 times increment during the pandemic [6]. *HBO Now* observed a 40% increase in viewing numbers compared to the average for the last 4 weeks before March 14, 2020 [7]. All these sudden amendments have also caused an increase in data transfer traffics and unprecedented demand for data centers to maintain the services.

Owing to the growing demand for computational and storage infrastructures, the size and number of geographically distributed DCs are drastically increased to provide reliable low latency services to the customers [8], [9]. DCs consist of a large number of servers, cooling units, large-scale storage units, networking equipment, and power infrastructures. Because of having a huge amount of hosted servers, associated workload, and cooling units, the energy consumption of DCs has attained gigantic numbers [10], [11]. According to The United States (U.S.) Environmental Protection Agency (EPA) report, the demand in DCs has been increasing by approximately 12% per year [12]. According to [13], the total electricity usage of all DCs in the world increased by 56% between 2005 to 2010. EPA Report mentioned that DCs in the U.S. consumed about 61 TWh which equal to 1.5% of total U.S. electricity consumption in 2006 [12]. Moreover, the worldwide energy consumption of DCs was 198 TWh in 2018 [14]. The reports published in 2013 [15], [16] mentioned that the IT sector which includes DCs was consuming about 10% of the world's electricity generation.

Due to the huge power consumption characteristic of DCs, different studies [17]–[21] about forecasting and efficiently managing power consumption of DCs have become more popular in the literature. Also, DCs can be significant players for the power systems in terms of their ability to become prosumer and they are good candidates for demand-side management applications in order to compensate demand fluctuations and power curve smoothing.

In classical power systems, demand fluctuation is an important problem with regard to its effects on power loss, voltage/frequency control, and stability of power systems. It is generally compensated by dispatching reserve generation resources using unit commitment techniques. But renewable-based distributed generators cannot be used for unit commitment due to their intermittent nature. In the power system sense, they are non-dispatchable units and further contribute power fluctuation problems due to the fluctuating nature of weather conditions. These problems with widespread usage of renewable energy sources are caused to make energy management more important.

On the other hand, a tool called demand-side management has been in place for a time with the development of smart grid technologies. In demand side management systems, the loads are dispatched instead of generations. DSM provides benefits to consumers such as fulfilling required demand, decreasing electricity bills, and improving lifestyle. DSM also causes advantages to the supplier such as providing a more efficient system and requiring less capital for generation, reducing costs of generation, transmission, and distribution systems [22]. DSM aims to provide required changes on electricity consumption demand in time through load control systems, on-site energy storage packages, or encourage non-peak electricity demand [23], [24]. In that sense, both big and small DCs can be used as a participant for DSM systems in terms of their flexible loads which are easier to control and shift in time than the other big industrial customers. One of the goals of demand side management for DCs is to efficiently manage DCs' energy consumption and generation resources, another one is to contribute to smoothing demand fluctuations in power systems. However, the focus of most researchers has been generally on minimizing energy cost of DCs. The studies related to DCs implemented with DSM mechanisms can be examined in two subcategories: Time of Use Pricing and Market Mechanism. Relevant studies have been summarized in Table 1.

A. TIME OF USE PRICING

Time of Use (ToU) pricing is based on adjustment electricity price by the time of the day. There is an electricity tariff that has higher prices at peak hours and lower prices at non-peak hours. ToU pricing has long been used by most utilities in the world [25].

B. MARKET MECHANISM

The market mechanism is based on determining electricity prices according to the participants' bids for the day-ahead or intraday electricity market. Bidders can participate in the market through their generation or consumption amount and accept to be penalized if they don't provide their commitment [11], [26], [27]. According to the literature of DSM market mechanism implementation to the DC ecosystem, there are three techniques: (I) load shifting which is shifting energy consumption in time, (II) load migration which is migrating the load geographically, and (III) load shedding which is temporarily enabling the sleep mode or shutting down the servers to reduce energy consumption while they are in idle condition [27], [28]. DCs' workloads are generally divided into two subcategories, delay-sensitive and delay-tolerant workloads [9]. The delay-sensitive workload must serve immediately without any delay. On the other hand, delay-tolerant workloads can be postponed to another period and can be used for load shifting technique which is based on shifting load from the time with higher electricity prices to lower prices. Delay-tolerant workloads can also be migrated to the DCs at a different location which has lower electricity prices.

C. CONTRIBUTIONS

As seen from the compact literature review, most researchers are focused on the technical and mathematical processes of how the DCs can participate in DSM with the scope of providing benefits (minimizing electricity cost, etc.) for solely DCs side instead of the utility. The motivation of this paper is to draw attention to the prosumer

TABLE 1. The studies related to DCs implemented with DSM.

Existing Studies	**Time of Use Pricing**	**Market Mechanism**			
		Load Shifting	**Load Migration**	**Load Shedding**	**Objectives**
[29]	✓				Mahmoudi et al. proposed a Residential Energy Management system that aims to reduce customers' electricity bills and improve the utility load curve through integrating ICT equipment with electric vehicles to the power grid.
[30]	✓				The authors have performed ToU based optimization methods for DCs in order to reduce operational expenditures and power consumption. The study shows that there is a reduction in the electricity bill. However, propagation delays increase.
[20]	✓				In [20], the authors aim to minimize energy cost of distributed data centers, which have wind farms and solar panels, using deep learning based optimizer.
[31]	✓		✓		Kantarci et al. extended their previous work [30], by implementing heuristic solutions while considering inter-DC traffic. Also, the load migration method has been used without migrating 30% of the original workload.
[32]		✓			In this study, a workload shifting mechanism is established to smooth power fluctuations and reducing power cost of a data center using renewable resources and UPS batteries of DC.
[33]		✓			The authors propose peak shaving strategies include both load shifting and energy storage alternatives in order to minimize electricity cost of DCs using the convex optimization model.
[34]		✓			In this study, the authors propose a real-time model that controls HVAC, IT workload, and battery energy storage systems for DC's participation in demand response through the load shifting method.
[35]		✓			In this study, the authors developed a system that optimizes the memory of multiple VMs based on the Xen balloon driver. This system shifts overloaded memory in a VM to another VM automatically using a global-scheduling algorithm. The authors use load shifting method but do not intend to participate in DSM
[36]		✓			This study emphasizes that network traffic costs should be considered while the process of load shifting via VM migration in a DC. The authors solve network-aware VM migration problem using genetic algorithms and artificial bee colony methods. The authors use load shifting method without participating in DSM.
[37]		✓			AMMAR et al. propose an algorithm for load shifting via VM migration considering service level agreement (SLA) violation in a DC. The proposed algorithm balances the consumption of resources, minimizes resource wastage, SLA violation, and migration cost.
[38]		✓		✓	In this study, an energy management system is proposed considering delay tolerant workload and maintaining the quality of service to minimize the energy cost. Authors compare different working scenarios to determine cost effective solutions including load shifting and shedding methods.
[39]		✓		✓	This study is related to a type of DCs that provides server rental services to the tenants to participate in emergency demand response by Nash Bargaining Theory without use back up energy resources. Using an incentive approach, tenants shift or shed their workloads during emergency situations.
[40]		✓		✓	The authors propose a new method called "usage-based pricing with monetary reward" based on shifting/shedding tenants' workloads to reduce energy cost of DCs using decomposition based algorithm.
[41]			✓		In this study, Fridgen et al. present an economic analysis to minimize DC's electricity cost by adjusting the optimum load migration schedule.

TABLE 1. (***Continued.***) **The studies related to DCs implemented with DSM.**

[42]	✓		By extending Ref [41]'s approach, Thimmel et al. used load migration method for balancing demand between different electricity markets via geographically distributed DCs. Their model achieved to compensate for balancing power demand without a conventional balancing mechanism.
[43]	✓		In this study, the authors focus on minimizing DC's electricity cost via load migration method between multiple cloud providers using coalitional game theory instead of examining the benefits for the utility side.
[44]	✓		The authors aim to eliminate congestion between cross-region grids using load migration between geo-distributed data centers via congestion management method. The proposed mechanism minimizes congestion costs and provides revenue to data centers corresponding to the migrated load.
[45]	✓	✓	The authors aim to minimize long term operation cost and solve real time energy management problem of geographically distributed data centers. The lyapunov optimization method is used to solve optimum energy management problem considering workload shedding and migration.
[46]		✓	The authors developed an online carbon-aware incentive mechanism based on gathering of tenants' bids correspond to the amount of reduced load in order to minimize the carbon footprint of DCs and operator's cost. An online optimizer determines the winning bid that is used to rewarding tenants.
[47]		✓	The authors devise an incentive-based scheme which enables DCs to participate in emergency demand response via servers workloads and office buildings' cooling load instead of backup generators. During the emergency period, the setpoints of air conditioners are reduced, and the server workloads are dropped.

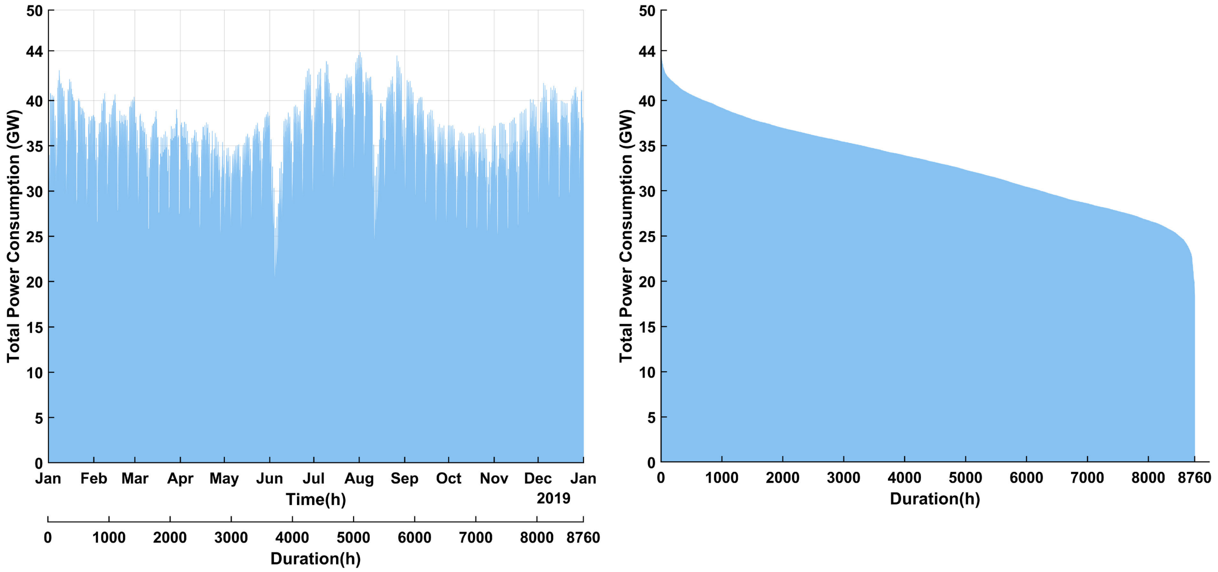
characteristic of data centers and to raise awareness of its various contributions to both the power systems and data centers. This paper investigates the impact of DCs' participation in DSM on power systems in terms of economic and environmental effects, so far lacking in the scientific literature. The peak point shaving method has been used via DCs' participation energy involved in DSM. The possible results such as improving energy saving capacity of the grid, decreasing power loss, benefits due to avoidance of building new power plants are quantitatively analyzed using actual data of Turkey's power consumption as a case study. Additionally, the economic and CO_2 emission impacts of reducing power losses in transmission systems have been analyzed. The main contributions of this paper are summarized as follows:

- The consequences of peak-point shaving of Turkey load duration curve have been analyzed. The peak point of load curve could be reduced by up to 2.18% relative to the initial case. Correspondingly, the load factor could be improved by 2.2% while the improvement of loss factor could be reached up to 4.3%. Thus, up to a 4.13% reduction in power transmission loss could be achieved.
- The effects of global DCs' participation in DSM for all around the world have been carried out. The global peak point of the world could be reduced by up to 0.77%. The worldwide transmission losses could be reduced by up to 1.5%. Consequently, 0.03% of the world's total CO_2 emission, equal to the CO_2 emission of Senegal, could be reduced.
- The global DCs' participation in DSM could cause to defer 12.5% of the worldwide installed power plants put into service in 2018.

The remaining part of this paper is structured as follows: Section II gives information about the status and importance of DCs in terms of its prosumer characteristics. Additionally, the main definition and assumption of DCs' participation process in DSM have been explained in Section II. The economic and environmental results of DCs' participation in DSM for Turkey and all around the world have been clarified in Section III. The conclusions have been drawn in Section IV.

II. DATA CENTERS AS A PROSUMER

Besides the global reasons for the growing demand in DCs for all the countries around the world, the young population is another reason for the increased requirement of DCs for Turkey. Broadband internet customers of Turkey, which were around six million in 2008, exceeded 68 million in 2017 [48]. In the third quarter of 2017, total broadband internet usage reached 3.5 exabytes. Approximately 91% of this usage was data download and 9% was data upload [48]. Furthermore, in 2011, Turkey ranked first in the world with a 60% growth rate in the white area where the servers are located in and ranked second with a 74% increase in the investment rate of DCs [49], [50]. The global growth rate of the DCs market is expected to increase by 15% between 2014 to 2021 while it is 30% for Turkey [50]. All these data show that global DC



(a)

(b)

FIGURE 1. **Total power consumption of Turkey for 2019: (a) Hourly Load curve; (b) Load duration curve.**

needs, and growth rates have increased significantly, while Turkey has more than the world average. Furthermore, the amount of consumed energy by DCs will rise enormously with the development of DC business. Thus, DCs will be good players in terms of power systems. Moreover, along with the law enacted in 2018 for Turkey [51], the utility supports large energy-consuming industries to participate in DSM programs through ancillary services. Therefore, DCs can be significant participants for DSM since its ability to consume too much energy and its prosumer characteristic [18]. That is one of the reasons why this study was carried out to examine the impact of the idea of using DCs as prosumers. Furthermore, based on the analysis conducted for Turkey, the global effects of DCs' participation in DSM has been carried out. The following subsection presents analyses of Turkey's electricity consumption, main definitions, and process of load curve smoothing.

A. THE ANALYSIS OF TURKEY ELECTRICITY CONSUMPTION AND DEFINITIONS OF LOAD AND LOSS FACTORS

The real hourly power consumption data of Turkey for 2019 have been taken from the webpage of Turkey Load Dispatch Information System (YTBS) [52] via a software developed to get the data automatically. All analyses and the peak shaving method are carried out in MATLAB environment.

The actual hourly power consumption has been depicted in Fig. 1- (a) [52] and the load duration curve, which is obtained by sorting power consumption values from maximum to minimum, has been shown in Fig. 1-(b). The integrated areas in both graphs are the same and represent the annual energy consumption.

In order to measure the efficiency of electrical transmission systems, generally, two different indices are used: load factor and loss factor. The load factor is defined as follows [53]:

$$Load\ Factor = \frac{\frac{1}{8760} * \sum_{t=1}^{8760} P_t}{P_{max}} \tag{1}$$

The number of total hours of a year is 8760. P_{max} represents the maximum power consumption value over a year and P_t indicates hourly power consumption. According to Gustafson [54], the loss factor can be approximated as:

$$Loss\ Factor = (Load\ Factor)^{1.912} \tag{2}$$

The loss factor and the load factor values vary from 0 to 1. The system efficiency rises up if these factors approach 1. The changes in the load curve affect the loss factor much more than the load factor because of the nonlinear characteristic of losses. The relationship between bus power to total power loss is defined in [55] and shown in (3).

$$P_{loss} = \sum_{j=1}^{nb} R_j(a_j P_i^2 + b_j P_i + c_j) \tag{3}$$

The impedance of j^{th} line is indicated by R_j, "nb" is the branch number and a_j, b_j, c_j represent coefficients. The power of i^{th} bus is represented by P_i. As can be seen from (3), there is a nonlinear relationship between loss and power load [55], [56]. In electric power transmission systems, the load curve is generally expected as smooth as possible in terms of system stability, lower loss, and efficient usage of installed power plants. Therefore, the difference between maximum and minimum consumption values of load curve is desirable to be small. Additionally, two different load curves can have the same total consumed energy, but the load factor and loss factor can be quite different. For example, Fig. 2 presents two

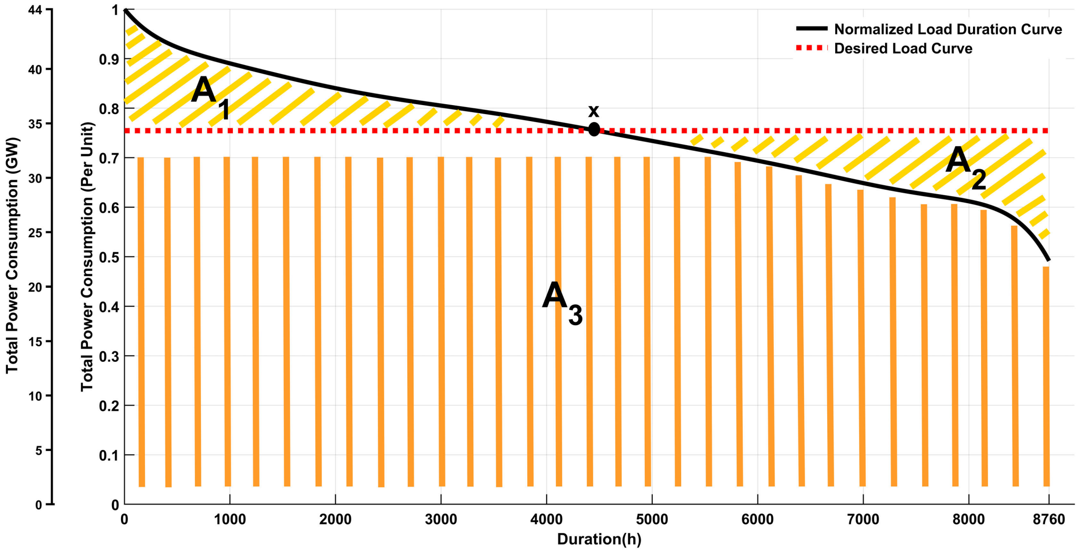


FIGURE 2. Desired and real normalized load duration curves.

different curves which have the same energy consumption value. One of them is the normalized load duration curve of Turkey which is obtained by dividing actual consumption data to its maximum value drawn in the black solid line. The other is the desired load curve of Turkey drawn in a red dotted line. The energy amount of normalized load duration curve is equal to the sum of A_1 and A_3. Desired load curve is obtained by shifting the energy amount of A_1 after the "x" point of the real load duration curve. The maximum point of the desired load curve is also the mean value of the normalized load duration curve and this point is calculated as the peak point that can be shaved as much as possible. The energy amount of desired load curve is equal to the sum of A_2 and A_3. The integrated areas "A_1" and "A_2", which also means the amount of energy, are equal. However, both curves have different load and loss factors. While load and loss factors for the real normalized load duration curve are 0.7544 and 0.5834, both factors are 1.00 for the desired load curve that means the system has perfect efficiency. Thus, it is seen that "peak point shaving/shifting" extremely affects the system efficiency even if the total consumed energy does not change.

In this study, the relationship between peak point shaving/shifting to the load and loss factors has been used in order to improve electrical system efficiency, reduce power losses in transmission systems, obtain monetary saving via power curve smoothing, and improve load and loss factors without changing the amount of total energy consumption. The overall approach has been demonstrated in Fig. 3.

B. THE PARTICIPATION OF DATA CENTERS IN DSM

In this section, all analyses have been done using Turkey's energy consumption data for the year 2019 which was 290.4 TWh [52]. The total energy consumption rate of the

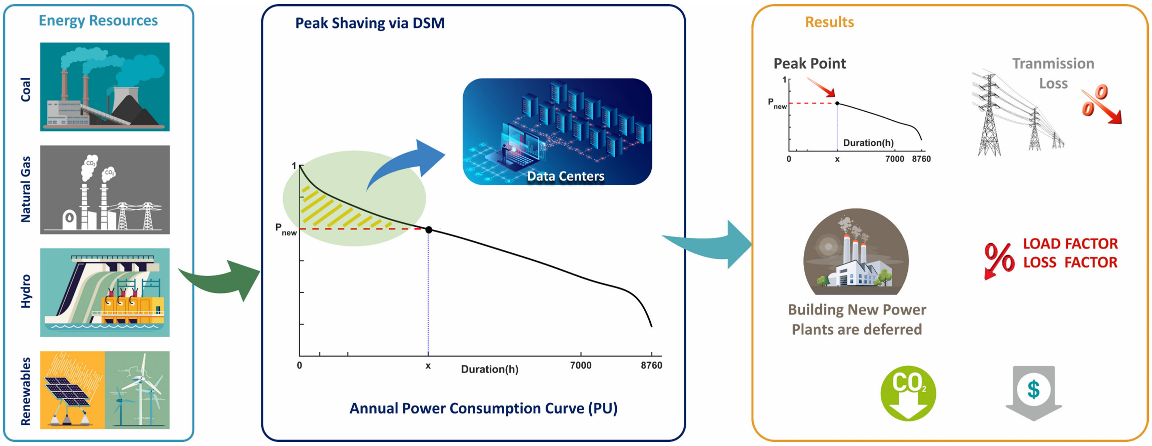


FIGURE 3. The schematic view of overall approach.

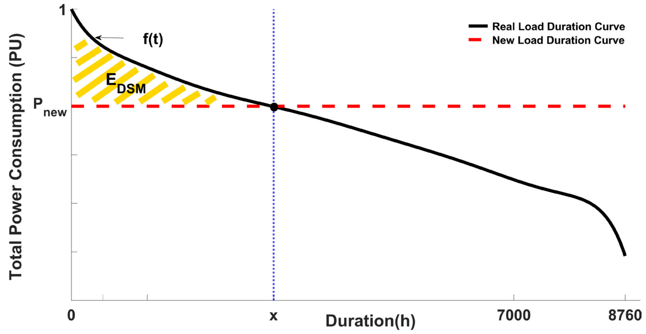


FIGURE 4. **The process of determining peak shaving point.**

DCs for 2019 has been considered as two percent of Turkey's total energy consumption and is calculated as 5.8 TWh.

In order to examine the effects of the energy consumed by DCs participating in DSM at different rates, seven different ratios ranging between 10 to 70 percent of hourly DCs energy consumption is assumed to be used in DSM and the analyses are carried out for each case. While determining the maximum participating rate (70%), it was taken into consideration that a data center cannot shift the entire workload instantaneously and the fact that the backup power capacity of a DC should have at least twice the average power consumption of a DC [57]. Since the secondary energy resource amount and the shiftable workload ratio of each data center are different from each other, various participation rates allow analyzing the results of DCs' participation in DSM at different levels.

The peak point of load duration curve has been shaved/shifted as much as the participated DCs' energy in DSM. This process has been depicted in Fig. 4 and the used mathematical formulation is defined in (4), (5), and (6). DCs' power consumption has been considered as uniformly distributed in the analyses due to the lack of power consumption profile data of individual DCs. Thus, the hourly power consumption of DCs, DCs_{Pow}, is calculated by dividing the total energy consumption of DCs (5.8 TWh) by the total hours (8760). The hourly total power consumption of all DCs is calculated as 663 MW (DCs_{Pow}). The amount of DCs' hourly power involved in DSM is represented as $DSMhourlyP$ and calculated as in (4).

$$DSMhourlyP = DCs_{Pow}{}^{*}DSM_{ratio} \tag{4}$$

DSM_{ratio} is the percentage ratio of DCs' participation in DSM per hour. $DSMhourlyP$ is calculated for each value of DSM_{ratio} which are 10%, 20%, 30%, 40%, 50%, 60%, and 70%. In Fig. 4, the load duration curve of Turkey is defined as a time-dependent function, $f(t)$, where the initial peak point is "1". During peak shaving procedure, three unknown parameters should be calculated for each DSM_{ratio}. One of them is "x" indicating how many hours DCs participated in DSM, the other one is E_{DSM} which is indicating the DCs' energy participated in DSM for each DSM_{ratio} also equal to the energy calculated between the initial peak point to the new peak point and the last one is the new peak point, P_{new}, determined after shaving/shifting the E_{DSM}.

In order to determine P_{new}, firstly, the value of "x" should be calculated because the P_{new} can be obtained using the equation of $P_{new} = f(x)$ for each DSM_{ratio}. The total time of DCs' participated in DSM, "x", can be determined using E_{DSM} that can be calculated using two different methods.

One of them is multiplying the amount of DCs' hourly power involved in DSM ($DSMhourlyP$) by the value of "x" as shown in (5). The other one is the mathematical calculation of the integration between the initial peak point to the new peak point of load duration curve as shown in (6).

$$E_{DSM} = DSMhourlyP\,{}^{*}x \tag{5}$$

$$E_{DSM} = \int_{0}^{x} [f(t) - f(x)]\,dt \tag{6}$$

The value of x is obtained by solving both (5) and (6) which are used to calculate E_{DSM} as x dependent. Then, substituting the value of "x" at the $f(t)$, P_{new} can be calculated. These steps are repeated for each DSM_{ratio}. After that, the amount of E_{DSM} is added to the end of the current curve and the new normalized load duration curve has been created. The new curves are sketched in Fig. 5. The calculated P_{new} for each percentage of DSM_{ratio} can be seen in Fig. 5.

III. RESULTS OF ANALYSES

In this section, different effects of peak point shaving of load duration curve are explained. The main results of DCs' participation in DSM have been discussed in Subsection A. The cost saving calculations, which is occurred by deferring the establishment of new power plants, are described in Subsection B. The CO_2 reduction happened as a result of avoiding energy generation as much as the amount of prevented power losses and the economic impact of it have been clarified in Subsection C. The results of global DCs participation in DSM for all around the world have been demonstrated in Subsection D.

A. THE RESULTS OF DCs' PARTICIPATION IN DSM

The information about how the load and loss factors change depends on each DSM_{ratio}, the amount of reduction in peak point of the load curve and power losses can be interpreted from Table 2. In order to reveal the effects of different percentages of DSM_{ratio}, the calculations have been made for each ratio between 10% to 70% and without DSM. The corresponding results are shown in Table 2. The minimum and maximum total annual hours of DCs' participation in DSM range between 12 to 93 hours and the corresponding energy amount range between 796 MWh to 43,161 MWh. The peak point of load curve for 2019 was 43,948 MW and could be reduced to 43,821 MW or 42,990 MW using the minimum and maximum DSM_{ratio}. The peak point of load duration curve could be decreased between the amount of 127 MW to 958 MW which correspond to a minimum of 0.28 percent and a maximum of 2.18 percent reduction in the peak load of Turkey. This reduction has improved Turkey's load and loss factors even the total consumed energy has not changed. When the peak point of load curve is

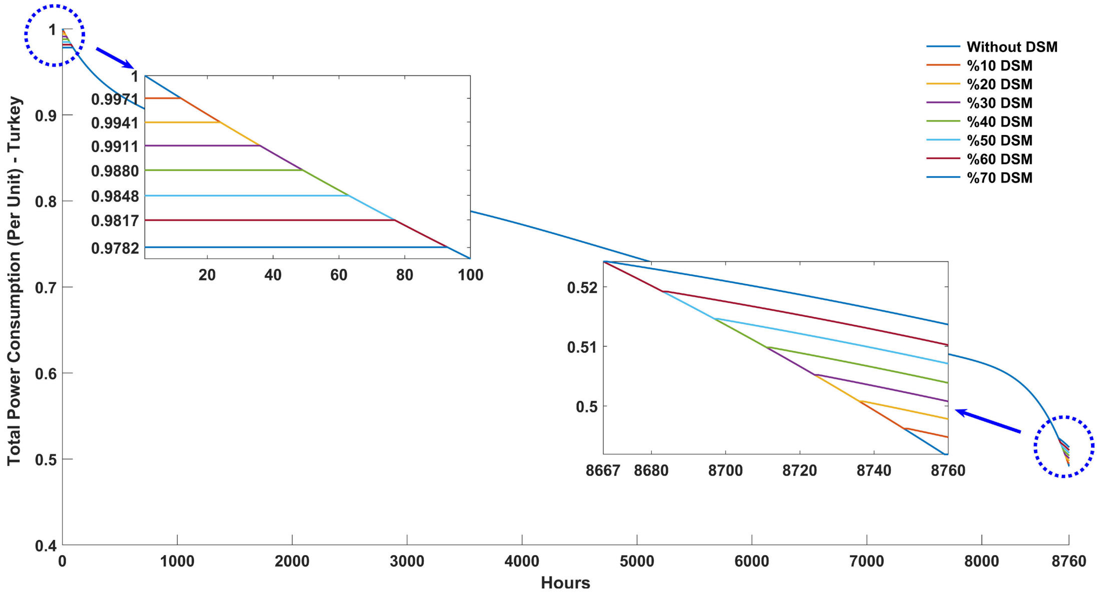


FIGURE 5. The normalized load duration curves of Turkey after peak shaving for different percentages of DSM_{ratio}.

reduced from 43,948 MW to 42,990 MW, the load factor of Turkey could be improved from 0.7544 to 0.7712 with a 2.2% increase and the loss factor could be improved from 0.5834 to 0.6085 with an increment of 4.3%. This means that the improvement in the loss factor is almost two times greater than as much as the improvement in the load factor for the same DSM_{ratio}. As explained in the previous section, these results also show that the load curve smoothing affects the load and loss factors in different amounts. Loss factor improvement causes a reduction in power losses of the transmission systems. The information of power losses rate for 2019 had not been published yet while this study was being prepared. Thus, the average rate of power losses between 2006 to 2017 in Turkey, which is 2.34% of total consumed energy [58], is used to calculate the power losses for 2019. The total amount of losses calculated as 6.79 TWh and the corresponding loss factor was 0.5834. Depending on the loss factor improvement, the minimum and maximum amount of power loss reduction are calculated as 37 GWh and 280 GWh which equal to 0.54% and 4.13% reduction, respectively. The corresponding savings, which are calculated using the conversion rate of $87,000 per GWh [59], vary between $3.2 million to $24.3 million as seen in Table 2. Additionally, improving the loss factor causes to increase in the carrying capacity of transmission lines and prevents the construction of new transmission lines.

B. COST SAVING CALCULATIONS CONSIDERING DEFERRED NEW POWER PLANTS

In addition to cost saving from the reduction of the losses in the transmission systems which are caused by DCs' participation in DSM, a much larger amount of the savings can occur due to the reduction in peak point of Turkey load duration curve.

Reducing the peak point means that deferring the new power plants which Turkey aims to build in order to meet growing energy demand and peak point in each year.

TABLE 2. The results of DCs' Participation in DSM.

DSM_{ratio}	Total Hours of DCs' Participation in a Year (h)	DCs' Participation Amount (MWh)	Peak Point of Load Curve (MW)	Reduction in Peak Point (MW)	Load Factor	Loss Factor	Reduction in Power Transmission Loss (GWh)	Savings from Loss Reduction
Without DSM	-	-	43,948	-	0.7544	0.5834	-	-
10%	12	796	43,821	127	0.7566	0.5866	37	$3.2 million
20%	24	3,182	43,687	261	0.7589	0.5900	76	$6.6 million
30%	36	7,160	43,557	391	0.7612	0.5935	116	$10.1 million
40%	49	12,995	43,421	527	0.7636	0.5970	155	$13.5 million
50%	63	20,885	43,278	670	0.7661	0.6008	197	$17.1 million
60%	77	30,631	43,141	807	0.7685	0.6044	236	$20.5 million
70%	93	43,161	42,990	958	0.7712	0.6085	280	$24.3 million

TABLE 3. Distribution of Turkey installed power by energy resources.

Energy Resources	Installed Power Capacity (MW) 2018	Installed Power Capacity (MW) 2019	Difference 2018-2019 (MW)
Natural Gas	25,909	26,186	277
Coal	19,742	20,284	542
Hydro	28,293	28,505	212
Renewables	14,005	15,773	1,768
Fuel Oil	493	312	-
Total	88,442	91,060	2,799

According to [60], the installed power capacity of Turkey was 88,442 MW in 2018 and it was 91,060 MW in 2019 [61]. So, new power plants with a size of 2,799 MW was put into service in 2019. The distribution of new power plants by energy resource is shown in Table 3 [58], [60], [61]. Natural gas includes LNG, the energy resource of coal consists of hard coal, imported coal, lignite, and asphaltite. Renewables comprise geothermal, wind, solar, biomass. The liquid fuel, naphtha, and oil are involved under the Fuel Oil category.

According to Table 2, if the DCs had participated in DSM for 2019, new power plants would not have required the amount of installed power between 127 MW to 958 MW which are equal to the amount of decreased peak points of Turkey. Thus, Turkey could have deferred the installed power plants put into service in 2019 by 4.5% at the minimum and 34.3% at the maximum. Therefore, Turkey could gain huge monetary savings. The capital and operations and maintenance (O&M) cost of power plants are calculated according to [62] and shown in Table 4.

TABLE 4. Unit values of capital and O&M costs by power plant resources.

Power Plant Resources	Capital Cost	O&M Cost
Coal	3,676 \$/kW	40.58 \$/kW-year
Natural Gas	1,810 \$/kW	35.16 \$/kW-year
Hydro	5,316 \$/kW	29.86\$/kW-year

Total cost calculations of avoided new power plants are given in Table 5.

New coal based power plants with the size of 542 MW have been put into service in 2019 as shown in Table 3. Because the coal based power plants produce more pollution than others, in this paper, building new coal power plants is preferred to be deferred first, then the natural gas and hydropower plants are preferred. Thus, the avoidable power plants with the size of 127 MW are chosen to be coal for 10% of DSM_{ratio}. Turkey could have obtained \$472 million due to avoid building coal based installed power plants for the minimum DSM_{ratio}. With the maximum DSM_{ratio}, Turkey could have avoided building 542 MW of coal, 277 MW of natural gas, and 139 MW of Hydro based installed power plants as shown in Table 5. Hereby, \$3.276 billion could have been saved.

TABLE 5. Cost calculation of deferred new power plants.

DSM_{ratio}	Power Plant Resources	Deferred Installed Power (MW)	Capital Cost	O&M Cost	Total Cost
10%	Coal	127	\$467 million	\$5 million	\$472 million
70%	Coal	542	\$2 billion	\$22 million	\$3.276 billion
	Natural Gas	277	\$501 million	\$10 million	
	Hydro	139	\$739 million	\$4 million	

C. THE EFFECTS OF DCs' PARTICIPATION IN DSM ON CO_2 EMISSIONS

The rapid development of technology in the 21st Century provides many benefits that will make people's life easier. At the same time, it causes irreversible damage to nature in many ways. Currently, one of the most crucial issues for humanity is global warming which is caused by raised greenhouse gas emissions due to the increasing consumption of fossil fuels and the destruction of forests. Among the greenhouse gases, carbon dioxide (CO_2) has the biggest responsibility with a 72% ratio of the greenhouse effect. Methane (CH_4) follows it with a 19% ratio after that nitrous oxide (N_2O) and fluorinated gases (F-gases) share the responsibility by 6% and 3%, respectively [63].

DCs' participation in DSM can contribute to preventing CO_2 emissions thanks to reducing the power losses in transmission systems. According to conversion rates in [64], [65], coal based power plants produce 908 tCO_2 per GWh, natural gas power plants emit 400 tCO_2 per GWh and hydro power plants produce 21 tCO_2 per GWh. If the energy between 37 GWh to 280 GWh, which correspond to power loss reduction at the minimum and maximum rate as seen in Table 2, had not generated, the CO_2 emission could have decreased as between 33,596 tCO_2 to 254,240 tCO_2. Coal based power plants have been used for the calculation due to their more polluting characteristic than other power plants Since the negative effects of carbon emissions on health, water, food production, and environment, economic loss has been also occurred. According to [66], per ton of CO_2 can cause an economic loss of up to \$100. Hereby, DCs' participation in DSM could have additionally made a profit for Turkey between \$3.3 million to \$25.4 million in 2019 by reducing the CO_2 emission.

D. GLOBAL EFFECTS OF DCs' PARTICIPATION IN DSM

It can be inferred from the above results that DCs in all around the world can provide more gains if they can participate in DSM globally in terms of their flexible and huge

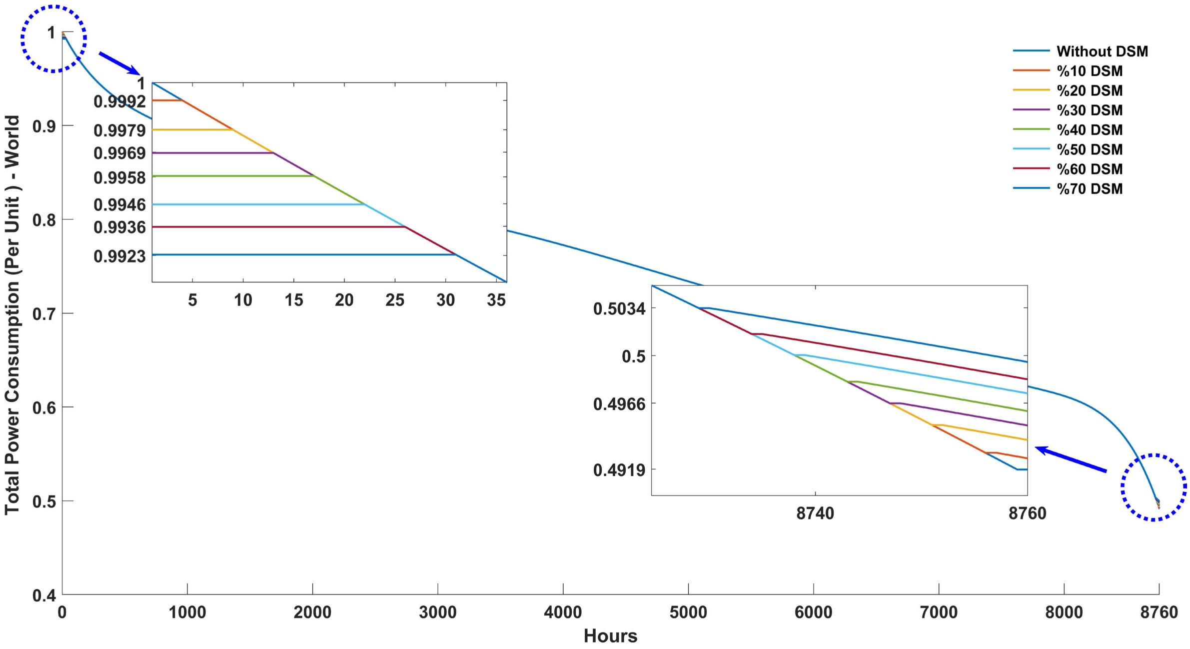


FIGURE 6. The normalized load duration curves of the world after peak shaving for different percentages of DSM_{ratio}.

power consumption which was 198 TWh in 2018 [14]. As a result of DCs' participation in DSM at certain times for peak shaving/shifting, there may not need to build new power plants, especially for countries that have large populations and mainly generates electricity from coal. Therefore, both monetary and environmental gains could have reached a significant amount.

Since global power consumption and generation data for 2019 has not been published yet, in this section, all calculations and analysis for environmental and economic effects of global DCs' participation in DSM have been carried out for the year 2018. Additionally, the world load duration curve has been assumed to be the same as Turkey's profile, which is shown in Fig. 3, because there is no hourly power consumption data for all the world. The only known value is the total energy consumption of the world that was 26,615 TWh in 2018 [67]. To reveal the effects of global DCs' participation in DSM, similar steps and methods in Section II are used. The peak point of the world load duration curve has been shaved/shifted as much as the energy in different participation ratios that vary 10% to 70% of DCs' hourly power consumption. The amount of energy involved in DSM, E_{DSM}, is shifted to the end of the curve for each DSM_{ratio}, thereby new normalized load duration curves of the world have been created as shown in Fig. 6. The calculated new peak points of load curves for each percentage of DSM_{ratio} can be seen in Fig. 6.

In order to calculate required real values such as DCs' participation amount, the amount of decreased peak point, etc., the total energy amount (E_{pu}) has been calculated in per unit by integral of the load duration curve without DSM in Fig. 6. Then, (7) has been used to calculate the base value.

$$E_{real} = E_{pu} {}^{*} E_{base} \tag{7}$$

E_{pu} represents the calculated energy amount in per unit which is 6,609PU and E_{real} is the real energy consumption of the world which is 26,615 TWh [67]. According to the (7), the base value (E_{base}) is calculated as 4,027 GWh. All other requirement values are calculated using the base value. Similar to Section II, the main purpose is to decrease the peak point of the world duration curve by peak shaving. Thus, (4), (5), and (6) are used to calculate a new peak point after peak shaving likewise in Section II. Accordingly, DCs_{Pow} is calculated as 22.6 GW. The results of peak shaving for each DSM_{ratio} are summarized in Table 6. The peak point of the world power consumption is calculated as 4,027 GW for 2018. This amount could be reduced to 4,024 GW, which equals a decrease of 0.08%, if the DCs in all around the world were participating in DSM with 10 percent of its hourly power consumption. The maximum reduction in peak point, which is 30.8 GW and equals a decrease of 0.77%, could be obtained with 70 percent of DSM_{ratio}.

Decreasing peak point leads to an improvement in load and loss factors. Based on the World Bank data [68], the world average electric power transmission and distribution (T&D) losses between 2010 to 2014 is 8.23% of the world's total electricity generation. According to The Regulatory Assistance Project (RAP) report [69], the rate of T&D losses varies from 6% to 11%. Additionally, the National Association of Clean Air Agencies (NACAA) report [70] says that transmission line losses range between 2% to 5%. Since T&D losses include non-technical and transformers losses, we focus on only transmission losses related to loss factor for calculating worldwide power loss reduction that happened due to peak shaving. Consequently, the amount of worldwide transmission losses for the year 2018 have been considered as 3% of worldwide energy generation. So, the

TABLE 6. The results of global DCs' participation in DSM.

DSM_{ratio}	Total Hours of DCs' Participation in a Year (h)	DCs' Participation Amount (GWh)	Peak Point of Load Curve (GW)	Reduction in Peak Point (GW)	Load Factor	Loss Factor	Reduction in Power Transmission Loss (GWh)
Without DSM	-	0	4,027	0	0.7544	0.5834	-
10%	4	9.1	4,024	3.2	0.7550	0.5843	1,230
20%	9	40.7	4,019	8.4	0.7560	0.5858	3,271
30%	13	88.2	4,015	12.6	0.7568	0.5870	4,897
40%	17	153.7	4,010	16.7	0.7576	0.5882	6,516
50%	22	248.6	4,005	21.8	0.7585	0.5895	8,262
60%	26	352.6	4,001	25.8	0.7593	0.5907	9,867
70%	31	490.5	3,996	30.8	0.7603	0.5922	11,865

worldwide transmission losses are calculated as 798.45 TWh that corresponds to the loss factor value of 0.5834. After peak shaving for each DSM_{ratio}, minimum and maximum amounts of loss reduction have been calculated as 1,230 GWh and 11,865 GWh which are corresponded to the loss factors of 0.5843 and 0.5922 respectively. This means that worldwide energy generation could be reduced between 1,230 GWh to 11,865 GWh via global DCs' Participation in DSM for 2018. These amounts are equal to 0.15% and 1.5% of worldwide transmission losses of 2018. Thus, the global CO_2 emission could be reduced between 1.2 Mt of CO_2 to 10.78 Mt of CO_2 and it is caused to monetary savings between \$120 million to \$1.078 billion due to negative effects of CO_2 on nature. These calculations are determined based on the conversion rates explained in Section III-C. The maximum avoidable CO_2 amount is equal to the CO_2 emission of Senegal [71], which is also equal to 0.03 percent of the world total CO_2 emission (37,887Mt) for 2018.

The peak point reduction could have also led to deferring build new power plants. In order to decide which type of power plants could be deferred, the amount of world total installed power capacity [72] by resource between 2017 to 2018 is shown in Table 7. The Renewables category includes geothermal, wind, solar, biomass, nuclear, and battery. As can be seen in Table 6, if the DCs all around the world had participated in DSM in 2018, new power plants would not have required in the amount of installed power between 3.2 GW to 30.8 GW corresponding to the minimum and maximum DSM_{ratio}. These amounts are equal to 1.3 percent and 12.5 percent of the total global capacity of installed power plants launched in 2018. In other words, 1.3% to 12.5% of global installed power plants could be deferred if the DCs participated in DSM globally. When the power plants to be built are allocated to energy resources, coal, and natural gas based power plants primally preferred to be deferred in terms of their more polluting nature than others.

Considering the values in Table 7, the amount of deferring coal power plants is determined as 3.2 GW for 10% DSM_{ratio} while it is determined as 8 GW for 70% DSM_{ratio}. The rest amount (22.8 GW) is decided to be as natural gas based power plants for 70% DSM_{ratio}. Therefore, huge monetary savings and environmental benefits could be obtained.

The avoided cost has been calculated using capital and O&M costs of power plants defined in Table 4 [62], and the results are shown in Table 8.

As a result, if the DCs all around the world had participated in DSM for the year 2018, the minimum monetary saving could have been \$11.95 billion for minimum DSM_{ratio} and \$72.8 billion with 70% DSM_{ratio} in maximum by deferring the establishment of new power plants and preventing the harmful effects of CO_2 emission.

TABLE 7. Distribution of world installed power by energy resources.

Energy Resources	Installed Power Capacity (GW) 2017	Installed Power Capacity (GW) 2018	The Capacity of Installed Power Plants Established in 2018 (GW)
Natural Gas	1,693	1,745	52
Coal	2,071	2,079	8
Hydro	1,269	1,290	21
Renewables	1,488	1,654	166
Oil	450	450	0
Total	6,971	7,218	247

TABLE 8. Cost calculation of deferred new power plants for all the world.

DSM_{ratio}	Power Plant Resources	Deferred Installed Power (GW)	Capital Cost	O&M Cost	Total Cost
10%	Coal	3.2	\$11.7 billion	\$129.8 million	\$11.83 billion
70%	Coal	8	\$29.4 billion	\$324.6 million	\$71.72 billion
	Natural Gas	22.8	\$41.2 billion	\$801.6 million	

IV. CONCLUSION

In this paper, the reasons and the significance of using DCs as participants of DSM in classical electrical systems have been clarified. At first, the needs for DCs and effects of COVID-19 Pandemic on it have been described. Additionally, it is explained why DCs can be used as a prosumer. Then, the consequences of DCs' participation in DSM for Turkey have been examined with the actual data and corresponding benefits are analyzed. The effects of DCs' participation in DSM on load and loss factor, power losses in the transmission systems, avoided cost of new power plants planned to be established, and reduction in CO_2 emissions of Turkey have been examined. Furthermore, all these analyses have been carried out for global DCs' participation in DSM for all around the world as well.

This study exemplifies that the values of load and loss factors for two different load curves might not be the same even if they have the same energy consumption. This enables us to reduce losses and increase monetary savings just by using peak point shaving method without changing overall energy consumption. It is clearly shown that the ratio of DCs' participation in DSM affects the loss factor more than the load factor. Seventy percent of DSM_{ratio} improves the loss factor two times greater than the improvement ratio of the load factor. These advancements lead to a reduction in power losses in transmission systems, an increase in the carrying capacity of transmission lines, the prevention of constructing new transmission lines, and new power plants.

The most obvious findings to emerge from this study are as follows:

- DCs' participation in DSM could cause the peak point of Turkey to decrease by between 0.28% to 2.18%.
- DCs' participation in DSM could cause a 2.2% improvement in the load factor and 4.3% improvement in the loss factor.
- DCs' participation in DSM could cause power transmission loss to decrease by between 0.54% to 4.13% which could provide to save between \$3.2 million and \$24.3 million.
- DCs' participation in DSM could cause 4.5% to 34.3% of the installed power plants put into service in 2019 to defer. Thus, the cost of new power plants between \$472 million to \$3.276 billion could be avoided.
- DCs' participation in DSM might have provided to reduce 254,240 tCO_2 emissions of Turkey for maximum DSM_{ratio}. Corresponding cost saving could be \$25.4 million in terms of the harmful effects of CO_2 on nature.
- The results of global DCs' participation in DSM for all around the world have been examined using similar steps and analyses carried out for Turkey.
- Global DCs' participation in DSM for all around the world could cause the peak point of the world to decrease by between 0.08% to 0.77%.
- Global DCs' participation in DSM for all around the world could cause worldwide power transmission loss to decrease by between 0.15% to 1.5%.
- Global DCs' participation in DSM for all around the world 1.3% to 12.5% of the installed power plants put into service in 2018 to defer. The monetary saving of \$11.83 billion could be obtained due to the deferring establishment of new power plants for 10% of DSM_{ratio}, while it could be \$71.72 billion for 70% of DSM_{ratio}.
- The global CO_2 emission could be reduced by 1.2 Mt of CO_2 emission for minimum global DCs' participation ratio (10%). The maximum amount could be 10.78 Mt of CO_2 which is equal to the total carbon emission amount of Senegal and 0.03% of the worldwide emission in 2018. Due to the harmful effects of CO_2 on nature, it would provide financial gains between \$120 million to \$1.078 billion.

As a result, it is clearly shown that DCs are significant players in terms of power systems operations by compensating demand fluctuations and power curve smoothing. Besides the mentioned benefits, DCs' participation in DSM has great potential to provide financial gains. This study encourages similar studies by drawing attention to the importance of DCs in terms of power systems by examining the participation of DCs in DSM with a holistic view and highlighting its contribution to power systems. The future work is planned to examine the effects and contribution of *small data centers' participation in local DSM* for both themselves and distribution systems from a win-win perspective.

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