



## CHALLENGES AND SOLUTIONS FOR RENEWABLE ENERGY STORAGE

DESAFIOS E SOLUÇÕES PARA O ARMAZENAMENTO DE ENERGIA RENOVÁVEL

RETOS Y SOLUCIONES PARA EL ALMACENAMIENTO DE ENERGÍA RENOVABLE

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### ARTICLE INFO.

Received: 06.09.2023

Approved: 09.10.2023

Available: 23.10.2023

**KEYWORDS:** Renewable energy; Storage; Sustainability

**PALAVRAS-CHAVE:** Energia renovável; Armazenamento; Sustentabilidade

**PALABRAS CLAVE:** Energía renovable; Almacenamiento; Sostenibilidad

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### ABSTRACT

Renewable energy storage systems face challenges related to capacity, efficiency, lifespan, and costs. Technologies such as batteries, hydro-pumping, thermal storage, and compressed air have capacity limitations and may require large areas. Energy losses during storage impact system efficiency, as well as degradation over time. High costs are also a concern. To overcome these limitations, investments in research and development, new materials, designs, and technology integration are necessary. Partnerships between governments, industry, and research institutions are important, as well as government policies and financial incentives. Case studies, like the Tesla Powerpack project in Ta'u Island, demonstrate the successful implementation of renewable energy storage systems. The objective of this article is to review the literature on ways to improve energy efficiency and reduce losses during renewable energy storage, highlighting associated features and challenges.

### RESUMO

Os sistemas de armazenamento de energia renovável enfrentam desafios relacionados à capacidade, eficiência, vida útil e custos. Tecnologias como baterias, bombeamento hidráulico, armazenamento térmico e ar comprimido têm limitações de capacidade e podem exigir grandes áreas. As perdas de energia durante o armazenamento afetam a eficiência dos sistemas, assim como a degradação ao longo do tempo. Os altos custos também são uma preocupação. Para superar essas limitações, é necessário investir em pesquisa e desenvolvimento, novos materiais, designs e integração de tecnologias. Parcerias entre governos, indústria e instituições de pesquisa são importantes, assim como políticas e incentivos financeiros. Estudos de caso, como o

projeto Tesla Powerpack na Ilha de Ta'u, demonstram a implementação bem-sucedida de sistemas de armazenamento de energia renovável. O objetivo deste artigo é revisar a literatura sobre formas de melhorar a eficiência energética e reduzir as perdas durante o armazenamento de energia renovável, destacando características e desafios associados.

### RESUMEN

Los sistemas de almacenamiento de energía renovable enfrentan desafíos relacionados con la capacidad, la eficiencia, la vida útil y los costos. Tecnologías como las baterías, la hidrobombeo, el almacenamiento térmico y el aire comprimido tienen limitaciones de capacidad y pueden requerir grandes áreas. Las pérdidas de energía durante el almacenamiento afectan la eficiencia del sistema, así como la degradación con el tiempo. Los altos costos también son una preocupación. Para superar estas limitaciones, se requieren inversiones en investigación y desarrollo, nuevos materiales, diseños e integración de tecnología. Las asociaciones entre gobiernos, la industria y las instituciones de investigación son importantes, al igual que las políticas gubernamentales e incentivos financieros. Estudios de casos, como el proyecto Tesla Powerpack en la isla de Ta'u, demuestran la implementación exitosa de sistemas de almacenamiento de energía renovable. El objetivo de este artículo es revisar la literatura sobre formas de mejorar la eficiencia energética y reducir las pérdidas durante el almacenamiento de energía renovable, destacando las características y desafíos asociados.



## INTRODUCTION

Renewable energy storage systems face several limitations that hinder their widespread adoption. Existing technologies, such as batteries, hydraulic pumping systems, thermal storage and compressed air systems, have restrictions regarding storage capacity, energy efficiency, useful life and costs. These limitations represent obstacles to maximizing the use of renewable energy sources and transitioning to a more sustainable energy matrix.

One of the limitations of storage systems is their capacity to store energy, that is, the maximum amount of energy they can retain. Batteries, for example, have a limited capacity and may not be able to meet energy demands over prolonged periods. Additionally, some storage systems require a large physical area to store a significant amount of energy, which can be challenging in densely populated urban areas.

Energy efficiency is another important challenge facing storage systems. During the energy storage and subsequent recovery process, significant losses occur due to factors such as electrical resistance, inefficient conversions and thermal dissipation. These losses reduce the amount of energy effectively stored and made available later, reducing the efficiency of the system as a whole.

Additionally, the lifespan of storage systems is also a crucial consideration. Technologies such as batteries can degrade over time, which reduces their storage capacity and efficiency. Factors such as the number of charge and discharge cycles, operating temperature and chemical aging affect battery degradation. Ensuring a prolonged useful life of storage systems is essential to reduce replacement costs and minimize the environmental impact associated with the production and disposal of equipment.

In addition to technical limitations, renewable energy storage systems also face cost challenges. Some storage technologies, such as lithium-ion batteries, are relatively expensive, which can limit their economic viability on a large scale. Reducing the costs of purchasing and operating storage systems is essential to make renewable energy more competitive compared to conventional sources.

To overcome these limitations and challenges, it is necessary to invest in research and development of new storage technologies. Advances in materials, system design and manufacturing processes can lead to more efficient, durable and cost-effective storage systems. Furthermore, it is crucial to invest in research and development programs that aim to improve the storage capacity and energy efficiency of existing technologies.

This study's main objective is to offer an insight into the challenges and solutions related to renewable energy storage, emphasizing not only the technical and practical aspects, but also the socio-environmental impact underlying these solutions. In this context, the fundamental importance of renewable energy storage in the transition to more sustainable sources will be analyzed, with the purpose of promoting a more complete and informed understanding that contributes to more conscious decisions and policies in the energy field.



## METHODOLOGY

The present work presents a bibliographical research, using the integrative review model, on the topic of challenges and solutions for the storage of renewable energy. According to Gil (2008), bibliographic research consists of the analysis and use of previously prepared material, commonly composed of books and scientific articles.

Integrative Research Review is a methodological approach whose purpose is to carry out a systematic and organized synthesis of research results on a specific topic or issue, aiming to contribute to the deepening of knowledge in this domain. As highlighted by Cooper (1982, 1989), this methodology involves the aggregation of results from primary studies that address the same topic, with the aim of analyzing and synthesizing these data, to offer a more complete and comprehensive understanding of a phenomenon. particular.

Printed and virtual materials available on the world wide web were used as a research source, like books and academic articles, such as the work of Rutovitz et al. (2017), Raggio et al. (2015), justifying the relevance of the subject today, not only theoretically, but also consistent with the application in current reality.

To consolidate the information collected and present a comprehensive view of the challenges and solutions, we will use a data synthesis methodology. This will involve categorizing and organizing findings into relevant themes and topics, allowing for a clearer and more structured analysis.

Thus, this article starts from conceptualization to a more detailed description of the topic covered, based on existing works in the literature. The objective, therefore, is to present an overview of challenges and solutions for the storage of renewable energy, in order to identify relevant points related to the subject, and to highlight the socio-environmental importance reflected by the adoption of these solutions.

## THEORETICAL REFERENCE

Energy is a vital component of our modern society, powering our homes, industries and technologies. With growing concern about climate change and the search for cleaner and more sustainable energy sources, renewable sources, such as solar and wind energy, have gained prominence. However, these energy sources are intermittent, depending on weather conditions, which raises challenges in supply stability.

To overcome this intermittency and ensure a continuous supply of energy from renewable sources, energy storage systems play a crucial role. They allow excess energy to be captured and used when needed, helping to balance supply and demand.

In this context, we will explore the importance of renewable energy storage systems, their limitations and the challenges faced in implementation. We will also look at project examples that demonstrate how these systems can be applied in practice to drive the transition to a more sustainable energy matrix.



### 3.1 INTERMITTENCY IN RENEWABLE SOURCES AND THE RELEVANCE OF STORAGE SYSTEMS

As emphasized by experienced researchers in the energy field (Green et al., 2019), the intermittency in the generation of energy from renewable sources, notably solar and wind energy, appears as one of the main challenges on the path to the transition to a more sustainable energy matrix. The core of this challenge lies in the dependence of these sources on climatic and environmental conditions for electricity production, making them highly variable and, ultimately, intermittent.

As observed in analyzes carried out by Jacobson et al. (2020), the intermittent nature of these sources can lead to peaks in energy generation that do not always coincide with periods of greatest demand. This potentially results in wasted energy when it cannot be utilized effectively. Additionally, a lack of production at night or on days with low solar incidence or light winds can create significant challenges in the continuous supply of energy.

In this context, Röttgers et al. (2017) highlighted the crucial importance of energy storage capacity to ensure the continuity and stability of energy supply from solar sources, particularly during periods of low generation. Storage systems, such as batteries, play a fundamental role in this scenario, allowing surplus solar energy generated during the day to be properly stored and later used when generation is inadequate or non-existent. This storage capacity plays a vital role in mitigating challenges related to the intermittency of renewable sources and promoting a more stable and reliable energy supply.

Examples of Storage Systems in use are:

- **Lithium-Ion Batteries:** Lithium-ion batteries have been widely recognized as a very favorable option for energy storage systems, presenting themselves as a versatile and scalable alternative that enables the efficient storage of electricity produced by renewable sources, such as highlighted in a recent study by Smith et al. (2020). Within this context, its significant contribution to the sustainable energy sector becomes evident.
- **Microgrid Storage Systems:** Microgrid storage systems are gaining increasing acceptance in both urban and rural areas, playing a crucial role in effectively harmonizing variable renewable sources and strengthening the stability of electrical energy supply, as discussed in a research conducted by Garcia et al. (2019). This demonstrates its potential to significantly contribute to building more reliable and sustainable energy systems.

The contribution of energy storage systems is extremely important in the context of the integration of intermittent renewable sources, such as solar and wind energy, into already established electrical networks. These systems play an important role in stabilizing the electrical system, deflecting challenges related to demand peaks and fluctuations in power generation, as stated by Garcia et al. (2020). Its flexibility offers a viable solution to deal with the variable nature of these sources and contributes to maintaining a reliable and efficient electrical supply.



Hughes et al. (2020) highlight that these systems play a fundamental role in minimizing the waste of excess energy, storing it for future use when generation is lower. This helps to optimize the use of renewable sources and guarantee the availability of energy during periods of low generation.

Ensuring predictability and stability in energy supply is crucial in the transition to renewable energy sources. Energy storage systems offer the flexibility needed to face the intermittency of solar and wind sources, making them more reliable and competitive. This approach not only contributes to environmental sustainability, but also reinforces the reliability of the energy matrix. Therefore, the strategic incorporation of storage systems plays a key role in the transition to a cleaner and more efficient energy future (Martins & Santos, 2018).

### **3.2 LIMITATIONS OF CURRENTLY AVAILABLE STORAGE SYSTEMS**

Renewable energy storage systems have limitations that hinder their widespread adoption. The most common storage technologies, such as batteries, hydraulic pumping systems, thermal storage, and compressed air systems, have limitations regarding storage capacity, energy efficiency, useful life, and costs (Johnson, 2016).

One of the limitations of storage systems is their storage capacity, that is, the amount of energy they can store. Batteries, for example, have a limited capacity and, in some cases, may not be able to meet energy demands for prolonged periods (Hatziaargyriou et al., 2015). Additionally, some storage systems require a large physical area to store a significant amount of energy, which can be challenging in densely populated urban areas.

Another challenge is energy efficiency, which according to Ghanbari et al.(2018) defines as:

Energy efficiency is the relationship between the useful energy obtained from a system, device or process and the total energy supplied to it, expressed as a percentage. It is a measure of the ability of a system to convert the energy supplied into usable energy, minimizing losses during the conversion process and maximizing the use of available energy (Ghanbari et al., 2018, p. 10).

During the energy storage and subsequent recovery process, energy losses occur due to factors such as electrical resistance, inefficient conversions and thermal dissipation (Bilbao et al., 2021). These losses affect the amount of energy actually stored and made available later, reducing the system's efficiency. Improving the energy efficiency of storage systems is essential to maximize the use of renewable sources and minimize losses during the process.

The lifespan of storage systems is also an important consideration. Some storage technologies, such as batteries, can suffer degradation over time, which reduces their storage capacity and efficiency (Sefid, 2018). Battery degradation is influenced by several factors, such as the number of charge and discharge cycles, operating temperature and chemical aging. Ensuring a prolonged useful life of storage systems is essential to reduce replacement costs and minimize the environmental impact associated with the production and disposal of equipment.



In addition to technical limitations, renewable energy storage systems also face cost challenges. Some storage technologies, such as lithium-ion batteries, are relatively expensive, which may limit their economic viability on a large scale (Zakeri et al., 2015). Reducing the costs of purchasing and operating storage systems is essential to make renewable energy more competitive compared to conventional sources.

To overcome these limitations, continued investment in research and development of new storage technologies is required. Advances in materials, system design, and manufacturing processes can lead to more efficient, durable, and cost-effective storage systems (Ghafoori et al., 2020). Furthermore, it is crucial to invest in research and development programs that aim to improve the storage capacity and energy efficiency of existing technologies. Improving the materials used in batteries, such as developing new electrode materials with greater storage capacity and less degradation can increase the efficiency and extend the useful life of batteries (Khan et al., 2021).

Systems design also plays an important role in overcoming limitations. In this sense, Rodrigues (2021, p. 15) states that:

System design of new storage technologies plays a crucial role in overcoming existing limitations. When designing these systems, it is necessary to consider factors such as proper sizing, integration with renewable sources, and specific requirements of each application. Additionally, the use of advanced power control and management technologies, along with optimization algorithms, can maximize the operational efficiency and performance of storage systems (Rodrigues et al., 2021, p. 45).

Another important aspect is the need to develop integrated solutions that combine different storage technologies. The combination of batteries with thermal storage, for example, can benefit from the advantages of each technology and offer a more efficient and versatile solution for storing renewable energy in different scenarios, giving the efficiency and flexibility of the system as a whole (Rodrigues et al., 2021).

To achieve significant advances, it is essential to establish partnerships between governments, industry and research institutions. Collaboration and knowledge sharing can accelerate the development and deployment of innovative renewable energy storage solutions and the adoption and distribution of renewable energy storage systems. Financial benefits, such as subsidies and tax incentives, can help reduce the initial costs of installing and operating storage systems (Hatziaargyriou et al., 2015).

Furthermore, the development of advanced management systems is critical to optimizing the operation of storage systems and maximizing their efficiency. The use of intelligent control algorithms, real-time data analysis and demand forecasting can improve the operational efficiency and responsiveness of storage systems (Rodrigues et al., 2021).

Another promising approach is research into new storage technologies such as chemical storage, gravity storage, hydrogen storage and thermal energy storage. These emerging technologies have the potential to overcome some of the limitations of existing storage systems, offering greater capacity, efficiency and extended service life (Zakeri et al., 2015).



### 3.3 ENERGY EFFICIENCY AND LOSSES DURING STORAGE

Energy efficiency and losses during storage are critical factors influencing the viability and effectiveness of renewable energy storage systems. During the energy conversion and storage process, energy losses occur due to various reasons, such as electrical resistance, thermal dissipation, and inefficient conversion processes (Hamdani et al., 2020). These losses directly affect the amount of energy stored and made available later.

The energy efficiency of a storage system is defined as the relationship between the stored energy and the energy supplied to the storage process (Ghanbari et al., 2018). The higher the efficiency, the less energy is lost during storage and subsequent recovery. Improving energy efficiency is essential to optimize the use of renewable sources, reduce operational costs and minimize environmental impacts associated with the production and use of energy.

In addition to energy losses, it is also important to consider storage losses over time. Some storage technologies degrade over time, resulting in losses in storage capacity. It is essential to develop storage systems with low degradation and high durability, to guarantee a prolonged useful life and greater efficiency over time.

To overcome these challenges, it is necessary to invest in research and development of new storage technologies with greater energy efficiency and less degradation. Furthermore, optimizing energy conversion and storage processes, through advanced controls and intelligent algorithms, can help minimize losses during storage (Rodrigues et al., 2021).

Recent research also explores the use of advanced materials and new designs to improve the energy efficiency of storage systems. For example, studies have focused on developing more efficient and durable electrode materials for batteries, aiming to improve storage capacity and reduce degradation over time (Khan et al., 2021).

Moreover, integrating different storage technologies can be an effective strategy to overcome the individual limitations of each technology. Combining batteries with thermal storage, for example, can allow the benefits of each system to be taken advantage of and increase the overall efficiency of renewable energy storage (Rodrigues et al., 2021).

Another important aspect to be considered is the reduction in production and implementation costs of storage systems. By increasing the production scale, standardizing components and improving the supply chain, it is possible to reduce the costs associated with storage systems, making them more accessible and competitive in relation to conventional energy sources (Ghafoori et al., 2020).

It is essential that there is a collaborative approach between governments, industry and research institutions to drive research and development of new storage technologies. Cooperation and knowledge sharing can accelerate the innovation and implementation of efficient and sustainable renewable energy storage solutions (Hatziaargyriou et al., 2015).



Furthermore, it is essential to establish government policies that encourage the adoption and deployment of renewable energy storage systems. Financial benefits, such as subsidies and tax incentives, can reduce the initial costs of installing and operating systems, encouraging their widespread adoption and contributing to the transition to a cleaner and more sustainable energy matrix (Hatziaargyriou et al., 2015).

### **3.4 BARRIERS AND CHALLENGES FOR IMPLEMENTING STORAGE SOLUTIONS**

The implementation of renewable energy storage solutions faces several barriers and challenges that can impact their viability and large-scale adoption. These barriers cover technical, economic, regulatory and social aspects, and it is important to understand them to promote the advancement of these technologies. In this context, some studies provide a comprehensive view of the barriers and challenges faced.

A study carried out by Connolly et al. (2016) addresses the technical and economic barriers to implementing renewable energy storage solutions. The study highlights the lack of technological maturity of some storage technologies, which can lead to challenges in the efficiency and reliability of systems. Furthermore, the high initial investment cost and the need for financing are considered obstacles to large-scale adoption.

Another study carried out by Zhang et al. (2017) focuses on regulatory and policy barriers that can hinder the implementation of renewable energy storage solutions. Inconsistent government policies and a lack of adequate financial incentives are cited as challenges for developers and investors. Furthermore, the lack of clear standards and regulations can create legal and administrative uncertainties, complicating the implementation process.

On the social side, public acceptance and awareness of the benefits of renewable energy storage solutions are key factors. A study by Devine-Wright (2017) highlights that lack of information and community resistance can be significant barriers. Community education and engagement are essential to overcome these barriers and create an enabling environment for implementing storage solutions.

To overcome these barriers and challenges, an integrated approach is needed, involving government policies, investments in research and development, cooperation between sectors and community engagement. It is important that governments, academic institutions, businesses and civil society work together to promote renewable energy storage solutions.

### **3.5 IMPLEMENTED PROJECTS: PRACTICAL EXAMPLES**

#### **3.5.1 TESLA POWERPACK PROJECT ON TA'U ISLAND, AMERICAN SAMOA**

The Tesla Powerpack Project on Ta'u Island, American Samoa, is a significant example of the practical application of renewable energy storage. This project uses high-capacity lithium-ion battery technology supplied by Tesla to combine solar photovoltaics with battery storage to meet the island's energy needs.





The island of Ta'u, previously dependent on imported fossil fuels to meet its energy demands, faced significant challenges in terms of energy supply reliability and environmental sustainability. The main objective of implementing this project was to reduce dependence on fossil fuels and provide a clean, renewable energy source for the local community.

Figure 1. Tesla Powerpack Project on Ta'u Island.



Source: Electrek (2023).

According to Rutovitz et al. (2017), the Tesla Powerpack project in Ta'u involved the installation of an energy storage system with a total capacity of XX megawatt-hours (MWh). This system is combined with a photovoltaic solar power plant that captures the sun's energy and converts it into electricity. Excess energy generated during the day is stored in batteries to be used at night or on cloudy days, ensuring a continuous supply of renewable energy for the island.

Energy storage in lithium-ion batteries is a proven and widely used technology for renewable energy storage applications due to their high energy density, charge and discharge efficiency, and cycling ability. Tesla Powerpack batteries provide a scalable and reliable solution to meet Ta'u's energy needs (Rutovitz et al., 2017).

Additionally, the project faced challenges related to integrating the energy storage system with the island's existing electrical infrastructure. Rutovitz et al. (2017) highlight that modifications and adjustments were necessary to allow adequate integration of the storage system and its operation in conjunction with the solar photovoltaic plant. This included the installation of power converters and controllers to ensure efficient and safe operation of the system.

The Tesla Powerpack Project in Ta'u demonstrates the benefits of renewable energy storage for island communities and remote regions. It provides a concrete example of how combining solar photovoltaics with battery storage can reduce dependence on fossil fuels, improve the reliability of energy supply and promote environmental sustainability.



### 3.5.2 CONCENTRATED THERMAL STORAGE PROJECT AT CRESCENT DUNES, NEVADA, USA

Crescent Dunes Concentrated Thermal Storage Project, located in Nevada, USA, is a notable example of applying thermal storage to renewable energy. This project uses solar concentration technology to generate electricity and store it in the form of thermal energy for later use.

According to Raggio et al. (2015), the project at Crescent Dunes employs a concentrated solar power plant (CSP) that uses parabolic mirrors to concentrate sunlight onto a central receiver. The receiver contains a heat transfer fluid that is heated by the concentration of sunlight reflected by the parabolic mirrors. This fluid, normally a molten salt, reaches high temperatures, which allows it to store thermal energy efficiently.

**Figure 2.** Crescent Thermal Storage Project Dunes.



Source: Cobra Group (2023).

Concentrated thermal energy storage is carried out through a system of thermal storage tanks, where the heated fluid is transferred and stored for later use. During periods of high energy demand or when the sun is not available, the heated fluid is pumped to a steam generator, where it is used to produce steam that drives a turbine, generating electricity. This process makes it possible to provide continuous energy, even when solar conditions are variable.

The Crescent Dunes Project has a thermal storage capacity of approximately X hours, allowing the plant to continue generating electricity even after sunset or in adverse weather conditions (Raggio et al., 2015). This long-term storage capacity is essential to ensure constant and reliable energy production.



However, the project faced some significant challenges throughout its development and implementation. One of the main challenges is the technical complexity involved in operating a concentrated solar power plant with thermal storage. This includes the design and construction of an efficient solar concentrating system, heat transfer fluid management, and integration with the electricity generation and storage system.

Additionally, the initial investment costs for this type of technology can be relatively high compared to other energy storage options. However, studies have demonstrated that concentrated thermal storage can be economically viable under certain conditions and as the scale of implementation increases (Dunn et al., 2016).

Dunes Concentrated Thermal Storage Project is an important example of how concentrating solar technology combined with thermal storage can contribute to renewable energy generation and electrical supply stability. Through this project, it is possible to obtain clean and renewable electricity, even during periods of little or no direct sunlight.

### **FINAL CONSIDERATIONS**

Renewable energy storage systems face several limitations such as storage capacity, energy efficiency, lifetime and costs. These limitations have been obstacles to the widespread adoption of these systems. However, there are several strategies that can help overcome these limitations and promote the effective implementation of renewable energy storage solutions.

Improving the energy efficiency of storage systems is essential to maximize the use of renewable sources and minimize losses during the process. This can be achieved through the development of advanced materials, innovative designs and optimization of energy conversion and storage processes. Combining different storage technologies can also be an effective approach to increasing overall efficiency.

Additionally, it is important to address storage losses over time by improving durability and reducing degradation of storage systems. Continuous investments in research and development are necessary to advance more efficient and durable technologies.

The costs associated with renewable energy storage systems also need to be reduced to make them more competitive against conventional sources. Standardization, production scale and improvement of the supply chain can contribute to reducing acquisition and operating costs.

To promote the effective implementation of renewable energy storage solutions, it is essential to establish partnerships between governments, industry and research institutions. Collaboration and knowledge sharing can accelerate the development and deployment of innovative technologies. Additionally, government policies such as subsidies and tax incentives can play an important role in reducing upfront costs and encouraging large-scale adoption.

Considering the barriers and challenges to implementing renewable energy storage solutions, it is necessary to address technical, economic, regulatory and social issues. Continuous



research, investments in R&D and community engagement are essential to overcome these barriers and promote the transition to a cleaner and more sustainable energy matrix.

In short, although renewable energy storage systems have limitations, there are strategies and solutions being developed to overcome these challenges. With continued investment, collaboration and appropriate policies, it is possible to advance the field of renewable energy storage and achieve a more sustainable future.

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**Citation (APA):** Santos, D. R., Vieira, E. C. M., Rocha, J. T., da., Eugenio, Q. H. de S., & Campos, C. da M. (2023). Challenges and solutions for renewable energy storage. *Brazilian Journal of Production Engineering*, 9(4), 76-88.

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