Impacts of COVID-19 pandemic on electrical energy storage technologies

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Abstract
In this study, the effect of the COVID-19 pandemic on electrical energy storage technologies was investigated. The results of the crises and opportunities created by this unpredictable epidemic in the future processes were evaluated according to energy and especially electrical energy storage areas. Home quarantines used to reduce the spread of the epidemic significantly increased the electrical energy needs of home users. In addition, great changes have occurred in public transportation habits during the COVID-19 pandemic, and it has been observed that approximately 20% of individuals may prefer electric micromobility devices working with lithium batteries due to the risk of infection in closed areas such as public buses or metros. Although the demand for main energy sources has decreased significantly during the COVID-19 pandemic, it is important that the percentage of energy produced from renewable energy sources increases by about 1%. With the increasing use of renewable energy sources and the increasing importance of the concept of sustainability in all areas of our lives, energy storage systems compatible with renewable energy technologies will become more and more important. At the beginning of these technologies, hydroelectric energy storage systems with closed-loop pumps are preferred for large-scale applications.

KEYWORDS
COVID-19, energy storage, lithium-ion battery, micromobility, pumped hydro

1 | INTRODUCTION

First detected in 2019 in Wuhan, Hubei Province, China, the SARS-CoV-2 virus causes respiratory infections called COVID-19 disease, which can even be fatal to humanity.¹ This disease has turned into an epidemic that has caused unprecedented effects in the world since the day it was first seen and humankind is working to minimizing the effect of the COVID-19 pandemic on daily life.² The emergence of an epidemic with such wide effects and the rapid change of our habits in about 1 year proves that we do not have a safe and sustainable living space as we thought.³ The fact that if we do not recycle the effects of climate change caused by global warmings, such as the COVID-19 epidemic, these effects can affect our lives faster than expected is now widely accepted by people. As a result, it has emerged as an important fact that fossil fuels, one of the main causes of global warming, are rapidly replaced with clean energy technologies, which are sustainable energy sources.⁴ It is predicted that after the COVID-19 outbreak, the effects of the concept of sustainability on our lives will gain significant momentum.⁵ The basis of this concept of sustainability is energy resources and renewable energy systems are the main framework of sustainability according to energy sources. However, in order...
to use solar energy and other discontinuous energy sources effectively, large-scale energy storage systems that do not disturb the electricity balance in the grid are required. Therefore, solutions are needed to transform energy storage technologies such as redox flux or sodium-ion battery technologies into a more efficient and cost-effective electrical energy storage option. To minimize the effect of instant changes in energy demand, energy storage technologies with low unit energy storage costs are needed. Energy storage technologies with low unit energy storage costs are required to minimize the impact of sudden changes in energy demand according to time.

The demand for large-scale energy storage technologies will increase significantly in the next COVID-19 period, and investments in this area will improve to meet those requirements. As an outcome, it is predicted that the use of long-term and large-capacity energy storage technologies such as thermal energy or hydrogen-based energy storage will increase. In future, the popularity of energy storage technologies that can balance the seasonally changing supply and demand of electrical energy will increase. Studies and investments in energy storage technology that will work in tandem with renewable energy technologies to ensure grid electricity continuity and react rapidly to demand changes are expected to raise momentum.

There are important events such as the COVID-19 pandemic that affect humanity’s energy demand globally. Figure 1 shows the influence of events that have become important in the last century on energy demand. As seen in the figure, the COVID-19 outbreak was seen as the event that had the most significant negative impact on energy demand after World War 2. In addition, as seen in the graph, energy demand is rapidly increasing after worldwide catastrophic events. Energy demands in various industries have been expected to rise sharply in the following of the COVID-19 pandemic, as they did in the following of the Spanish flu and other catastrophic events.

There are many studies to analyze the impact of an unexpected large-scale event such as the COVID-19 pandemic on energy demand. According to the international energy agency, energy demand is predicted to decrease by 3.8% globally in the first quarter of 2020 due to the effects of the COVID-19 pandemic in general. Furthermore, it is expected that in the future, demand for only renewable energy resources will increase, while demand for other energy resources will decrease. Figure 2 shows the change in energy resource demand during the first quarter of 2020 when the effect of the COVID-19 epidemic was at its high.

The demand for fossil-based energy resources has decreased significantly, while the demand for renewable energy resources, which is an intermittent energy source, is rising, as seen in the related graph. Although renewable energy sources have significant advantages in areas such as carbon emission, they need energy storage systems with large capacities due to the significant relationship between air exchange and their efficiency. The changes in energy demand significantly affect energy storage technologies because the type and usage area of the energy produced, as well as energy storage technologies, should be taken into consideration as a whole.

Epidemics with global and long-term effects, such as COVID-19, have significant effects in a variety of fields, including energy. The effects of the COVID-19 pandemic
on the energy sector, particularly on energy storage, are investigated in this paper. Energy storage technologies, which may become more important following the COVID-19 pandemic, were examined including its reasons. The abbreviations and acronyms used in this article are defined in Table 1.

## 2 | ENERGY STORAGE TECHNOLOGIES

Energy storage technologies can generally be defined as a reliable bridge that is constructed between the supply and demand sides of energy systems. Energy storage technologies are also one of the major elements for the security of energy systems. These technologies provide quality energy to the end-user by ensuring the continuity of the supply. They cover a broad spectrum of resources, technologies, rates, and purposes. The chemical, electrical, kinetic, potential, and thermal forms can all be used to store energy. Electrical and thermal energy storage systems are the two most common types. Electrical energy management encompasses all technologies and processes with an electrical interface to the outside world and it is important in the continuity of energy production processes. The percentage of global total operational energy storage technology is given in Figure 3 for 2020. As seen in the figure, two energy storage technologies stand out according to their usage areas. The first one is pumped hydroelectric energy storage (PHES) for stationary applications and the second one is lithium-ion battery (LIB) for mobile applications.

The dominance of PHES in stationary energy storage applications seems obvious and the LIB is the most preferred technology in nonstationary applications, such as electric vehicles, cell phones. In terms of electrochemical energy storage technologies, the usage rate of LIB technologies is around 90%. These rates will change in favor of these two leading storage technologies during and after the COVID-19 outbreak according to changes in usage habits. In this study, basic energy storage systems are explained by giving brief information about them.

### 2.1 | Pumped hydroelectric energy storage

The working principle of PHES basically is related to the transformation of potential energy and kinetic energy. The gravitational force is used in the PHES technology. In case of need, the water in the high reservoir is directed to the low areas by gravity, and thus, electrical energy is obtained by driving turbines when needed. In the energy storage process, this process is reversed. The water in the lower reservoir is transported to the upper part and stored as potential energy at the upper region.

The illustration of the PHES system is given in Figure 4. In PHES technology, the low complexity of working and maintenance price is the main reason for low operation cost.

With the latest technological developments in this field, PHES facilities have been made more sensitive to the demands of the power network and they can respond more quickly according to energy demand change. In addition, it is also allowed to have variable speed control while running in closed-loop structures. Closed-loop pumping structures can be operated without the need for a continuously flowing water source, and thus much more mobility can be provided for the localization of energy storage systems.
2.2  |  Compressed-air energy storage

Compressed-air energy storage (CAES) is a technology that uses air pressure to store energy. The air is pumped into an underground space and which is usually a salt cave, at times when electricity is cheap due to low energy demand.\(^{17}\) When electrical energy is needed, the stored air is directed back to the facility and heated there and the expanded air as it is heated is released to drive the gas-powered turbine generator. The most used fuel for this heating mechanism is natural gas, which emits carbon. On the other hand, CAES can be triple the electricity generation of natural gas-only plants. The energy efficiency of up to 70% can be achieved if the heat from the air pressure can be covered with this energy storage system and otherwise, the energy storage efficiency of these systems varies between 40% and 55%.\(^{18}\)

2.3  |  Lithium-ion battery

Today, LIB is the most common nonstationary energy storage choice, accounting for nearly 90% of the global grid battery storage industry. LIB has a high energy density and are lighter than other battery alternatives. It is frequently preferred in mobile applications and electric vehicles due to these advantages and decreasing production costs day by day.\(^{19}\) The ability of LIB to deliver high
currents to the system continuously has moved them to the forefront of the race for energy storage systems in electric vehicles. One of the important parameters when defining LIB characteristics is the C-rate and this parameter is the measurement of the charge and discharge current with respect to its nominal capacity. Most portable batteries are rated at 1C and there are R&D studies ongoing to increase the C-rate in electric vehicles to 4 or higher. LIB is becoming more competitive for long-term storage thanks to new technologies including the replacement of graphite with silicon for improving the battery’s power capacity. With the upward movements in the electric vehicle market, it is predicted that LIBs will be the dominant technology in portable technologies for many years. The main elements of LIBs are given in Figure 5.

The following are descriptions of the LIB elements.

- **Positive current collector**: The negative current collector receives electrons from the external circuit discharging the capacitor.
- **Negative current collector**: The positive current collector receives electrons from the external circuit charging the capacitor.
- **Cathode**: When the battery is charging, it stores lithium and emits lithium ions.
- **Anode**: As the battery is discharging, it stores lithium and emits lithium ions.
- **Separator**: Lithium ions are allowed to freely migrate from the anode to the cathode and vice versa. It also prevents electrical flow inside the battery system.
- **Electrolyte**: The liquid or gel which functions as a lithium-ion carrier.

### 2.4 | Lead-acid battery

Lead-acid is one of the first and most common batteries are utilized in energy storage technologies. Although, they are not preferable for grid energy storage due to their poor energy density and, low usage cycle and limited lifetimes. In the initial process, it was preferred for electric cars due to their costs. But lately, it has been largely replaced by LIB with longer life and high energy density. Despite these disadvantages, it is an important alternative for stationary systems due to its low cost. In addition, having significant experience in production and logistics is among the positive features of lead-acid batteries.

### 2.5 | Flow battery

Flow battery can be seen as a LIB competitor. However, it appears as a poor alternative due to its disadvantages such as low energy density. Due to that, they may find very little place in the market and they can find a place in applications that require long energy storage periods and have long life cycles. Because of these properties, they are suitable for applications that require continuous energy.

### 2.6 | Hydrogen fuel cell

Hydrogen fuel cell (HFC), which can produce electrical energy by combining hydrogen and oxygen, have several important features. First of all, they are reliable and silent...
as they have no moving parts. It has a very low carbon footprint and high energy density. They do not cause carbon emissions and pure hydrogens work and water is obtained as a by-product at the end of the process.25 As a result, fuel cell plants may generate hydrogen while energy is cheap and then use it to produce energy while the cost of energy is high. Often, the place where hydrogen is needed and where it is used is different. Reforming biogas, ethanol, or hydrocarbons into hydrogen is also a less expensive and carbon-emitting method. However, HFC is used in critical applications such as credit card center, primary and backup energy storage.26 A schematic illustration of a HFC is given in Figure 6.

2.7 | Supercapacitor

Supercapacitor (SC) is used for energy storage, they can store much more electrical charge compared to electrolytic capacitors and conventional capacitors. SC store energy in the same way as a traditional capacitor does, but they are better suited for fast energy release and storage. SC store electrical energy using two mechanisms: double-layer capacitance and pseudocapacitance, rather than a traditional dielectric. The double-layer capacitors or ultracapacitors are terms used in the literature to describe them. SC is an important and promising energy storage technology intermediate between batteries and conventional capacitors. SC has an important advantage over LIBs in terms of the life cycle.27 LIBs have a life cycle of 500 to 10 000 cycles on average, whereas SCs have a life cycle of 100 000 to 1 million cycles on average. SC technology is developing faster than both of these technologies and its potential is quite high. SC are the technology of choice for backup power, cold start, flash cameras, regenerative braking, and hybrid electric vehicles due to their high-power density and successful low-temperature performance. The future growth of SC technology is largely dependent on advances that will result in energy density, cycle life and most importantly, lower production cost. Despite these advantages, SCs also have significant disadvantages. When compared to other popular energy storage technologies such as LIBs, the rate of self-discharge is higher. It is not a suitable technology for long-term energy storage. They can lose 10% to 20% of their charge daily for this high self-discharge rate. The comparison between LIB and SC is given in Table 2.

### Table 2 Performance compare between SC and LIB28

| Function                     | Supercapacitor | Lithium-ion battery |
|------------------------------|----------------|---------------------|
| Charge time                  | 1–10 s         | 10-60 min           |
| Cycle time                   | 1 million or 30.000 h | 500 and higher |
| Cell voltage                 | 2.3-2.75 V     | 3.6-3.7 V           |
| Specific energy (Wh/kg)      | 5 (typical)    | 100-200             |
| Specific power (W/kg)        | Up to 10 000   | 1000-3000           |
| Cost per Wh                  | $20            | $0.5-$1.00          |
| Service life (in vehicle)    | 10-15 years    | 5-10 years          |
| Charge temperature           | –40°C to 65°C  | 0°C to 45°C         |
| Discharge temperature        | –40°C to 65°C  | –20°C to 60°C       |

Abbreviation: LIB, lithium-ion battery; SC, supercapacitor.
technologies with different features according to different end-user energy demands. Different energy storage technologies according to the area of usage, discharge time, and capacities are given in Figure 7.

Although the parameters of energy storage technologies such as discharge time, capacity, and usage areas are important. Another key parameter in the selection process is the cost of energy storage per kW. The cost comparison of commonly used energy storage technologies is given in Figure 8. As shown in the figure, the PHES has the cheapest cost for storage. It has also, very large storage capacity and discharge time. With these important features, it is an expected result that PHES will come to the forefront in stationary energy storage systems.

There are many other factors in choosing energy storage technologies. As energy generation technologies develop day by day, storage technologies are developing in every aspect with each passing day. Important parameters such as the response time and efficiency of the energy storage system to be established affect the selection process significantly. The most common and large-scale energy storage technologies are given with their characteristic parameters in Table 3.

Parameters such as efficiency, lifetime, max power rating, which are characteristic, come to the fore in the PHES. With this information, it is a 90% expected result that PHES is used worldwide in stationary applications. Efficiency is another important term for EES system and the ratio of energy efficiency to the PHES system is about 80%. The response time of PHES is in the order of seconds and it becomes quicker day by day with technological improvements. But one of the main cons about the PHES is high investments costs. Depending on the increase in the network structure and the use of alternative energy sources, it is anticipated that the use of the PHES system and the innovative studies in this field will increase. Since our electricity network consists of many different types of loads and energy sources, each
innovative solution is important to improve the energy quality of the end-user. The representation of the electrical grid with energy storage systems is given in Figure 9.\textsuperscript{33}

### 3 | COVID-19 PANDEMIC AND ENERGY DEMAND

The COVID-19 pandemic has had an undesirable and enormous impact on many industries. The impact on the energy field has become enormous. The total energy demand for electrical energy was determined to be 10\% lower in April 2020 compared to the same period of the previous year.\textsuperscript{34} As we all know, the change ratio of energy demand is a good indicator of a country’s economic growth rate. The impact of the COVID-19 pandemic on electric energy demand was become maximize in April 2020 and electric energy demand in Italy has dropped by about 30\% and during the same time period, global energy demand fell by nearly 20\%.\textsuperscript{35}

One of the rare positive effects of the COVID-19 pandemic has been on the environment, with a 29\% reduction in the rate of fossil fuels in electricity generation due to reduced energy demand. With this change, the carbon emission rate decreased by about 20\%, while the rate of renewable energy-based electric energy production has been increased by 46\% in 2020. It is predicted that this paradigm change processes in energy production processes will be permanent. Due to the increasing

| Energy storage technology | Max power rating (MW) | Discharge time | Max cycles or lifetime | Energy density (Wh/L) | Efficiency |
|--------------------------|----------------------|---------------|-----------------------|-----------------------|------------|
| PHES                     | 3000                 | 4-16 h        | 30-60 years           | 0.2-2                 | 70\%-85\% |
| CAES                     | 1000                 | 2-30 h        | 20-40 years           | 2-6                   | 40\%-70\% |
| Molten salt (thermal)    | 150                  | h             | 30 years              | 70-210                | 80\%-90\% |
| LAB                      | 100                  | 1 min-8 h     | 6-40 years            | 50-80                 | 80\%-90\% |
| FB                       | 100                  | hours         | 12 000-14 000         | 20-70                 | 60\%-85\% |
| HFC                      | 100                  | min-wk        | 5-30 years            | 600 (at 200 bar)      | 25\%-45\% |
| Flywheel                 | 20                   | s-min         | 20 000-100 000        | 20-80                 | 70\%-95\% |

Abbreviations: CAES, compressed air energy storage; FB, flow battery; HFC, hydrogen fuel cell; LAB, lead-acid battery; LIB, lithium-ion battery; PHES, pumped hydroelectric energy storage.
importance of the concept of sustainability and becoming more prominent.36

4 | COVID-19 PANDEMIC AND MICROMOBILITY

The COVID-19 pandemic affected the industries and energy consumption as well as the transportation habits of the people globally.5 Since the risk of transmission of the COVID-19 is high in closed areas and public transportation is one of the most used closed areas in daily life, people moved to different alternatives for transportation in the pandemic process.37 In April, when the epidemic's impacts were at their peak, the use of public transportation in 2020 decreased by nearly 60%, and this decrease converged to 25% in the following period.38 The increase in the rate of working remotely is effective in this decrease, as well as the people's orientation to alternative ways from public transportation. One of these alternatives is micromobility devices since they are safe in terms of epidemics. In a study conducted in major cities around the world, it was determined that 20% of individuals prefer micromobility devices because they are safe for the COVID-19 pandemic, as seen in Table 4.

Electric micromobility devices are the most preferred micromobility devices in COVID-19. These devices are electric scooters, mopeds, bicycles, and mini electric vehicles. Large volumes of these devices are often preferred due to the increasing demand for cargo in the city, due to their mobility.39 Such micromobility tools are powered by LIB, and this will move LIBs, which are by far leaders in the field of electrochemical energy storage technologies, to a stronger position.40,41 Micromobility electric vehicles have energy storage capacity with LIB up to 20 kWh. The most preferred electric micromobility devices in transportation processes are given in Figure 10.

Even after the COVID-19 outbreak, transportation habits will not change for a long time and there will be searches for alternatives to public transportation. With the rising demand for electric micromobility devices and electric vehicles, LIBs are predicted to dominate the market for many years among stationary energy storage technologies.

5 | COVID-19 PANDEMIC AND ELECTRIC ENERGY STORAGE

One of the most critical matters in the epidemic has been how to revitalize the energy sectors. Although it is said that the effects of the pandemic on energy production processes will be difficult in the short term, it can be said that the increase in demand in renewable energy systems indicates a positive change. After the epidemic, renewable energy's share of electricity generation is expected to grow even faster. The renewable energy system will be the fastest-growing source of electricity generation until 2050, according to the IEA report, and will be in the third position in energy production by 2030 and COVID-19 pandemic will accelerate this rise.9 These changes in energy generation systems also have an effect on electrical energy storage technologies. LIBs have an important opportunity in terms of their use in renewable energy systems. However, it is predicted that it will be difficult in the short term to find the intensity of use of LIB technologies in mobile applications in large-scale and grid-related applications since the manufacturing costs are still not reaching the desired points. It is predicted that one of the biggest and important factors in the field of electrical energy storage technologies will be electric vehicles and related technologies. According to various countries' goals, the annual production of electric vehicles will hit 1500 GWh in 2030.43 Despite the large-scale economic crisis triggered by the COVID-19 pandemic, this aim has not changed; rather, it has become a stronger motivator, and work in this field has accelerated within the framework of sustainability. China produces 70% of the world’s batteries, and even though the COVID-19 outbreak slows down demand, it continues to recover quickly today. The demand for LIB technology is expected to increase from $36.7 billion in 2019 to $129.3 billion in 2027.44 Even though LIB technologies seem to be the electrical energy storage system of the future in terms of mobile applications, it can be said that it has a rather fragile structure due to this imbalance in manufacturing processes and China's dominance in terms of both production and demand. As a result, large-

| City        | Micromobility preference due to Covid-19 pandemic |
|-------------|-------------------------------------------------|
| Paris       | 16.40%                                          |
| Athens      | 28.10%                                          |
| Saint Petersburg | 13.80%                                |
| Barcelona  | 21.30%                                          |
| Madrid      | 17.70%                                          |
| Ankara      | 30.65%                                          |
| London      | 19.60%                                          |
| Los Angeles | 19.10%                                          |
| New York City | 21.40%                              |
| Average     | 21%                                             |
scale studies in the fields of SCs and HFCs have been conducted in various countries. As a result of the COVID-19 outbreak, it is possible to say that even if the production processes of electric vehicles slow down temporarily, they will recover in the short term. The demand on LIBs forecasting according to BloombergNEF is given in Figure 11. This figure gives an estimation of the possible change rates until 2030, considering the changes in LIB usage in today’s industries.

The demand for LIBs will increase from 223 to 1752 GWh/y, in other words, it will increase approximately 10 times for 2030. In this increase, electric two-wheeled vehicles, which are an important element of the electric micromobility system, are significantly effective. The demand for electric two-wheeler vehicle is estimated as increasing about 245% percent until 2030 and much more of this increase rate will be observed in passenger EVs and the rate of increase will be 1300% within 10 years in EVs according to LIBs. Although this rapid growth in the electric vehicle sector is promising in terms of sustainability and carbon emission, it is predicted that the production industry, which has slowed down as a result of COVID-19, will have short-term difficulties in terms of both raw materials and logistics to meet the demand for LIBs of the specified size.

Global energy storage investments, which have slowed down due to the impact of COVID-19, are expected to gain momentum again in the coming periods with innovative technology solutions. The sector of energy storage is projected to grow by 31% in 2030 and reach 741 GWh.\textsuperscript{46} Even if this rate causes a decrease of 17% in 2020 due to COVID-19 pandemic, this high rate of increase will enable the emergence of new energy storage technologies and increase the efficiency of existing solutions. Bloomberg NEF projects that the battery storage market could grow to $620 billion by the year 2040. In the field of electrochemical energy storage technologies, especially with the driving force of electric micromobility devices and electric vehicles, LIB technologies are predicted to come to the fore for a long time in the area.
of nonstationary applications. Due to the nature of the energy produced by renewable energy systems, which is discontinuous and difficult to predict, it requires energy storage technologies with high capacity and fast response time. PHES technology in large capacities comes to the fore as an energy storage technology suitable for these systems during the COVID-19 pandemic, leading to a rise in the share of renewable energy sources in demand. The market share of PHES systems, which is the dominant electrical energy storage technology in the global market among energy storage technologies in fixed applications, will increase even more. It is anticipated that PHES systems, which are defined as a closed loop, do not require a continuously flowing water source and have significant advantages such as adjustable turbine speed, will increase their market share after the COVID-19 pandemic.

Another prominent EES technology is LIBs systems, which are at the core of electric micromobility vehicles, which are preferred by approximately 20% of major city residents due to the risk of the COVID-19 pandemic. Furthermore, it is projected that LIBs technologies will continue at the core of EES systems for vehicle industries for a long period of time, as the importance of the concept of sustainability is understood by a large number of people and the electric vehicle concept gains momentum day by day.

CONFLICT OF INTEREST
The author declares that there is no conflict of interest.

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