Comparison of Power Storage Technologies in the Island of Crete, Greece: Batteries, Pumped-Hydro Storage and Hydrogen-Based Systems

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doi.org/10.51505/ijaemr.2026.11218 URL: http://dx.doi.org/10.51505/ijaemr.2026.11218

Received: Mar 10, 2026 Accepted: Mar 17, 2026 Online Published: Apr 01, 2026

Abstract

The integration of renewable energy sources into power systems requires the deployment of electricity storage technologies that enhance grid stability and reliability. Pumped-hydro storage (PHS), electric batteries, and hydrogen-based (H_2) storage systems have been investigated for potential application in the island of Crete, Greece, which possesses abundant solar and wind energy resources. Power storage technologies can be classified according to the type of energy conversion involved, including mechanical, chemical, electrochemical, electrical, and thermal storage. Pumped-hydro storage and battery technologies are already widely deployed in utility-scale applications worldwide, whereas hydrogen-based storage systems have not yet reached full technological maturity or cost competitiveness. Each power storage method is characterized by specific technical and economic parameters, including capital cost, response time, lifespan, safety, flexibility, scalability, modularity, storage duration, operational scale, and environmental impact. The advantages and limitations of these technologies with regard to their potential deployment in Crete have been analyzed. Among the available power storage technologies, batteries and pumped-hydro storage can currently be implemented in Crete, whereas hydrogen-based storage systems have not yet been fully commercialized. The results of the present study highlight the characteristics, advantages, and drawbacks of different energy storage technologies that are expected to play an important role in Crete's energy transition by facilitating the integration of intermittent solar and wind energy into the local power grid.

Keywords: batteries, Crete-Greece, hydrogen, power storage, pumped-hydro, technology

1. Introduction

Achieving net-zero carbon emissions in the coming decades requires the gradual substitution of fossil fuels with renewable energy sources. The integration of intermittent renewable energy into electricity grids necessitates the deployment of large-scale energy storage systems [Large scale electricity storage, 2023], [Fact Sheet, Energy Storage, 2019]. Several power storage technologies have been developed and are currently applied in various sectors [Elalfy et al., 2024].

These technologies are generally categorized as mechanical, electrical, chemical, thermal, and electrochemical storage systems. Historically, pumped-hydro storage systems have dominated large-scale electricity storage applications [Papadakis et al., 2023], [Blakers et al., 2021], [Kocaman et al., 2017], [IRENA, 2020]. However, recent technological advances in alternative storage solutions, particularly electric batteries, have significantly increased their use for electricity storage [Risin Ngoy et al., 2025], [Jiang et al., 2025], [Bielewski et al., 2022].

In addition, hydrogen production through water electrolysis, followed by storage and reconversion into electricity using fuel cells, has emerged as a potential electricity storage pathway within the context of the emerging hydrogen economy [Shiraishi et al., 2024], [Alasali et al., 2023], [Hydrogen production and storage, 2016]. Many remote islands worldwide operate isolated electricity systems that rely heavily on fossil fuels for power generation [Noro et al., 2021], [Papathanasiou et al., 2024].

Their transition toward sustainable energy systems requires the large-scale deployment of renewable energy sources to replace fossil fuels. However, because renewable sources such as solar and wind energy are inherently intermittent, their effective integration into island power systems requires the deployment of reliable energy storage technologies.

The aim of the present study is to compare three electricity storage technologies—electric batteries, pumped-hydro storage, and hydrogen-based storage systems—in the island of Crete, Greece.

This work addresses an existing research gap regarding the use of large-scale power storage systems in Crete by comparing three technologies that are either currently in use or expected to play an important role in future energy systems. The study contributes to the existing literature by providing a comparative assessment of storage technologies in the context of an island energy system. The findings may be useful for policymakers, public authorities, power generation companies, and other stakeholders involved in the energy sector.

2. Literature Survey

A report focusing on large-scale electricity storage in the United Kingdom has been published [Large scale electricity storage, 2023]. According to the report, by 2050 the UK's electricity demand could be largely met by wind and solar energy supported by large-scale energy storage systems. It also highlights hydrogen-based storage as one of the most promising technologies for long-duration energy storage. A report on energy storage focusing on the United States has also been published [Fact Sheet, Energy Storage, 2019]. The report states that pumped-hydro storage systems account for approximately 95% of utility-scale energy storage in the USA, with about 22 GW of PHS capacity integrated into the grid. It also indicates that by December 2017 approximately 708 MW of large-scale battery storage systems were operational in the US electricity grid. Energy storage systems, technologies, challenges, and future trends have been reviewed by Elalfy et al. [2024]. The authors emphasized that power storage systems enhance

Vol. 11, No. 02; 2026

ISSN: 2456-3676

grid stability, increase the penetration of renewable energy sources, and improve overall energy efficiency. They classified energy storage systems into electrical, chemical, thermal, mechanical, and electrochemical categories. PHS systems have been extensively reviewed [Papadakis et al., 2023]. The authors reported that these systems offer significant benefits for integrating renewable energy into electricity grids. However, they also emphasized the environmental and socioeconomic implications associated with their development. Blakers et al. [2021] reported that pumped-hydro storage accounts for approximately 96% of global electricity storage capacity and remains the most suitable option for large-scale energy storage. Most PHS installations are associated with hydropower plants located on river systems. Kocaman et al. [2017] investigated the integration of PHS systems within hybrid renewable energy systems. Their studies in India and the Himalayan region analyzed the combined use of solar power and open-loop PHS systems. They also reported that conventional hydropower stations can be converted into PHS facilities without modifying the upper reservoir. A report by IRENA [2020] states that pumped-hydro plants represent more than 10% of total hydropower capacity worldwide and approximately 94% of global installed energy storage capacity. The report emphasizes the role of PHS technology in facilitating the integration of solar and wind electricity into power systems. Lithium-ion batteries have been extensively studied in the context of the clean energy transition [Risin Ngoy et al., 2025]. These batteries are widely used in several sectors, including grid-scale energy storage. However, despite their advantages, they present certain limitations such as safety concerns, scarcity of critical raw materials, environmental impacts, and challenges related to end-of-life disposal. Jiang et al. [2025] examined battery technologies for grid-scale energy storage and emphasized that storage systems are essential for capturing surplus solar and wind electricity when supply exceeds demand. Batteries offer advantages compared with PHS systems, including greater location flexibility and rapid response times. Bielewski et al. [2022] reported that the European Union could potentially achieve self-sufficiency in battery production by 2030. However, shortages of raw materials and limitations in advanced materials production remain important challenges. Hydrogen's role in long-duration energy storage has been explored by Shiraishi et al. [2024], who emphasized its importance in providing reliable power over extended periods. The authors also recommended prioritizing domestically produced hydrogen in order to enhance energy independence. Numerous additional studies have examined hydrogen production technologies, hydrogen storage methods, hybrid renewable energy systems, and comparative analyses of energy storage technologies. Collectively, these studies highlight the growing importance of energy storage technologies for enabling renewable energy integration and ensuring the stability of modern electricity systems.

3. Use of Renewable Energy Sources and Power Storage

The transition toward clean energy systems is essential for addressing climate change and reducing dependence on fossil fuels. Renewable energy sources such as solar and wind power play a key role in this transition because they produce little or no greenhouse gas emissions. However, these energy sources are inherently intermittent and do not generate electricity continuously. Solar photovoltaic systems generate electricity only when sunlight is available, while wind turbines depend on favorable wind conditions. Consequently, efficient energy storage systems are required to ensure a stable and reliable electricity supply. Energy storage technologies enable excess electricity generated during periods of high renewable energy production to be stored and used later when production levels decline. Batteries, pumped-hydro storage systems, and emerging storage technologies such as hydrogen-based systems can help balance electricity supply and demand. By storing surplus energy, these systems reduce energy curtailment and improve the reliability of renewable energy generation. To date, utility-scale power storage systems have not been widely deployed in Crete. Nevertheless, energy storage systems can significantly enhance grid stability and resilience by mitigating fluctuations in electricity generation and reducing reliance on fossil-fuel-based backup power plants. As countries pursue the decarbonization of their energy systems, investment in both large-scale and distributed energy storage technologies is becoming increasingly important. Power storage therefore plays a crucial role in enabling a successful clean energy transition by ensuring reliability, efficiency, and sustainability in modern electricity systems.

The categorization of power storage technologies is presented in Table 1 while the distribution of various power storage technologies worldwide in Table 2.

Table 1. Categorization of power storage technologies

1	Thermal energy storage
2	Mechanical energy storage
3	Chemical energy storage
4	Electromagnetic/electrostatic energy storage
5	Electrochemical energy storage

Source: [Elalfi et al, 2024], [Malik et al, 2025]

Table 2. Installed capacity of various power storage technologies worldwide

Power storage technology	Power capacity (MW)	Share (%)
Pumped-hydro storage	181,700	98.378
Compressed air	1,622	0.878
Flywheel	973	0.527
Sodium Sulphur battery	316	0.171
Lead acid battery	35	0.019
Nickel cadmium battery	27	0.015
Lithium-ion battery	20	0.011
Flow battery	3	0.002

Source: [Malik et al, 2025]

4. Power Storage in Electric Batteries

Electric batteries have emerged as one of the most important technologies for high-capacity energy storage, enabling electricity to be stored and released when required. Their versatility,

Vol. 11, No. 02; 2026

ISSN: 2456-3676

rapid response time, and declining costs have made them a central component of modern power systems. Electric batteries store energy in chemical form and convert it into electrical energy through electrochemical reactions. Among the various battery technologies available, lithium-ion batteries are currently the most widely used for large-scale applications. These batteries are commonly deployed in grid-scale storage facilities, electric vehicles, and renewable energy systems. When excess electricity is generated, batteries store this energy through charging processes that involve chemical reactions within the battery cells. During periods of high electricity demand, the stored energy is discharged and supplied back to the grid, providing a reliable and controllable power source. One of the most significant advantages of battery storage systems is their extremely fast response time. Unlike conventional power plants, batteries can deliver electricity almost instantaneously, making them particularly suitable for frequency regulation, voltage control, and short-term grid balancing. This rapid responsiveness is especially valuable in power systems with a high share of renewable energy, where generation fluctuations may occur suddenly. Battery storage systems also offer significant flexibility and scalability. They can be installed at a wide range of capacities, from small residential systems to large grid-scale installations capable of storing hundreds of megawatt-hours of electricity. Furthermore, they can be deployed close to electricity generation or consumption sites, reducing transmission losses and alleviating congestion in power networks. Cost reductions have played an important role in the increasing deployment of battery storage systems. Over the past decade, advances in manufacturing technologies, improvements in materials, and economies of scale have significantly reduced the cost of lithium-ion batteries. As prices continue to decline, battery storage is becoming increasingly competitive with conventional storage technologies and fossil-fuel-based backup power plants. Despite these advantages, batteries also face several limitations when used for large-scale energy storage. One important constraint relates to storage duration. Batteries are generally well suited for short- to medium-term storage but are less effective for storing large quantities of energy over extended periods such as seasonal storage. In addition, battery performance gradually degrades over time, leading to a reduction in storage capacity and requiring eventual replacement. Environmental concerns also arise due to the extraction of critical raw materials such as lithium, cobalt, and nickel, which are often associated with environmentally intensive mining processes. Improper disposal of batteries may also lead to environmental pollution. Nevertheless, ongoing research into battery recycling technologies, alternative chemistries, and sustainable supply chains aims to mitigate these environmental impacts and improve the long-term sustainability of battery storage systems.

The characteristics of various power storage technologies are presented in Table 3.

Table 3. Characteristics of various power storage technologies

Technology	Categorization of technology	Maximum Power (MW)	Typical discharge time	Maximum cycles or lifetime	Energy density (Wh/lt)	Efficiency (%)
PHS	Mechanical	3,000	4h-16h	30-60 years	0.2-2	70-85
Compressed air	Mechanical	1,000	2h-30h	20-40 years	2-6	40-70
Molten salt	Thermal	150	Hours	30 years	70-210	80-90
Lithium-ion battery	Electrochemical	100	1min-8h	1,000-10,000 max. cycles	200-400	85-95
Lead-acid battery	Electrochemical	100	1min-8h	6-40 years	50-80	80-90
Hydrogen	Chemical	100	mins-week	5-30 years	600 (at 200 bar)	25-45
Flywheel	Mechanical	20	Secs-mins	20,000-100,000 max. cycles	20-80	70-95

Source: [Fact Sheet, Energy Storage, 2019]

5. Power Storage in Pumped-Hydro Systems

Among the various energy storage technologies currently available, pumped-hydro energy storage (PHS) systems represent the most mature, reliable, and widely deployed method for large-scale electricity storage. PHS operates based on a relatively simple but highly effective principle. During periods of low electricity demand or excess power generation, electricity is used to pump water from a lower reservoir to a higher reservoir, thereby storing energy in the form of gravitational potential energy. When electricity demand increases, the stored water is released back through turbines to generate electricity, in a process similar to conventional hydropower generation. This operating cycle can be repeated many times, making PHS systems highly durable and capable of providing long-term energy storage services. One of the main advantages of pumped-hydro storage is its high storage capacity and efficiency. Modern PHS plants typically achieve round-trip efficiencies ranging between 70% and 85%, allowing a substantial proportion of the stored energy to be recovered. In addition, PHS systems are capable of storing very large amounts of energy, often measured in gigawatt-hours, which significantly exceeds the capacity of most battery-based storage technologies. This characteristic makes them particularly suitable for grid-scale applications and for supporting national or regional electricity systems. Another important advantage of pumped-hydro storage is its contribution to grid stability and operational flexibility. These systems can respond relatively quickly to fluctuations in electricity demand and are able to provide important ancillary services such as frequency regulation, load balancing, and emergency backup power. This rapid response capability is particularly valuable in electricity systems with a high penetration of variable renewable energy

Vol. 11, No. 02; 2026

ISSN: 2456-3676

sources. Pumped-hydro systems also benefit from a long operational lifespan. Many existing facilities have been operating for several decades with relatively limited performance degradation. Compared with electrochemical storage technologies, which may require periodic replacement and involve complex recycling processes, PHS plants often provide lower long-term operating costs and reduced material requirements. Despite these advantages, PHS systems also face several limitations. A major constraint is their dependence on suitable geographical conditions. The construction of these systems requires appropriate terrain with significant elevation differences as well as sufficient water resources. Consequently, suitable sites for PHS development are limited. Furthermore, the initial capital investment required for the construction of pumped-hydro facilities can be substantial, particularly for projects involving large reservoirs, tunnels, and extensive civil engineering works. Environmental concerns may also arise due to potential impacts on local ecosystems, land use, and aquatic habitats. Nevertheless, recent technological developments are expanding the potential application of pumped-hydro storage. Innovations such as underground reservoirs, seawater-based PHS systems, and the utilization of abandoned mines as storage facilities are helping to reduce geographical and environmental constraints. These technological advances may allow PHS systems to be implemented in regions that were previously considered unsuitable.

The characteristics of pumped-hydro storage systems and lithium-ion batteries are presented in Table 4.

Table 4. Characteristics of pumped-hydro storage systems and lithium-ion batteries

Characteristic	Units	Pumped-hydro storage	Lithium-ion batteries
Energy density	kWh/m^3	0.5-1.33	94-500
Power density	kW/m^3	0.01-0.12	56.8-800
Efficiency	%	65-87	70-100
Life span	years	20-80	2-20
Lifetime cycles	cycles	10,000-60,000	250-10,000
Self-discharge rate	%/day	0	0.03-0.33
Response time	second – minutes - hours	min	m-second
Energy capital cost	$/kWh	1-291	200-4,000

Source: [Malik et al, 2025]

6. Power Storage in Hydrogen-Based Systems

Hydrogen has emerged as a promising energy storage medium capable of addressing the challenges associated with large-scale and long-duration energy storage. Its versatility, high energy content, and potential for zero-emission applications make hydrogen an important component of future sustainable energy systems. Hydrogen-based energy storage relies on the conversion of electrical energy into chemical energy. Through a process known as electrolysis, surplus electricity is used to split water into hydrogen and oxygen. The hydrogen produced can then be stored in various forms, including compressed gas, liquefied hydrogen, or chemically bound within other compounds. When electricity is required, the stored hydrogen can be reconverted into electricity using fuel cells or through combustion in gas turbines, producing water as the primary byproduct. In this way, hydrogen acts as an energy carrier rather than a primary energy source. One of the most significant advantages of hydrogen storage is its suitability for long-duration and large-scale energy storage. Unlike batteries, which are typically optimized for short-term storage ranging from minutes to several hours, hydrogen can store energy for extended periods ranging from weeks to months or even seasonal timescales. This capability makes hydrogen particularly valuable for balancing seasonal variations in renewable energy production. Hydrogen also offers considerable flexibility across multiple sectors. Stored hydrogen can be used not only for electricity generation but also in transportation, industrial processes, and heating applications. This sector coupling enables hydrogen to connect the electricity sector with industry, transport, and buildings, thereby enhancing overall energy system efficiency. From an environmental perspective, hydrogen has the potential to function as a clean energy storage medium when it is produced using renewable electricity, commonly referred to as green hydrogen. In such cases, the entire energy cycle generates minimal greenhouse gas emissions. However, the environmental benefits of hydrogen depend strongly on the production pathway. Hydrogen produced from fossil fuels without carbon capture can result in substantial greenhouse gas emissions. Despite its potential advantages, hydrogen-based energy storage systems currently face several technical and economic challenges. One major limitation is their relatively low round-trip efficiency, as significant energy losses occur during the processes of electrolysis, storage, and reconversion into electricity. In addition, hydrogen infrastructure requires specialized equipment, storage facilities, and transportation systems. Hydrogen's low volumetric density and high flammability necessitate strict safety measures during storage and handling. Cost also remains a significant barrier to widespread hydrogen deployment. Electrolyzers, hydrogen storage facilities, and fuel cells are still relatively expensive, although costs are gradually declining as technologies mature and deployment increases. Continued research and development efforts are required to improve system efficiency, reduce costs, and develop durable materials capable of safely handling hydrogen.

The hydrogen production and storage methods are presented in Table 5 while the characteristics of several power storage systems are presented in Table 6.

Table 5. Hydrogen production and storage methods

Hydrogen production	Hydrogen storage
Steam reforming of natural gas	Compressed gas storage
Water electrolysis	Liquid H_2 storage
Biomass conversion	Metal hydride storage
Photochemical processes	Chemical H_2 storage
Thermochemical water splitting	Solid state H_2 storage

Source: [Alasali et al, 2023]

ISSN: 2456-3676

Table 6. Characteristics of various power storage systems

Power storage technology	Max. power rating (MW)	Efficiency (%)	Discharge time	Cost ($/kW)	Cost ($/kWh)	Energy density (Wh/lt)	Life time/cycles
PHS	3,000	70-85	4h-16h	600-2,000	5-100	0,2-2	30-60 years
Compressed air	1,000	40-70	2h-30h	400-800	2-50	2-6	20-40 years
Flywheel	20	70-95	sec-mins	250-350	1,000-5,000	20-80	20,000-100,000
Lead-acid battery	100	80-90	1min-8h	300-600	200-400	50-80	6-40 years
Li-ion battery	100	85-95	1min-8h	1,200-4,000	600-2,500	200-400	1,000-10,000
Hydrogen	100	25-45	min-week	-	10	600	5-30 years
Superconductive Magnetic Energy Storage	10	95	Millisec - sec	200-300	1,000-10,000	0.2-2.5	20 years
Thermal	150	80-90	hours	200-300	30-60	70-210	30 years

Source: [Chakraborty et al, 2022]

7. Comparison of Pumped-Hydro Storage, Battery Storage and Hydrogen Storage Systems

Energy storage technologies represent a fundamental component of modern electricity systems, particularly as power generation increasingly relies on variable renewable energy sources such as wind and solar power. Among the various available technologies, pumped-hydro storage, battery energy storage systems, and hydrogen-based storage systems represent three of the most prominent options. Each of these technologies offers distinct advantages and limitations in terms of capacity, efficiency, cost, scalability, and operational role within electricity systems. Pumped-hydro storage remains the most mature and widely deployed large-scale energy storage technology. Its primary advantage lies in its ability to provide large-capacity and long-duration storage with high reliability and long operational lifetimes that often exceed fifty years. These systems are particularly suitable for grid-scale applications such as peak load management, renewable energy integration, and system balancing. However, the development of PHS systems is limited by geographical constraints, since suitable sites must possess adequate elevation differences and available land. In addition, the construction of such systems requires significant capital investment and may involve environmental and landscape impacts. Battery energy storage systems, particularly lithium-ion batteries, have experienced rapid deployment in recent years. Their main advantages include fast response times, operational flexibility, and modular design. Batteries are capable of responding almost instantaneously to grid fluctuations, making

Vol. 11, No. 02; 2026

ISSN: 2456-3676

them ideal for frequency regulation, voltage stabilization, and short-term balancing of electricity supply and demand. Furthermore, battery storage systems can be installed relatively quickly and can be located near electricity generation or consumption points. However, batteries are generally more suitable for short-duration energy storage, typically ranging from minutes to several hours. Their limitations include gradual performance degradation, shorter operational lifetimes compared with PHS systems, and concerns related to raw material supply, recycling, and safety risks such as thermal runaway. Hydrogen-based storage systems represent a fundamentally different approach to energy storage. In these systems, excess electricity is used to produce hydrogen via electrolysis, which can subsequently be stored and later converted back into electricity using fuel cells or turbines. Hydrogen storage offers the important advantage of enabling long-duration and seasonal energy storage, a capability that is difficult to achieve with batteries or pumped-hydro systems. In addition, hydrogen can be utilized across multiple sectors, including transportation, industry, and heating, thereby increasing energy system flexibility. However, hydrogen storage currently faces several limitations, including relatively low round-trip efficiency, high infrastructure costs, and technological maturity challenges. Consequently, rather than competing directly, these storage technologies should be considered complementary. A future sustainable energy system will likely rely on a combination of pumped-hydro storage, battery storage, and hydrogen-based storage to address different storage requirements across various timescales.

The advantages and drawbacks of these power storage systems are presented in Table 7.

Table 7. Advantages and drawbacks of the abovementioned power storage systems

Pump-hydro storage	Electric batteries	Hydrogen
Advantages	**Advantages**	**Advantages**
Suitable for large-scale and long-duration energy storage	Fast response	Long-duration and seasonal energy storage
Long lifetime	Operational flexibility	Hydrogen can be used beyond power generation, such as in transport, industry, or backup power
High efficiency and low operating costs	Modularity	Hydrogen enhances energy security by utilizing local renewable resources and reducing fuel imports
Stimulation of local economic activity.	Scalability	
Drawbacks	**Drawbacks**	**Drawbacks**
High upfront capital cost	High capital cost	High capital cost
Limited suitable sites	Short lifespan	Low round-trip efficiency
Construction of PHS systems	Degradation with repeated	Safety and technical

can lead to environmental and landscape impacts	charge–discharge cycles	challenges
Social acceptance due to conflicts with other activities	Environmental degradation during the extraction of critical raw materials	Requirements for infrastructure development
Low flexibility and relatively low response to grid's demand	The disposal of batteries might create environmental degradation	

Source: own estimations

8. Discussion

The development of energy storage systems is essential for the effective integration of intermittent renewable energy sources such as solar and wind power into electricity grids. Pumped-hydro storage has historically been the dominant large-scale power storage technology worldwide, while the rapid decline in battery prices has significantly increased their attractiveness for grid applications. The abundant solar and wind energy resources available in Crete could also be utilized for the production of green hydrogen through water electrolysis. However, hydrogen-based power storage systems have not yet reached full commercial maturity. Currently, pumped-hydro storage systems and lithium-ion batteries represent reliable and cost-effective technologies that could be deployed in Crete to facilitate the integration of renewable energy into the local electricity grid. The implementation of such storage systems would also reduce energy curtailment in existing solar photovoltaic installations and wind farms, which currently leads to reduced revenues and profitability for renewable energy projects. The results of the present study indicate that each of the three analyzed energy storage technologies presents specific advantages and limitations, while their combined use could enhance the overall flexibility and resilience of the electricity system. The deployment of hydrogen-based storage in Crete remains limited due to the high cost of hydrogen production and the absence of the required infrastructure. As a result, hydrogen storage systems are more likely to be developed in the long term rather than in the immediate future. The present study is primarily qualitative and does not provide quantitative results regarding the cost of energy storage in Crete or the capital investment required for the deployment of the examined storage technologies. Future research should focus on conducting detailed case studies related to energy storage implementation in Crete using different technologies. Such studies could incorporate techno-economic assessments and multi-criteria decision analysis in order to evaluate the most suitable storage solutions for the island's energy system.

9. Conclusions

Three electricity storage technologies—electric batteries, pumped-hydro storage systems, and hydrogen-based storage systems—have been analyzed and assessed for potential application in the island of Crete, Greece. The main findings of this study can be summarized as follows. Electric batteries play a crucial role in modern energy storage systems. Their rapid response

ISSN: 2456-3676

time, operational flexibility, scalability, and declining costs make them particularly suitable for supporting renewable energy integration and enhancing grid reliability. Although challenges related to resource availability, performance degradation, and long-duration storage remain, continuous technological advancements are improving battery performance and sustainability. Pumped-hydro storage systems also play a vital role in modern energy infrastructure. Their large storage capacity, high reliability, long operational lifespan, and ability to support renewable energy integration make them a cornerstone of large-scale energy storage. Despite challenges related to site availability, environmental considerations, and capital costs, ongoing technological developments may further expand their feasibility. Hydrogen represents a promising long-term energy storage solution, particularly for large-scale and seasonal energy storage applications. Although hydrogen-based systems currently face limitations related to efficiency, infrastructure requirements, and cost, their potential to store renewable energy, support multiple sectors, and enable deep decarbonization makes them an important component of future energy systems. In the short term, electricity storage through pumped-hydro systems and electric batteries can be implemented in Crete in order to enable higher penetration of solar and wind power into the local electricity grid. In contrast, the deployment of hydrogen storage systems will require the development of complex infrastructure and a significant reduction in the cost of green hydrogen production. Therefore, hydrogen-based energy storage systems are more likely to be developed in the island over the longer term.

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