

# Investigation of Residential Demand Response Flexibility Including the Effects of the COVID-19 Pandemic on Energy Usage Habits in Turkey

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**Abstract**—The COVID-19 pandemic has made a major impact on society and several sectors, including changes in household energy usage. The pandemic brings together changes and negative impacts that should be followed closely for the energy sector. The main purpose of this study is to comprehensively investigate the effects of the COVID-19 pandemic on electrical energy usage habits in Turkey through systematic methods that are adopted in different countries like the US, India, Europe, China, Canada, and Japan. Based on the analysis, residential load management flexibilities are investigated considering the pandemic impacts. The effect of the COVID-19 pandemic on electricity consumption in the energy sector in Turkey is extensively investigated for the first time. The study is of importance also for future pandemics or other conditions such as extreme wind and snow storms that temporarily lead to living and working from home.

**Keywords**— COVID-19, demand-side management, home energy management, residential energy use, time use survey.

## I. INTRODUCTION

Many global pandemics have occurred globally, and people have been harmed differently by this process. COVID-19, which still exists and is highly vital in the world for more than 2 years, seriously affects the economy and social life. The COVID-19 outbreak and the measures taken to reduce the number of cases also bring together significant changes in many sectors including the energy industry. The main changes occurring in the energy sector during the pandemic period can be listed as follows:

- The amount of energy that power plants based on fossil fuels or renewable energy sources can find buyers due to changes in energy demand and market clearing prices,
- The new version of the total consumption, peak demand, and daily demand profile due to the changes in the energy usage behaviors of home (residential) users due to remote working and closure measures,
- The times when flexible loads (washing machine, dishwasher, air conditioner, tumble dryer, water heater, refrigerator, and freezer) that have the potential to be used in demand management applications of home users are used, and the new management flexibilities.

It is significant to comprehensively evaluate the potential effects of the COVID-19 pandemic period in terms of electricity and energy use, specific to countries. Since the

pandemic process and its results are not predictable, it is important that these evaluations and analyzes have repeatable and comparable features. As a result of the COVID-19 restrictions, people have to work from their home a few days a year without going to their offices and continue their education from home. However, people may work from home or in general spend more time at home due to some other reasons such as extreme weather events or emerging technologies like a metaverse. Examples of these situations are heavy wind and snow storms. For this reason, it is vital to estimate and manage the changes in flexible demand in residential users, which is a result of working from home, minimizing possible operational challenges in the wholesale energy markets.

In the US, according to 2020 sectoral statistics, demand response programs saved more than 1.5 million MWh of energy, reduced peaks by 10 GW, reached 11 million customers (96% of whom are residential), and provided around \$1 billion in incentives [1]. The highest amount of energy savings was achieved by residential participators (1,186 million MWh). The increase in the time spent at home and the changes in device usage habits with the pandemic need to be assessed. In addition to the increase in consumption in the results of working from home, it is expected that many factors such as widespread internet banking, online grocery shopping and other virtual store shopping, new electronic appliances bought into the house as more time is spent at home, emerging technologies such as metaverse, and the energy demand of these appliances will cause changes in energy consumption habits. Using metrics provided by the Oxford COVID-19 Government Response Tracker, periods of restriction were found to be associated with overall load reduction (including commercial and industrial consumers) [2]. Despite the decrease in overall energy demand, spatial and temporal differences are observed. In addition, energy sector stakeholders state that increasing electricity demand uncertainty is putting greater pressure on system operators and energy market stakeholders [3]. In Turkey, there is no comprehensive study on the change in electricity consumption in residences with the effects of the pandemic and related practices. The effects of the pandemic on load demand can be examined by monitoring and analyzing electricity consumption habits comparatively in homes. In this way, solutions can be developed to minimize the negative effects of the pandemic period on the energy sector in Turkey.

Section 2 presents the related studies in the literature and identifies a number of gaps that will be addressed with this study. Section 3 provides the methodology, while section 4 presents survey results. Section 4 models daily residential demand and demand response changes and section 5 conclude the paper with a discussion of the findings.

## II. STATE OF ART

It has been determined that the impact of the uncertainties from the pandemic on most of the national energy sectors intensifies and then weakens as the pandemic is controlled [4]. For example, a study in Ireland found that energy use in homes increases by up to 30% during lockdowns between 9:00 am and 5:00 pm, as residents often spend daylight hours at home during lockdown [5]. In a similar study conducted in Canada, it was determined that at the beginning of the quarantine, electricity use increased by 46% in the middle of the day which means between 9:00 am to 5:00 pm [6]. Another study which is done in Canada demonstrates that the average daily household power consumption in 2020 increased by about 12% compared to 2019, about 13% due to rising temperatures and the rest mainly from lighting and appliances [7].

Residential electricity demand in Australia was increased by 14% during the lockdown in March 2020 compared to pre-lockdown. [8]. In a study done in Vietnam compared the effect of the COVID-19 lockdown on spatiotemporal electricity throughout different classes in the United States considering three datasets. At the end of the study, the authors suggested that the impact of COVID-19 was mitigated since changes in residential and non-residential loads were of comparable magnitude however went in opposing directions [9]. A study analyzes the South Korean situation in lockdown, stating that energy consumption in residential facilities increased during COVID-19 [10]. Another similar study was conducted in Warsaw with data collected from smart meters from 7000 houses finding that the energy consumption of residential users increased during the COVID-19 period, on the other hand, the amount of peak demand (the highest power demand during the day) did not change much, but it has been found to spread over a wider period of time [11]. A similar study was conducted with data from 390 residences in New York, revealing that the demand between 12.00 and 17.00 on weekdays was increased between 35% and 53%. They concluded that the projected increase in peak demand with stay-at-home guidelines could pose network management challenges, especially for residential feeders. The authors also noted that utilities will need to rethink load profile considerations if there is a longer transition to working from home. Since increased hourly peak demand could challenge grid management [12]. In another study conducted in New York, the relationship between pandemic effects with energy consumption was examined using an internet-based survey. A study was conducted with 632 participants. The survey resulted in an increase in electricity usage during the weekdays [13].

On the other hand, when the data received by the energy producers are evaluated, extensive research conducted in countries such as the UK and Sweden, energy transfers between these countries have also been investigated. Moreover, it has been revealed that there is an overall increase in both imports and exports. In addition, coal-based countries such as Poland, Czechia, and Germany have been highlighted to increase their net incoming energy at a high

rate [2]. In another study conducted in Germany, it was revealed that the average proportion of net energy generation from Renewable Energy Sources surpassed 55% in the first half of 2020, up from 47% in the same time in 2019 [14]. Sectoral data was also analyzed in Denmark. The effects of COVID-19 on the production capacities of renewable energy sources have been observed. [15] corroborates that, the stringency index, economic help offered to prevent the pandemic, and daily verified COVID-19 death, each have a negative impact on renewable electricity production in Denmark. In addition to the previous studies, in a study examining changes in consumption and production in the USA, Italy, Australia, India, and other countries. As a result, most of the county home load demand increases significantly while industrial load demand decreases significantly [16].

There is no systematic study in Turkey on the change in energy use in residences as a result of the pandemic and related practices. This study has a number of original contributions to the literature:

- The impact of the COVID-19 pandemic on electricity consumption in the energy sector in Turkey will be extensively investigated for the first time.
- Reliable methods that are individually adopted in the literature, used in the US, Canada, Japan, China, Denmark, the Netherlands, and some other European countries, will be applied together to develop a systematic and comprehensive impact analysis method by analyzing together the results of the survey applied to the houses and time-series residential load profiles with demand response flexibilities.

As a result, with these aspects, this study will make significant original contributions to the literature and relevant stakeholder institutions in a unique field (the effects of the pandemic on the demand management potential) that studies abroad have not yet addressed in detail.

## III. METHODOLOGY

In this section, the Time Use Survey, demand-side management approaches, and residential demand profile generation methodologies are explained under specific subsections.

### A. Time Use Survey

The Time Use Survey has been preferred as a reliable method for modeling consumption behaviors in over 90 studies and publications in many countries such as diverse European countries, Japan, and Canada, with resolutions such as under 1 hour, 30 minutes, and even 15 minutes [17]. Electricity consumption behaviors and the changes in these behaviors due to the pandemic reveal regional differences in studies conducted in many countries [10]. For this reason, it is crucial to conduct the survey in many cities and contribute to the determination of regional differences. The behavior of the occupants plays a major role in the timing and magnitude of energy demand. In this content, the Time Use Survey represents a promising solution to data and modeling problems [17]. In addition to this, in similar surveys conducted for the pandemic, additional questions about the energy consumption habits based on the number of days working from home, pre-pandemic, lockdown periods, and periods when restrictions are loosened are used [13].

TABLE I. A SAMPLE VIEW OF PART OF THE TIME USAGE SURVEY

Household Appliances		12:30 AM	1:00 AM	1:30 AM	2:00 AM	2:30 AM
1	Washing Machine					
2	Dish Washer					
3	Tumble Dryer					
4	Refrigerator					

In this study, online survey tools and the Time Use Survey method were applied. It is aimed to conclude the electricity consumption behaviors of the users in the determined cities of the seven regions in Turkey. The results can also be expressed regionally. In this way, the pandemic effect of the energy usage habits of home users in Turkey will be observed. The Time Use Survey method was used to assess changes in the energy demand of home users with COVID-19 (Table 1). In this way, the changes in energy demand during the time people spend at home can be detected. Also, electricity usage habits in Turkey during the pandemic period were analyzed in detail.

### B. Demand Side Management

The changes in electricity usage habits due to the pandemic also affect the demand-side management (DSM) flexibility of users. It is important to examine in detail the changes in working times and frequencies of devices like washing machines, dishwashers, air conditioners, tumble dryers, refrigerators, deep freezers, and water heaters.

Demand management means changing the electricity consumption of users, directly or indirectly, in a way that helps the operation of the network with various methods, strategies, and practices [19]. Demand management approaches can be classified according to two main features: strategy and method. There are six demand management approaches in terms of strategy. These are strategically reducing demand at all times, strategically increasing demand at all times, clipping peak demand, shifting demand from one-time slot to another, filling times of low demand, and demand flexibly following the desired reference profile [20]. The applied methods are divided into two main categories as direct and indirect demand management.

Flexible loads that can be used for demand management applications in homes. Their classification in terms of control method such as thermostat-controlled, program-based, and controlled manually. While early or delayed start (heating/cooling for thermostat-controlled loads) and temporary stop methods can be applied for many loads, temperature setting change can only be applied to thermostat-controlled loads, and program setting change can only be applied to program based loads. On the other hand, lighting devices have the option to change the brightness value specific to them and to manage them as a group. Washers and dryers have the flexibility to be run for 3 to 6 hours, dishwashers for 3 to 8 hours, and refrigerators and freezers for 15 to 30 minutes in terms of early or delayed starting [21]. In terms of temporarily stopping a working appliance, washing and dishwashers can be managed for 15 minutes, dryers for 30 minutes, and refrigerators and freezers for around 15 minutes. In this study, demand management flexibilities that can be utilized will be analyzed by considering DSM approaches together with Turkey's energy usage habits that have changed with the pandemic period. By

using these data, detailed models specific to the closure periods and the periods when the measures are relaxed during the pandemic process of home users and manageable loads can be developed. The time-varying share of flexible loads in the total load and the flexibility that can be utilized with appropriate management methods will be analyzed.

### C. Residential Demand Profile Generator

In this study, different energy usage scenarios for home users were developed with the Residential Demand Profile Generator of Loughborough University, which is widely accepted in the literature and is intended to be used for an exemplary house. Also, it helps better analysis of the supply and demand of energy [22]. The Residential Demand Profile Generator is an actively used scientific model referenced in more than a thousand studies. This model can provide valuable insights into how routine activities related to energy consumption. CREST model is a profiling methodology that combines qualitative research on household behavior and routines with statistical energy demand analysis and modeling. It is based on a time-geographic diary technique that was used to accomplish daily activities and their links to energy usage [23]. CREST is useful to analyze daily activity profiles that describe households who spend their time with doing specific tasks like washing their clothes, washing dishes and cooking, etc. It's a realistic model prepared with real data from 33 household appliances. The basic component of the model is the appliance. In here, "appliance" refers to the specific electrical needs of the home, such as a TV, washing machine, or vacuum cleaner. Real usage data of 33 household appliances are used. It was prepared with real data from the electricity meters of the household items in the UK. Using CREST in this study is consequential since it allows for modeling the scenario before and after the pandemic. Thanks to the CREST, potential loads can be analyzed hourly, daily, and weekly.

## IV. RESIDENTIAL PANDEMIC IMPACT SURVEY

The survey applied to residential users in Turkey consists of three parts. The first part covers the pre-pandemic period, the second part covers the effects of the pandemic period, and the last part covers the pricing and potential determination questions. The survey mainly focused on four flexible home appliances: washing machine, tumble dryer, dishwasher, and air conditioner, respectively. Moreover, there are questions to understand the changes in the general electricity consumption of the participant. It is aimed to determine the usage behaviors of home users by dividing 24 hours into 30-minute intervals. Time of use survey is conducted with over 290 participants included in the analysis. The survey was conducted through the online platform and it was obligatory to answer all questions. Participants could not leave any questions blank which allowed consistency between answers.

The surveys that are filled out without care are eliminated. For example, when the participant stated that there was no tumble dryer at home, however answered the questions about the consumption of the tumble dryer in the survey, this person's answers were deemed invalid and the remaining cluster is considered in the analysis.

### A. Pre-Pandemic Period

The first part of the survey includes pre-pandemic questions. In this part, it is aimed that specify what times of the day people use flexible loads (washing machine,

dishwasher, air conditioner, tumble dryer) in the pre-pandemic period.

It is asked the participant to fill in at what times of the day they usually use the home appliances given by the time of use survey method, in 30-minute periods. The same question was asked in the second part covering the pandemic period. Since, it is aimed to see what time of day the loads shift, increase or decrease compared to the pre-pandemic period. After recording the 24-hour consumption in 30-minute periods, if participants compare the pre-pandemic and the pandemic period, participants were asked if they think that the frequency of use of electrical appliances in their homes has changed, especially during the "periods of staying at home". It was determined during the pre-pandemic period in Turkey at which hours their consumption was dense and at what hours they did not use it. From the results of the survey, it was concluded that the household appliance with the highest consumption increase was the dishwasher from the answers obtained. The biggest reason why the dishwasher is used more in lockdown than in the pre-pandemic period is interpreted as the increase in the time spent at home and the fact that people spend more in the kitchen. People usually had both meals at school or work before the pandemic. Therefore, the demand for using a dishwasher at home is less. However, during the pandemic, people cook and eat more than two meals a day, especially when full lockdown restrictions are implemented, thus the demand for dishwashers has increased.

### B. During the Pandemic Period

In the second part of the survey, it is the goal that determines whether the energy consumption habits of the participants have changed or remained stable compared to the pre-pandemic period. In Fig. 1, 79% of the participants from different cities in Turkey stated that there was an increase in their consumption, and a minority of participants (2%) indicated that consumption decreased, 14% did not change, and finally 5% were not sure.

More than half of the participants stated that there has been a change in their energy consumption habits and demands. Then, the participants were asked a direct question about the increase in demand. 88% of participants stated that electricity usage increased especially during full lockdown periods (Fig. 2).

For more consistent results, after examining the change in energy demand of the participants, they were asked how this situation reflected on their electricity bills. 76% of the participants stated that there was an increase, 8% stated that there was no increase, and 16% were not sure.

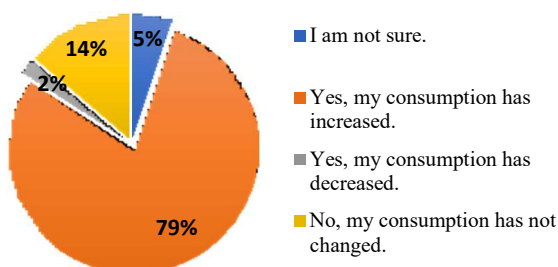


Fig. 1. Comparison of energy consumption in the pandemic period and pre-pandemic period by participants from Turkey

The pandemic has made it possible to examine the increased or decreased consumption of residential users with the electricity bill with a completely visible result. In order to base the increase in the demand of the participants and to determine how the effect of pandemic effect on the home users, the participants were asked whether changes were made to the electrical appliances. For example, participants who needed a smaller refrigerator before the pandemic saw that their refrigerators could not meet their needs during the pandemic, and they went to buy a new refrigerator. In addition to this, there are different scenarios such as switching non-technological personal care items to electronic ones like toothbrushes.

### C. Pricing and Determining Potential

In the final part of the survey, the participants were asked whether they think electricity pricing is essential or not. In this regard, the importance of DSM according to the home users was detected. Latterly, they were asked whether their consumption behaviors would take form in accordance with the time period in which it was better or not if the pricing is improved to a level they have demanded. While 81.2% of the participants gave importance to the pricing from their energy usage habits, 18.8% stated that it was insignificant. In response to the question of whether they would change their daily electricity usage habits for consumption when electricity is more convenient than electricity pricing, 76% of the participants answered "Yes" and 24% answered "No".

At the end of the study, it was verified how early or late the participants could operate their washing machines, dishwashers, and tumble dryer which are among flexible loads, according to electricity pricing (Fig. 3). The options offered are 6 hours early, 3 hours early, 1 hour early, 1 hour later, and 3 hours later. The last part of the survey showed that how much delayed or earlier home users in Turkey can start their use of household appliances.

## V. MODELING THE IMPACT OF THE PANDEMIC ON HOME USERS

The data of real household items were produced using the CREST model. 1 week (7 days) of electrical energy consumption data of a house are obtained both before pandemic data and during the pandemic data with using the CREST model.

The analysis showed that flexible loads have a significant rate in weekly demand. In the blue area indicated in Figure 4, it is seen that flexible loads have a 31% ratio on the first day a week. How flexible loads affect one-day home demand data is also shown in Fig. 7. The effect of flexible loads on total demand in a day varies on different days. Therefore, by using DSM approaches flexible loads can be managed according to demand during the pandemic according to TimeUse Survey's results. In this way, the importance of flexible loads is emphasized by making a sample home study.

Evaluating DSM applications with a pandemic scenario is a critical stand for the management of loads. As a result of the survey, the consumption of the users before and after the pandemic was evaluated. Consumptions recorded at 30-minute intervals were evaluated both pre-pandemic and during the pandemic, based on the washing machine, dishwasher, and tumble dryer.

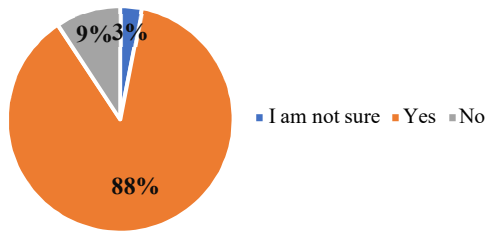


Fig. 2. Evaluation of energy consumption during staying at home decided by the participants from Turkey in terms of increase or decrease

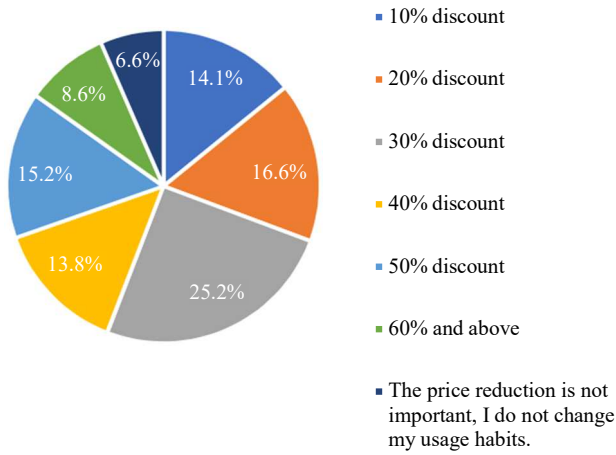


Fig. 3. Money saving preferences of home users in Turkey

Fig. 5 is an overview of the 30-minute consumption status of the washing machine before and during the pandemic. As emphasized in the reference studies, the use of washing machines by Turkey residential users has shifted from morning hours to afternoon hours during the pandemic period. Fig. 6 compares the results obtained from the analysis of the CREST model which means pre-pandemic days and survey results which means during the pandemic day for dishwashers. It is apparent that while the consumption of the dishwasher is in the evening before the pandemic, it is used in the middle of the day during the pandemic period.

The results indicate that residential users in Turkey used their home appliances in the middle of the day instead of during evening hours. This analysis is important since if this increase in load demand is not managed properly, it will be a result that will force the grid and the producers to future working from home events.

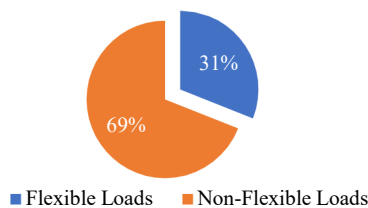


Fig. 4. Percentage of flexible loads in daily residential energy consumption

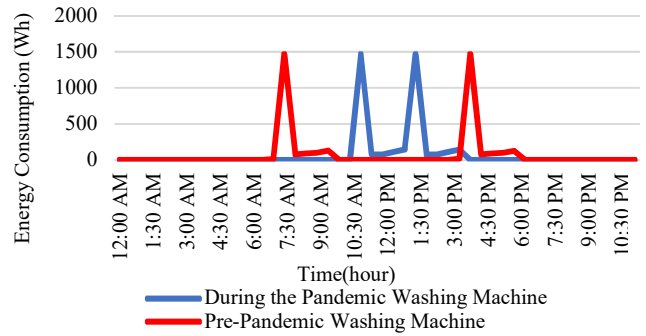


Fig. 5. Comparison of pre-pandemic and during the pandemic period of washing machine consumption

Together these results and Fig. 7 provide strong insights into a strong relationship between working from home and load shifting that has been reported in the literature. In addition, it can be observed at which hours the household items are more active or out of use. All in all, according to the time of use survey answer, most of the people (79,1%) change their energy usage habits in lockdown, especially for their washing machine, dishwasher, and tumble dryer. Fig. 8 signifies how much of the daily demand includes flexible loads at a specific time both during the pandemic and pre-pandemic. According to the data model from studies and survey results, people have changed in the frequency and time of consumption in their manageable loads with the increase in the time they spend at home.

## VI. CONCLUSION

This study clarified various aspects of the changes in electricity demand in Turkey during the pandemic. A significant increase in the energy demand of home users in Turkey and mighty shifts in operation time of flexible loads to midday hours like scenarios in reference countries were observed. Additionally, according to survey result home users needed new technological devices or made changes to existing devices during pandemic. The time use survey contains two limitations. First and foremost, the answers depend on the statement, for this reason, the questions are detailed and conflicting answers are eliminated. Secondly, the survey results are not enough to make a definitive assessment.

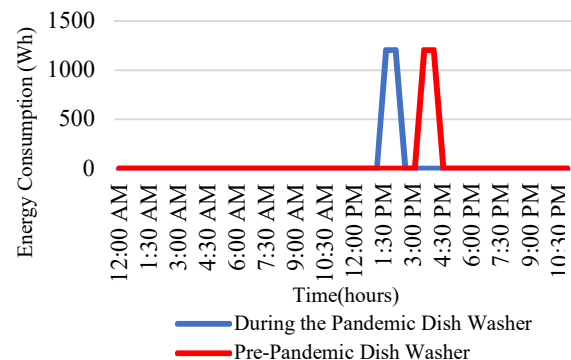


Fig. 6. Comparison of pre-pandemic and during the pandemic period of dishwasher consumption

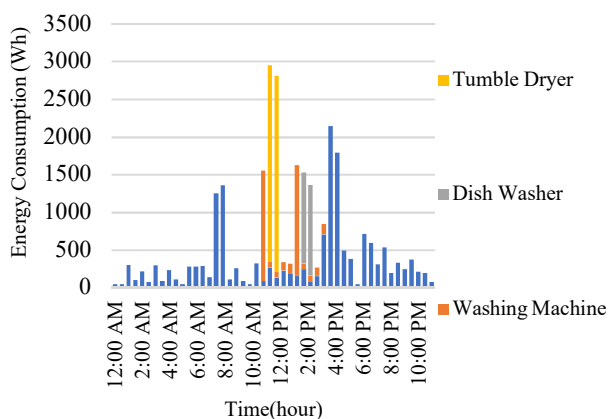


Fig. 7. Effect of the pandemic on manageable loads in a day

Future work is to be compared the energy production and consumption data with the pre-pandemic period using smart meters and smart plugs in order to get the more reliable findings. In the targeted future study, consumption hours and quantities of flexible loads will be evaluated with smart sockets while real usage data will be obtained with smart meter data. Future study should further develop and confirm these initial findings by taking into account both consumption and production data to compare the pre-pandemic and the pandemic period. It is critical to assess the power providers' side in order to ensure reliability. In addition, it is also important in determining government policies in the field of import and export. For this reason, a comparison of production and consumption data with pandemic data and demand-side management including pandemic impacts in distributed generation and local storage scenarios from renewable energy was determined as a future work of this study.

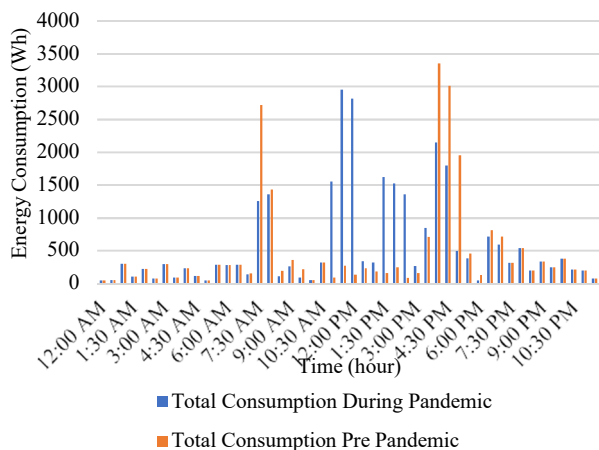


Fig. 8. Comparison of flexible load both during the pandemic and pre-pandemic period

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