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Master's Degree Thesis

Empowering the Energy Transition

A comprehensive analysis of Battery Energy Storage Systems

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Abstract

The climate crisis requires significant changes across society. While reducing emissions remains crucial, the intermittent nature of renewables like wind and solar poses challenges. Innovative energy storage solutions are needed to enhance the reliability, stability, and accessibility of renewable energy. The adoption of Battery Energy Storage Systems (BESS) is decisive in addressing the criticalities of transitioning to a sustainable energy system more rapidly. This thesis examines the regulatory, technological, and economic context that influences the diffusion of Battery Energy Storage Systems (BESS), with a focus on the European and Italian situations. It covers the initial developments of energy storage technologies, including mechanical, chemical, electrochemical, and electrical storage. Additionally, it provides a cost analysis based on CAPEX/OPEX data of BESS projects developed in Italy. The revenue section examines the Italian electric market's size and regulatory scope, the incentive schemes required for full investment profitability (Fast Reserve, Capacity Market, and *Decreto Grandi Accumuli*), and the latest updates from Terna regarding the MACSE mechanism. Additionally, this thesis provides a European overview of recent BESS projects and presents a case study that highlights key considerations for designing a BESS plant, including compliance with urban and territorial regulations, detailed system descriptions, grid connections, and related infrastructure. The conclusions emphasize the significance of investing in the expansion of BESS to ensure a secure, clean, and efficient energy future. However, it raises the question of whether society is prepared to embrace growth and innovation to address global climate challenges.

Summary

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Acronyms

AC = Alternating Current

aFRR = automatic Frequency Restoration Reserve

ARERA = "*Autorità di Regolazione per Energia Reti e Ambiente*", Regulatory Authority for Energy, Networks and Environment

AU = *"Autorizzazione Unica"*, Single Authorization

BESS = Battery Energy Storage Systems

BMS = Battery Management System

BoP = Balance of Plant

C&I = Commercial & Industrial

CAES = Compressed Air Energy Storage

CAPEX = Capital Expenditure

CCTV = Closed Circuit Television

CM = Capacity Market

COD = Commercial Operational Date

DC = Direct Current

DGA = "*Decreto Grandi Accumuli*"

EFR = Enhanced Frequency Response

EIA = Environmental Impact Assessment

EMS = Energy Management System

EPC = Engineering, Procurement and Construction

FES = Flywheel Energy Storage

FFR = Firm Frequency Response

FO = Fiber Optic

FRNP = *"Fonte rinnovabile Non Programmabile"*, Non-Programmable Renewable Source

FRU = Fast Reserve Unit

GHG = Greenhouse Gas

GSE = *"Gestore Servizi Energetici"*, Energy Services Manager

HV = High Voltage

HVAC = Heating, Ventilating and Air Conditioning

IRR = Internal Rate of Return

LCOE = Levelized Cost of Electricity

LDES = Long-Duration Energy Storage
LFP = Lithium Iron Phosphate
LODES = Longer Duration Energy Storage Competition
LV = Low Voltage
MASE = "*Ministero dell'Ambiente e della Sicurezza Energetica",* Ministry of Environment and Energy Security
MB = *"Mercato di Bilanciamento"*, Balancing Market
MGP = *"Mercato del Giorno Prima",* Day-ahead Market
MI = *"Mercato Infragiornaliero"*, Intraday Market
MPE = "*Mercato Elettrico a Pronti",* Spot Electricity Market
MPEG = *"Mercato dei Prodotti Giornalieri"*, Daily Products Market
MSD = *"Mercato del Servizio di Dispacciamento",* Dispatching Service Market
MTE = "*Mercato Elettrico a Termine",* Future Electricity Market
MV = Medium Voltage
NCA = Nickel Cobalt Aluminum oxide
NMC = Nickel Manganese Cobalt oxide
O&M = Operation and Maintenance
OPEX = Operating Expenditure
PAS = *"Procedura Abilitativa Semplificata"*, Simplified Qualification Procedure
PCR = Primary Control Reserve
PCS = Power Conversion System
PHS = Pumped Hydroelectric Systems
POC = Point Of Contact
PoI = Point of Interconnection
PTO = "*Piano Tecnico delle Opere",* Technical Plan of the Works
RED = Renewable Energy Directive
RES = Renewable Energy Sources
RFI = Radio Frequency Interference
RTN = *"Rete di Trasmissione Nazionale"*, National Transmission Power Grid
SCADA = Supervisory Control and Data Acquisition
SCCI = Integrated Central Control System

SCI = Integrated Control System

SE = *“Stazione Elettrica”*, Electrical Station

SEE = Strategic Environmental Evaluation

SMES = Superconducting Magnetic Energy Storage

SoC = State of Charge

SoH = State of Health

STMD = “*Soluzione Tecnica Minima Definitiva”*, Definitive Minimum Technical Solution

STMG = “*Soluzione Tecnica Minima Generale”*, General Minimum Technical Solution

Terna = “*Rete Elettrica Nazionale”,* National Electricity Network

TIDE = “*Testo Integrato del Dispacciamento Elettrico”*, Integrated Text of Electricity Dispatching

TSO = Transmission System Operator

UP = Production Unit

UVAM = *“Unità Virtuali Abilitate Miste”*, Mixed Enabled Virtual Units

Introduction

In the contemporary era, humanity is facing one of the most significant challenges in its history: **climate change**. The scientific consensus is clear that urgent global action is necessary to mitigate the catastrophic impacts of this phenomenon. As greenhouse gas emissions continue to rise, the Earth's climate system is undergoing destabilizing changes, posing threats to ecosystems, societies, and economies worldwide.

Addressing the climate crisis requires transformative action across all sectors of society. Although mitigating emissions is still a top priority, the intermittent nature of renewable energy sources, such as wind and solar, presents a significant obstacle to their widespread adoption.

The need of innovative solutions for **energy storage** arises from this scenario, which requires increasing reliability, stability and accessibility of renewable energy.

Nowadays, we are experiencing a significant **energy transition** characterized by the growth and penetration of renewable sources in the energy market.

We are transitioning from a world dominated by thermal generation sources, where a few large power plants supplied energy to all consumers, to a world with renewable production sources. This shift leads to a more decentralized context, with many assets directly connected to the medium or low voltage grid.

Until recently, the main sources of electricity supply were thermoelectric and gas generation, which were easily programmable and located close to the demand. As a result, managing the real-time matching between supply and demand, as well as the injection and withdrawal of electricity, was a simple task. However, this will get more and more difficult in the future.

The ability to shift energy production to times of consumption is becoming increasingly relevant on various time scales.

Energy storage systems act as a balance between energy supply and demand, facilitating the transition process by storing large amounts of energy and making it available to the grid during times of high demand.

In particular, battery storage technology is considered the most mature and innovative and is making its way into large-scale applications.

The diagram below summarizes the challenges that energy supply has posed in recent years and how Battery Energy Storage System (**BESS**) fits into this context.

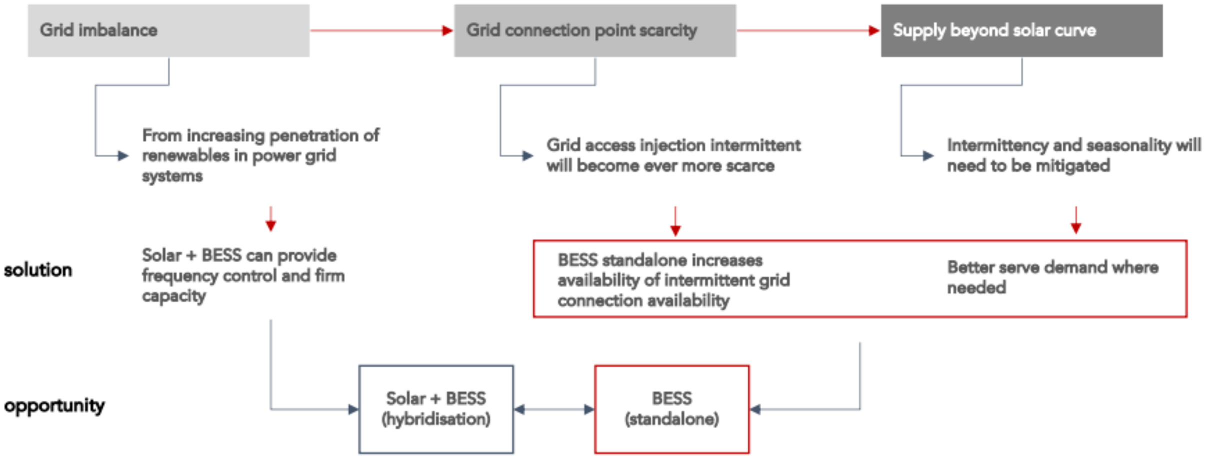

Figure 1: Energy management challenges faced by BESS

Due to the significance of storage systems in the energy transition, this thesis, which is based on an internship experience at **Kiwa Moroni Srl**, a company operating in the energy sector, explores the multifaceted landscape surrounding BESS, including authorization frameworks, technological underpinnings, and revenue dynamics driving their adoption.

In the European Union, the authorization of Battery Energy Storage Systems is governed by a complex regulatory framework, encapsulated in UE 2022/2577 and RED III directives.

In the first chapter, it is described how these recent directives delineate the parameters within which BESS projects must operate, ensuring alignment with overarching sustainability objectives while fostering innovation and investment in the energy storage sector.

Italy, a significant player in the European energy sector, has established its own authorization procedure for BESS projects, as delineated in DL 7/02/2002 no.7. This legislative framework outlines the specific requirements and procedures for obtaining authorization, reflecting Italy's commitment to facilitating the integration of BESS into its energy infrastructure.

The second chapter covers instead the evolution of BESS technology, which has undergone significant advancements since its inception. From the nascent stages of development to the present, BESS has experienced remarkable technological maturation, paving the way for its widespread deployment and commercial viability.

The storage technology landscape embraces a variety of technologies, from mechanical to electrochemical systems, each one with its own benefits and challenges. However, it is important to focus specifically on batteries since they are more mature and commonly used in stationary energy storage applications.

Furthermore, an analysis of the costs associated with battery energy storage systems, including both capital expenditure (CAPEX) and operational expenditure (OPEX), has been conducted, providing valuable insights into the economic feasibility and long-term sustainability of projects.

Moving forward, the third chapter presents the regulatory framework that governs revenue streams and market participation in which BESS projects operate. It is essential to understand the nuances of this framework to maximize the economic viability of BESS investments.

The Italian government has demonstrated its willingness to integrate battery storage into the energy system through recent policy developments and through the opening of several Pilot Projects.

An evaluation of the Italian market for BESS indicates favorable prospects in several areas, including the capacity market, fast reserve services, and recent legislative updates, such as the *"Decreto Grandi Accumuli"*.

Before diving into the case study in the last chapter, it is important to provide a Europe-wide overview of the current situation regarding the deployment of BESS technology. This involves identifying the market leaders, the dominant countries in terms of installed and authorized capacity, and providing examples of major projects under development.

To conclude, a **case study** is presented. Specifically, the design of a 'stand-alone' BESS plant of 190 MW to be built in the province of Viterbo (Lazio, Italy), a real project in which I actively participated in the last weeks of my internship in the company.

This section conducts an extensive evaluation of urban and territorial compliance, assessing landscape, archaeological, and hydrogeological constraints at different levels of government, also examining the request for grid connection.

Furthermore, it presents a succinct summary of the BESS system, encompassing its structure and individual elements, also outlining all construction and operational works.

In conclusion, this work emphasizes the critical importance of addressing climate change through urgent global action with renewable energy and energy storage solutions emerging as indispensable components of this effort.

The objective of this research is to comprehensively explore Battery Energy Storage Systems and their role in the energy transition. This includes regulatory compliance, economic feasibility, market dynamics, and real-world case studies with the aim of contributing to a deeper understanding of their integration into the evolving energy infrastructure.

1. AUTHORIZATION FRAMEWORK

Europe is currently experiencing an energy crisis, but the European Commission is providing leadership through the *Fit for 55*[1]and *REPowerEU*[2] packages.

However, Europe today is not yet prepared to integrate high shares of renewables and make them available when needed. Operating the energy system on fossil-based principles will result in continued reliance on fossil fuels and curtailment of clean and affordable renewable energy.

Energy Storage is an essential component for enabling the integration of renewables and establishing a secure, low-emission, and affordable energy system. It provides critical energy shifting and fast-response flexibility services.

The European Commission has recognized the crucial role of storage in achieving its energy transition strategy, as confirmed by its own study.

EASE (European Association for the Storage of Energy) conducted a comprehensive review of the system requirements for energy storage in 2030 and 2050. In this document, EASE estimates *"a no regret energy storage requirement of approximately 200 GW by 2030 and 600 GW by 2050 (including 435 GW from power-to-X-to-power solutions for energy shifting as a no regret option in 2050)"(*EASE, 2022).

Energy Storage Targets 2030 and 2050

If urgent measures are not taken now, the current market trajectories for storage will fail to meet the requirements by 2030. To meet the targets, a massive ramp-up in storage uptake of at least 14 GW/year is required compared to historic rates.

Energy Storage targets are a necessary complement to existing EU climate targets. They will allow Europe to foster a local, sustainable green energy system independent of external energy imports.

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[1] The *Fit for 55* package, presented in July and December 2021, is designed to realize the European Climate Law objectives: climate neutrality by 2050 and a 55 % reduction of net greenhouse gas (GHG) emissions by 2030, compared with 1990 levels.

[2] *REPowerEU* proposal aims to strengthen the strategic autonomy of the Union by diversifying energy supplies and boosting the independence and security of the Union's energy supply.

Energy security risks will become increasingly critical without clear policy intervention. The joint letter (EASE, Breakthrough Energy, SolarPower Europe, WindEurope, 2022) sent to the Commission emphasized the key priorities for storage, including:

- A clear political commitment from the European Commission on an energy storage strategy that replicates the scope and ambition of the Hydrogen strategy, with energy storage targets;
- The driving of the necessary scale-up of storage solutions and the removal of existing barriers to their deployment and operation, clear signals should be provided to investors and the energy storage industry to promote the uptake of energy storage technologies;
- Mainstream of energy storage in the European Commission's implementation of the *REPowerEU* action plan and in the ongoing review of the Electricity Market Design.

That being said, several additional sets of legislative changes are necessary to prevent falling short of the flexibility needs in 2030 and beyond. However, without urgent measures to ensure low-carbon flexibility, Europe will fail to achieve its ambitious climate goals and further jeopardize its energy security.

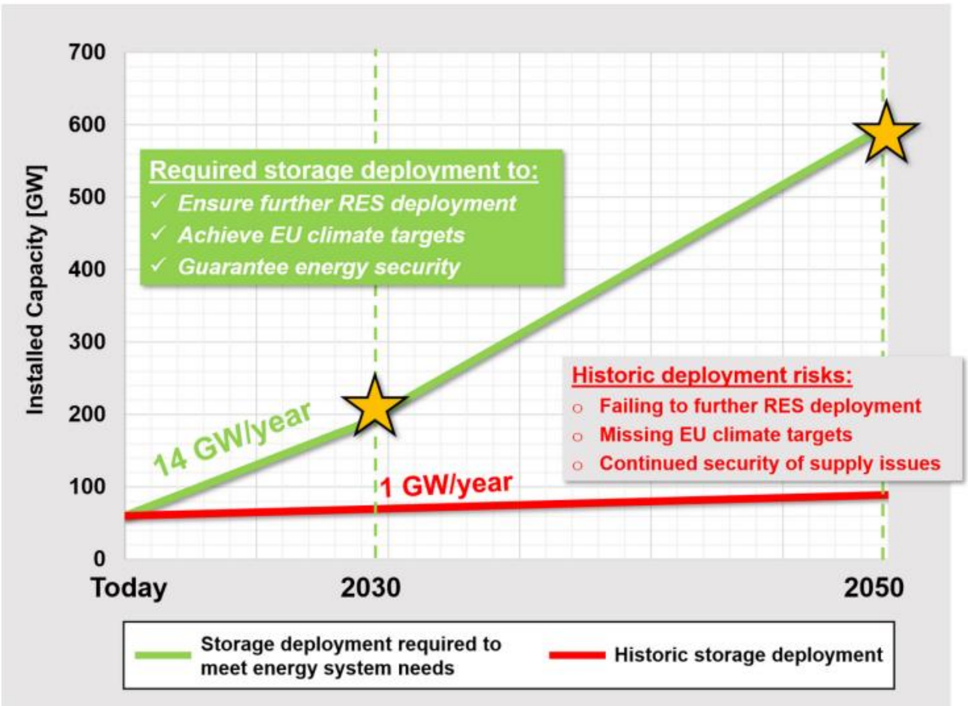


Figure 2: Different scenarios for storage deployment

Source: EASE

Cost assumptions are crucial in determining the future energy storage requirements in energy system models today. If cost projections are high, certain technologies may not be included. However, current cost projections and technological innovations are constantly changing and must be kept up to date for system models to remain relevant.

Technologies should be evaluated based on their value to the system. Selection criteria should consider benefits such as energy security, low emissions, and curtailment minimization.

Future projections indicate a 60% decrease in Capex costs. This can be achieved by scaling production efforts and driving down costs, as has been done for similar breakthrough technologies like wind and solar. Widespread deployment of these technologies is dependent on investment signals, as well as enabling policy and legislation.

System models should account for uncertainty, as technologies may be limited by cost assumptions, making them currently unviable solutions for the future.

In recent years, Europe has aimed to accelerate the energy transition by introducing new legislation.

1.1 BESS in the European context

The European Union has implemented several measures to promote the use of renewable energy production plants while acknowledging the importance of balancing conflicting interests.

These measures include:

- Principle of maximum diffusion of energy from renewable sources;
- Landscape protection.

The EU has intervened multiple times to establish common objectives and guidelines for its Member States. As part of this effort, the EU has approved **Regulation 2022/2577**, and work is currently underway to define the final proposal for the EU's Renewable Energy Directive III (**RED III**).

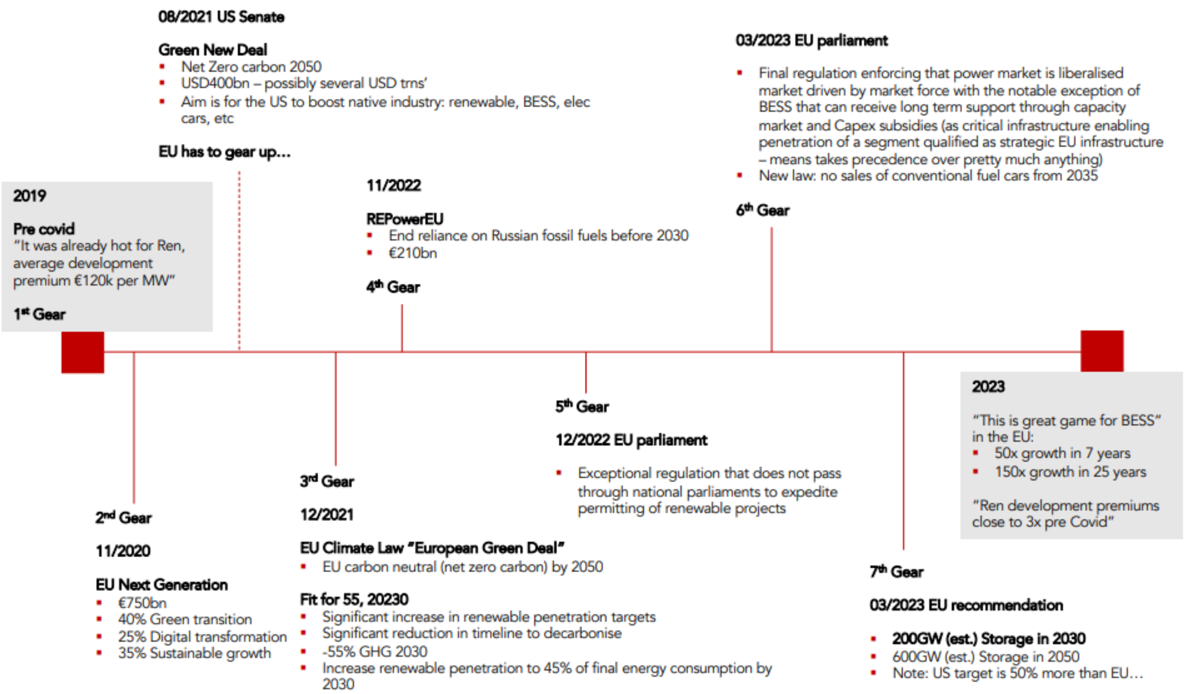


Figure 3: Legislative and regulatory framework timeline from renewable generation to a fully independent and reliable green electricity system

Source: Sun capital

The image above displays a timeline highlighting recent actions taken by the EU to promote the growth of renewable energy.

1.1.1 UE 2022/2577

On December 22nd 2022 the EU Council approved the Regulation proposed by the EU Commission on November 9th 2022, which aims to accelerate the deployment of energy from renewable sources.

The Regulation was published in the European Union Official Journal on December 29th 2022. It introduces measures to streamline and expedite the permitting process for renewable energy projects. The goal is to address the challenges related to energy supply resulting from the current international situation and the resulting consequences for consumers, such as increasing exposure to volatile electricity prices.

In this context, the Regulation includes both urgent actions with a general scope, such as the introduction of a relative presumption that renewable energy projects are of overriding public interest for the purposes of the relevant environmental legislation, and simplifying the permitting framework for repowering renewable plants. It also includes more specific measures, such as granting shorter and faster authorizations for photovoltaic installations to be built on existing rooftops or on existing or future artificial structures.

The Regulation is valid for eighteen months, starting from December 29th 2022 until August 2024, and is immediately applicable in all Member States. The European Commission may request the Council to extend its validity.

<u>Overriding public interest</u>

As expected, one of the main measures is the introduction of the presumption that renewable energy projects serve the overriding public interest and promote public health and safety.

Article 3 of the Regulation outlines this in detail:

- the planning, construction, and operation of plants and installations for renewable energy production, as well as their connection to the grid, the related grid itself and storage assets, are considered to be in the public interest and serve public health and safety. This presumption is made when balancing legal interests in individual cases (see Article 3, Paragraph 1 of the Regulation);

- Member States must prioritize projects recognized as being of overriding public interest during the planning and permit-granting process, at least. This is to ensure that legal interests are balanced in the individual case. Regarding species protection, this provision applies only if appropriate measures for species conservation are taken and sufficient areas and financial resources are available for that purpose (see Article 3, Paragraph 2 of the Regulation).

The main objective of this provision is to streamline the authorization procedures, prioritizing the construction of renewable power plants when balancing the interests involved.

<u>Solar energy and self-consumption</u>

The Regulation intervenes in the maximum duration of authorization procedures for the construction and operation of renewable facilities. It establishes that these procedures should not exceed three months.

Article 4 of the Regulation contains the relevant provisions:

- The process of granting permits for the installation of solar energy equipment and co-located energy storage assets, including building-integrated solar installations and rooftop solar energy equipment, in existing or future artificial structures (excluding artificial water surfaces) shall not exceed three months. This time frame applies only if the primary aim of such structures is not solar energy production. The installation of solar energy equipment is exempt from the requirement for an Environmental Impact Assessment or a dedicated Environmental Impact Assessment (see Article 4, Paragraph 1 of the Regulation);
- Member States may exclude certain areas or structures from the provisions of paragraph 1 for reasons of cultural or historical heritage protection, or for reasons related to national defense interests or safety (see Article 4, Paragraph 2 of the Regulation).

The European Union reaffirms the crucial role of solar energy in the transition to a climate-neutral economy by introducing a specific regulation for renewable installations on roofs and artificial structures.

In this perspective, faster authorization procedures are introduced for these types of installations, which, given their characteristics, are generally less complex than ground-mounted installations and can quickly contribute to mitigating the effects of the current energy crisis.

Furthermore, Article 4 of the Regulation aims to simplify and speed up the construction and operation of small power plants, including those intended for self-consumption, with a capacity of 50 kW or less. The authorization procedures related to such power plants will follow the silence-approval mechanism. If the competent public authority has not provided any feedback within one month from the submission of the application by the relevant operator, the authorization will be granted.

The authorization processes are streamlined to reduce the demand for natural gas and encourage self-consumption of energy from renewable sources. This aims to decrease consumers' exposure to the volatility of electricity prices.

Repowering of existing renewable power plants

The EU Regulation focuses on the repowering of existing renewable power plants as a means of rapidly increasing renewable energy production.

Authorization procedures' duration limits are provided, even in cases such as on-roof and artificial structures, as previously seen.

Specifically, Article 5 of the Regulation describes these limits:

- The process of granting permits for repowering projects, including permits related to upgrading assets necessary for grid connection, shall not exceed six months, including Environmental Impact Assessments where required by relevant legislation, if the repowering results in an increase in capacity;
- Where the repowering does not result in an increase in the capacity of the renewable energy power plant beyond 15%, connections to the transmission or distribution grid shall be permitted within 3 months following application to the relevant authority, unless there are justified safety concerns or technical incompatibility with the system components. It is important to note that any potential environmental impacts must still be assessed;

- When determining whether a renewable energy power plant repowering or related grid infrastructure upgrade requires an Environmental Impact Assessment (EIA) or a dedicated EIA, only potential significant impacts resulting from the change or extension compared to the original project should be considered.

Heat pumps

Lastly, the Regulation introduces provisions to expedite authorization processes for installing renewable energy heat pumps as a replacement for natural gas and other fossil fuel-based boilers.

In this perspective, Article 7 of the Regulation provides that:

- The permit-granting process for the installation of heat pumps below 50 MW electrical capacity must not exceed one month, whilst in the case of ground source heat pumps must not exceed three months;
- Unless there are justified safety concerns, further works are needed for grid connections or there is technical incompatibility of the system components, connections to the transmission or distribution grid are permitted following notification to the relevant authority.

The rationale for these provisions is that the increased use of renewables in the heating sector, which accounts for almost half of the Union's energy consumption, will contribute to the security of supply and help tackle a more difficult market situation by allowing for quicker and easier installation of heat pumps.

The recent Regulation follows the simplifications and incentives promoted at the EU level to encourage the wider use of renewable energies. The goal is to mitigate the risks to energy supply resulting from the Russian-Ukrainian conflict.

It is important to note that some of the simplifications introduced by the Regulation have already been partially transposed at the national level. This includes the Simplification Decree, Simplification Decree bis, and *Aiuti* Law Decree, as well as in case law.

Considering the magnitude of the energy crisis and its social, economic, and financial impact, it is crucial that the simplifications mentioned above will be promptly and fully incorporated into the practices of public authorities and bodies involved in permitting processes.

This includes local authorities, in order to realize the benefits of sustainable energy production and address the supply risks highlighted at the EU level.

The recent EU Regulation could further support this direction.

Table 1: Key points of the EU Regulation

Solar	• Maximum limit of 3 months for authorization procedures for solar and related storage systems, located in existing or future artificial structures, including buildings. • Power plants are exempt from any obligation to EIA. • Member States may exclude from simplifications certain areas or structures for reasons related to the protection of cultural and historical heritage.
Self-consumers of renewable energy	• For systems under 50 kW, in the absence of a response within 1 month from the instance, the authorization is considered granted, provided that the power of the system does not exceed existing capacity connection to the distribution. • In the event that it involves charges and administrative constraints, the 50 kW threshold can be reduced by the Member States up to a minimum of 10.8 kW.
Repowering	• Maximum limit of 6 months for the issuance of authorizations for RES (Renewable Energy Sources) Repowering projects, including all relevant EIAs. • Environmental protection must be limited to the potential significant effects resulting from the modification or from the extension of the initial project. • For solar installations, if the repowering does not involve the use of additional space, and comply with environmental mitigation measures, the project is exempt from EIA.
Heat pumps	• Maximum limit of 1 month for the authorization procedures for heat pumps of less than 50 MW and 3 months in the case of geothermal heat pumps. • For heat pumps under 12 kW and those of self-consumers under 50 kW, connections to the transmission or distribution are allowed upon notification. • Member States may exclude from simplifications certain areas or facilities to protect the cultural heritage or national security.

1.1.2 RED III

The revision of the EU Directive 2018/2001 ("RED II") is part of the *Fit for 55* Package. This package aims to adapt existing climate and energy legislation to achieve a 55% reduction in greenhouse gas emissions by 2030, compared to 1990 levels.

The proposed directive (RED III) states that the share of renewable energy in the Union's final energy consumption will be 42.5% by 2030. The Member States Council is encouraged to reach a 45% share.

To this end, it is expected that the authorization procedures for renewable energy production plants will be significantly simplified. These plants will be recognized as having an overriding public interest, while still maintaining a high level of environmental protection.

In areas with a high potential for renewable energy and low environmental risk, Member States will establish dedicated acceleration zones for renewable energy. These zones will have particularly simple and fast permitting procedures.

In the summer of 2023, the EU Council reached an agreement on the content of RED III. The agreement was made after months of opposition from several Member States, led by France, which opposed the exclusion of hydrogen produced from nuclear energy in the definition of 'low-carbon hydrogen'.

In line with the *Green Deal* and *REPowerEU*, the European Parliament in plenary gave its final approval to RED III on September 12th 2023.

Table 2: Key points of the RED III

Transport sector	• 14.5% reduction in greenhouse gas emissions' intensity, or alternatively in a share of 29% of renewables in final energy consumption. • Envisaged as a sub-objective is the reaching of a 5.5% quota of advanced biofuels and renewable fuels of non-biological origin (i.e. hydrogen), as well as a minimum level of 1% of renewable fuels of non-biological origin (i.e. hydrogen).
Industry	• An important novelty contained in the agreement is the inclusion for the first time in the RED III directive of a highly energy-intensive sector such as industry. A choice that represents a further step in the EU's strategy to decarbonize the European industrial sector, in the wake already traced by the recent presentation of the European Green Deal industrial plan. • Indicative objective of the 1.6% annual increase in renewable energy use in the industry sector. • Binding target of the attainment of 42% usage of renewable hydrogen compared to the total consumption of hydrogen in industry.
Heating and cooling	• Reinforcement of annual objectives concerning renewables for the heating and cooling system and renewables used for district heating. • Introducing a reference of 49% of renewables for energy consumption from buildings by 2030.
Use of bioenergy	• Promoting more use of sustainable bioenergy. • Defining more stringent requirements for the qualification of the use of bioenergy as sustainable. • In the future, these criteria will also apply to smaller plants (equal to or more than 7.5 MW) instead of limit itself to the threshold of 20 MW provided for in the current Directive.

1.2 Authorization procedure for BESS in Italy

Numerous guidelines and regulations convey the energy transition, outlining future scenarios, objectives, and progress steps to pursue them.

The *Fit-for-55* package, *RePowerEU*, *Next Generation EU* at the European level, and the Italian implementing decrees, particularly Legislative Decree no. 199 of 08/11/2021 (RED II), the National Recovery and Resilience Plan (PNRR) and the National Integrated Energy and Climate Plan (PNIEC), outlined the country's objectives for implementing EU guidelines:

- increasing the EU target for RES to 45% by 2030;
- new installed renewable capacity equal to 85 GW;
- new storage capacity equal to 80 GWh.

Most of the new storage capacity will be in large-scale storage facilities, mainly located in the south where the greatest photovoltaic capacity is expected. The accumulations will be distributed throughout the peninsula to cope with the instability caused by the spread of non-programmable renewable sources.

1.2.1 DL 07/02/2002 No. 7

The regulations governing authorizations for storage facilities are outlined in Article 1 of Decree-Law no. 7 of 7 February 2002, which was converted, with amendments, by Law no. 55 of 9 April 2002.

This regulation was subsequently supplemented by Article 62, paragraph 1, of Decree-Law no. 76 of 16 July 2020 (the Simplification Decree) and subsequent amendments, as well as Article 31 of Decree-Law no. 77 of 31 May 2021 (Simplification Decree-Law bis) and subsequent amendments.

The authorization procedures for accumulations fall into one of the following categories:

- Simplified Qualification Procedure (PAS)
- Single Authorization procedure (AU)
- Modification procedures pursuant to Legislative Decree no. 387/2003
- Free construction

The size of the facility, location, coupling with other energy production plants, and occupation of new areas are the discriminating factors for authorization.

Storage authorized using PAS

According to the regulations, storage will be authorized through a simplified municipal authorization procedure pursuant to art. 6 of Legislative Decree no. 28 of 2 March 2011, if certain conditions are met.

These conditions include no extension of the storage areas, no increase in footprint compared to the existing situation, and no variation to the urban planning instruments.

Furthermore, the storage facility must be situated within areas where industrial plants or electricity production plants powered by renewable sources or fossil sources with a capacity of less than 300 MW in service are located, or in areas where quarry or hydrocarbon treatment facilities are being decommissioned.

In general, the Simplified Qualification Procedure (PAS) requires fewer steps than the Single Authorization procedure (AU) and therefore involves shorter waiting times.

The PAS declaration must be submitted to the competent Single Building Office (SUE at the Municipal Private Building Technical Office) at least thirty days before the actual start of works (pursuant to Article 6, paragraph 2, Legislative Decree No. 28/2011).

If, within the aforementioned period of thirty days for the completion of the PAS (starting from the date of submission of the PAS itself to the protocol of the Municipality of reference), it is established by the Municipal Offices that one or more of the conditions established by Article 6, paragraph 2, of Legislative Decree no. 28/2011 are not met, the Municipality of reference will immediately inform the interested party of the reasons preventing the formation of the tacit consent in accordance with Art. 10-bis of Law No. 241/1990, also requesting, if necessary, also the integration of the documentation already submitted as an annex to the PAS, to be sent within 10 days of receipt of the request.

In this case, the 30-day period for the completion of the documentary control procedure by the Municipality is interrupted and restarted from the date of submission of the required documentation.

The implementation of the intervention must be completed within three years from the completion of the PAS.

However, the interested party is obliged to inform the Municipality of the date of completion of the works and, consequently, to submit a certificate of final acceptance of the works performed, issued by a qualified technician, certifying the conformity of the works with the project submitted with the PAS declaration.

If the works subject to PAS have not been completed within the aforementioned three-year period, the execution of the unfinished part of the intervention is subject to the submission of a new PAS declaration, which should be accompanied by documentation relating only the unfinished part.

It is noted that these timelines refer to renewable energy systems and do not address storage systems specifically.

Storage authorized using AU

Storage facilities located in areas with electricity production plants powered by fossil fuels of P>300 MW thermal in service and stand-alone plants in non-industrial areas are subject to a Ministerial Single Authorization (in accordance with the provisions of Article 1 of Decree-Law no. 7 of 7 February 2002, converted, with amendments, by Law no. 55 of 9 April 2002).

The storage to be operated (in combination or not) with newly constructed RES plants must be authorized by an AU issued by the region or delegated provinces, in accordance with the provisions of art. 12 of Legislative Decree no. 387 of 29 December 2003.

According to art. 1 paragraph 2-quater of Legislative Decree no. 7 of 07/02/2002, the BESS and the grid connection works will be authorized with the Ministerial Single Authorization "AU" procedure issued by the Ministry of Environment and Energy Security, MASE - "*Ministero dell'Ambiente e della Sicurezza Energetica*", pursuant to art. 12 of Legislative Decree no. 387/2003.

According to Legislative Decree 387/03 the Single Authorization lasts approximately four months. After obtaining the Single Authorization decree, there is a challenge period to reach the Ready to Build (RtB) status, during which the project may be subject to appeal.
The challenge period is 60 and 120 days, respectively, to file claims before the regional administrative court (TAR – *"Tribunale Amministrativo Regionale"*) and before the President of the Republic.

Article 3 of the Legislative Decree no. 7/02 should be consulted for further information. If the BESS projects involve changes to the urban planning instruments, the release of the Single Authorization has the effect of an urban planning variation.

It should be noted that stand-alone BESS projects, regardless of their location, are not subject to the screening EIA or EIA procedures.
The only exception would be if such procedures were required for the related connection works, as outlined in annexes II and II-bis of Legislative Decree no. 152/2006, specifically:

- Overhead power transmission pipelines with a rated voltage exceeding 100kV and a route length greater than 10 km are subject to the EIA State procedure (pursuant to Annex II to Part II, no. 4-bis Environmental Code);
- Aerial cables that are above 100kV and have a length over 3 km are subject to the State EIA screening procedure (pursuant to Annex II-bis to Part II, no. 1 letter d) Environmental Code).

The positive conclusion of the Technical Meeting "*Tavolo Tecnico*" with Terna[3], the consequent definition of the RTN *"Rete di Trasmissione Nazionale"* (National Transmission Power Grid) works with the submission of the PTO "*Piano Tecnico delle Opere*" (Technical Plan of the Works) and the formal approval by Terna should be obtained before the end of the Single Authorization procedure.

Here is an overview of the assessment of project permitting timelines and expected RtB dates.

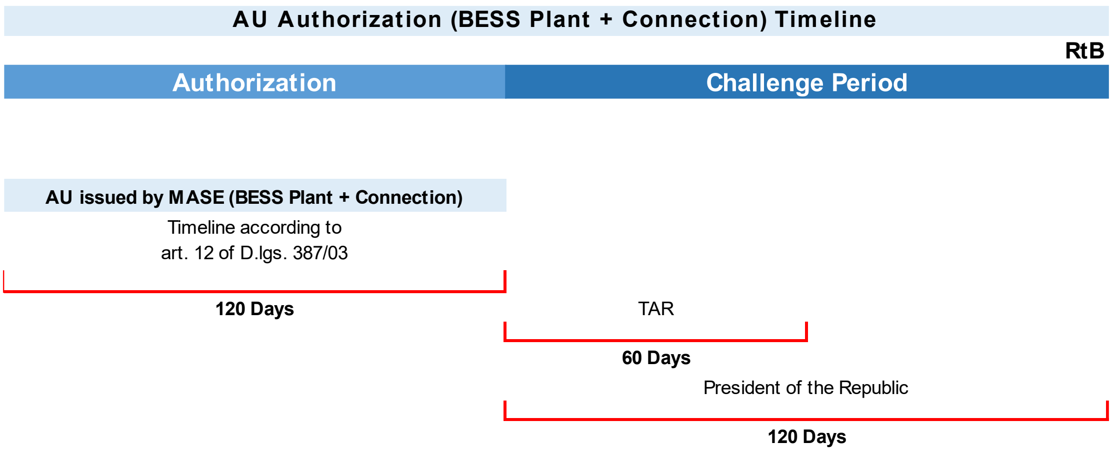


Figure 4: AU authorization timeline for a BESS plant

[3] Terna – *"Rete Elettrica Nazionale S.p.A."* is an Italian company that operates electricity transmission networks.

In reality, the time it takes for authorities to comply with the terms can range from 30 days to a maximum of 6 months. However, situations where the release of authorization has taken 1 year or more have been encountered. This typically occurs when the authorities do not fully understand the asset or are not well-informed about it.

Storage authorized by Modification Procedure

Storage to be operated with existing RES plants are authorized through a modification procedure according to art. 12 paragraph 3 of Legislative Decree no. 387 of 29 December 2003, as long as the storage does not involve the occupation of new areas beyond the existing plant.

Storage in free building activity

Any type of storage, regardless of their location, with a power of less than 10 MW is considered a free building activity and does not require permits, with the exception of the acquisition of the acts of consent as required by Legislative Decree no. 42 of 22 January 2004, and all necessary opinions, authorizations and clearances from the relevant authorities.

Entities planning to construct similar facilities must provide the National Transmission System Operator with a copy of the relevant project. The operator may provide comments within 30 days if a connection to the national electricity grid is necessary. The comments will also be sent to the entities responsible for issuing authorizations, who must inform the operator to monitor the progress towards achieving the national energy storage targets outlined in the Integrated National Energy and Climate Plan. Entities responsible for constructing storage facilities must inform the national transmission grid operator of the operational date.

It is noted that these timelines refer to renewable energy systems and do not address storage systems specifically.

Environmental Assessment

Projects may undergo an environmental assessment procedure to exclude negative impacts on the environment, in addition to authorization for construction and operation, depending on their characteristics.

According to Article 1, paragraph 2-quinquies of Decree 7/2002, stand-alone storage facilities and their connections to the electricity grid (referred to in paragraph 2-quater letters (a), (b), and (d)) are per se excluded from environmental procedures (screening EIA or EIA) unless the related interconnection works are themselves subject to such procedures.

Therefore, it is important to determine if the connections for stand-alone plants fall under the regulations for screening EIA or EIA (Articles 19 and Article 23 of Legislative Decree 152/2006).

Storage systems that are not designed as stand-alone will undergo the environmental procedure of the associated renewable energy plant.

Temporary exemptions from environmental procedures are applicable until June 30th 2024 for storage systems, including the related connection works. These exemptions apply to storage systems that are ancillary to new photovoltaic plants with a capacity of up to 30 MW, as well as those envisaged under renovation/revamping/repowering of existing PV plants up to 50 MW or designed as stand-alone facilities to store energy from renewable energy plants located on suitable areas under Legislative Decree 199/2021. These exemptions apply only if such areas are contemplated under planning instruments that have received a positive Strategic Environmental Evaluation (SEE).

Additional common authorization aspects

Additional permitting issues may be relevant to the permitting process, depending on the technical characteristics of the batteries and the configuration of the storage facility, whether it is stand-alone or integrated with production facilities. In particular, the following additional permits/assents may be required during the permitting process:

- A preliminary assessment from the Fire Department;
- Facilities operating with hazardous substances may require certain actions to prevent major-accident hazards, depending on the quantity and quality of the substances;
- When storage systems are integrated with power generation plants operated by the GSE[4], they must comply with the provisions set out in the 'Technical Rules for the implementation of the provisions related to the integration of storage systems for electricity in the national electricity system' as per ARERA[5] Resolution. The specific category of the storage system and the resulting level of risk for fire prevention will determine the applicable rules;
- Depending on the risk level associated with the electrochemical substances stored, it may be necessary to submit a notification to the regional technical committee, the region, MASE, the fire department, and the municipality. The notification should contain specific information about the facility, and a safety management report should be prepared. Prior consent from the technical committee attesting to the feasibility of the project is required before the permit is issued.

[4] GSE (Energy Services Manager). is an Italian joint-stock company, owned by the Ministry of Economy and Finance, which is entrusted with the promotion and development of renewable sources and energy efficiency.

[5] "*Autorità di Regolazione per Energia Reti e Ambiente*", Regulatory Authority for Energy, Networks and Environment.

For the purposes of repowering interventions, Art. 20, par. 8 , of RED II Decree provides under let. A) that are intended as "*suitable*", inter alia, "*for PV plants only, the sites where […] there are PV plants on which, without modification of the occupied area or in any case with variations in the occupied area within the limits set forth under letter c-ter), number 1) (i.e. 500 m), substantial modification works are carried out for the purpose of refurbishing, repowering or complete reconstruction, also with the addition of storage systems with a capacity not exceeding 8 MWh for each MW of power of the PV plant*".

Based on this provision, the buffer of 500 m from the authorized area of the existing PV plants can be considered as "suitable areas".

Recently, new suitable areas have been introduced, such as airports, public areas (known as "*aree demaniali"* according to art. 16 DL 13/2023, e.g. ports), as well as areas along roadways and railways, which are usually subject to concession. However, it is important to note that the renewable energy authorization framework should be the specific source of regulation on this subject matter.

2. TECHNOLOGICAL FRAMEWORK

2.1 First developments

The history of energy storage systems dates back to various technologies that emerged over the years.

Here are some key milestones in the early development of energy storage systems:

Battery Development:

- Voltaic Pile (1800): Alessandro Volta invented the voltaic pile, considered the first chemical battery. It consisted of alternating layers of zinc and copper separated by cardboard soaked in saltwater, producing a continuous electric current.
- Lead-Acid Battery (1859): Gaston Planté developed the lead-acid battery, a significant advancement in energy storage technology. This type of battery became widely used in various applications, including early automobiles.

Pumped Hydroelectric Storage:

- It was introduced in the late 19th century as a means of using excess electrical energy to pump water uphill and then release it later to generate electricity. This technology is still used today for grid energy storage.

Flywheel Energy Storage:

- The idea of using a rotating flywheel to store energy was explored in the early 20th century. The energy was stored in the kinetic motion of the spinning flywheel and could be converted back into electricity when required.

Compressed Air Energy Storage (CAES) (late 20th century):

- CAES involves compressing air and storing it in underground caverns. When electricity is demanded, the compressed air is released, and the expansion is utilized to generate electricity. The first commercial CAES plant was built in the 1970s.

Advancements in Battery Technology (late 20th century to early 21st century):

- The development of new materials and chemistries, such as lithium-ion batteries, marked a significant leap in energy storage technology. Li-ion batteries gain popularity for portable electronics and later found applications in electric vehicles and grid storage.

Grid-Scale Energy Storage (21st century):

- Growing concerns about renewable energy integration and grid stability have led to increased interest in large-scale energy storage systems. Technologies such as advanced batteries, pumped-hydro storage, and thermal energy storage have been deployed for grid-scale applications.

These early developments laid the foundation for the diverse and rapidly evolving landscape of energy storage technologies we see today. Ongoing research and innovation are driving advancements in energy storage, which play a crucial role in the transition to a more sustainable and resilient energy infrastructure.

IRENA (International Renewable Energy Agency) reports that energy stored with storage systems will increase from 4.67 TWh to 13 TWh between 2017 and 2030. This aligns with the objectives of *Fit for 55*, the European Union's program to rapidly achieve net zero emissions of carbon dioxide.

Furthermore, the significance and profitability of these services are supported by the substantial growth achieved in just six years. In 2015, the global capacity of storage systems installed in electricity systems was 0.8 GWh, which has since increased to 8.3 GWh in 2021.

According to the International Energy Agency (IEA), as reported in the article (G.B. Zorzoli, 2022), utility-scale battery installations are projected to reach 10 TWh globally by 2040.

In Italy, the capacity of electrochemical storage combined with photovoltaic plants has increased significantly from 1.62 MWh installed in 2015 to 220.09 MWh in the first nine months of 2021, in which has more than doubled from 102.02 to 220.09 MWh.

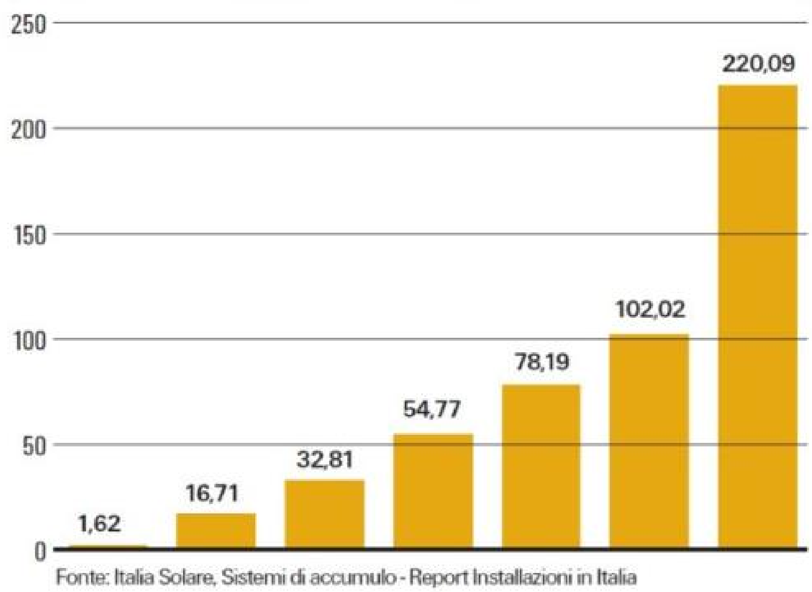


Figure 5: Growth of PV storage systems in Italy (installed capacity per year in MWh)

It is not surprising that batteries are the focus of significant research, development, and innovation activities in the electrical sector. This has resulted in batteries being at the top of the ranking for the number of patents applied for in the electricity sector.

Additionally, research is being conducted on technologies that can overcome the inherent limitations of lithium-ion batteries. These batteries can only store the energy produced by the plant they are combined with for a few hours, typically 1-2 hours, at a reasonable cost. This condition severely limits the performance of power shifts.

The decreasing cost of lithium-ion batteries will enable the installation of energy storage systems that can compete in terms of longer storage duration. However, progress in this area is slow and must also address the challenges posed by increasing dimensions.

In the following paragraphs, a closer look at these technologies will be taken from a technical and operational standpoint, going through the different types that characterize this sector and their strengths, as well as the critical issues.

2.2 Technology landscape

Currently, there is a wide range of storage technologies available, but not all of them are mature enough to participate in auctions.

The three main options are: pumped hydropower, lithium-ion batteries, which are the most widespread and advanced in the world of electrochemical storage to date, and flow batteries, which although further behind, still seem to be a promising technology.

The different technologies vary in cost and implementation time. In terms of efficiency (*round trip efficiency*[6]), lithium batteries have the highest values.

However, the energy that can be fed back into the grid is lower than the energy used to recharge due to energy losses, resulting in an efficiency of about 80-90%. Flow batteries, on the other hand, have a slightly lower efficiency of 70-75%.

In terms of costs, all technologies have varying levels of expense in both kW and kWh. However, emerging technologies have a higher potential for cost reduction compared to established ones.

Technologies differ based on their energy storage capacity and response times, making them more or less suitable for various purposes. For example, a supercapacitor can be an excellent choice if very fast discharge times or very low response times are needed. On the other hand, pumped-hydro or power-to-gas are more suitable if the system must be able to store a lot of energy, as they are capable of storing many GWh of energy.

Energy storage can occur in two ways: energy intensive or power intensive. The former refers to systems designed to alleviate grid congestion resulting from excessive wind or solar power production in areas where the grid cannot absorb all the energy produced.

In the second case, the systems are required to absorb and/or deliver a significant amount of power in a short time for short periods to modulate the production phases of photovoltaic and wind power.

Below is a brief description of the current systems in the technological landscape.

[6] The ratio between the energy that a battery can feed into the grid in a complete cycle and the energy it must absorb from the grid to fully charge.

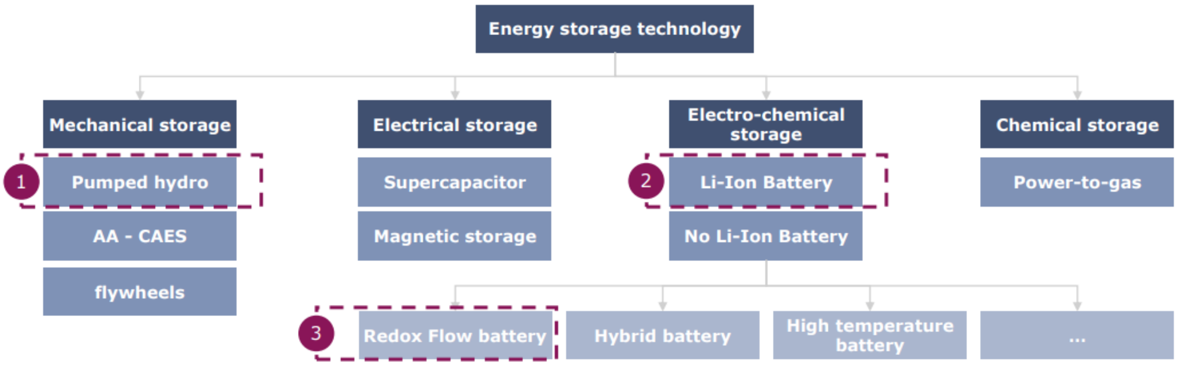


Figure 6: Illustrative diagram of energy storage technologies
Source: AFRY analysis

2.2.1 MECHANICAL STORAGE

Mechanical systems such as pumped hydroelectric systems, compressed air energy systems, and flywheel energy systems are used in the management of non-programmable renewable energy sources.

<u>Pumped-Hydro Storage systems (PHS)</u>

Starting from the PHS, the systems have now been consolidated into basic systems that transform surplus electricity into gravitational hydroelectric potential.

This system stores electricity during periods of low demand by pumping water from the low-altitude basin to the high-altitude basin. It also serves as a source of electricity production during periods of high demand due to the mass of water in the high-altitude basin, which powers the turbine.

The number and timing of operation reversals are dependent on the type of hydraulic machine installed, whether it is reversible or has a pump and separate turbine.

The PHS storage system offers several advantages. In addition to being technologically mature, it is the most widely used storage solution and is available in various sizes, ranging from small to large powers (up to tens of GW).

Moreover, the system boasts an efficiency rate of 60-80% and provides immediate access to stored energy. The system's core operator fluid is water, which is both free and environmentally friendly.

Finally, it has a high storage capacity.

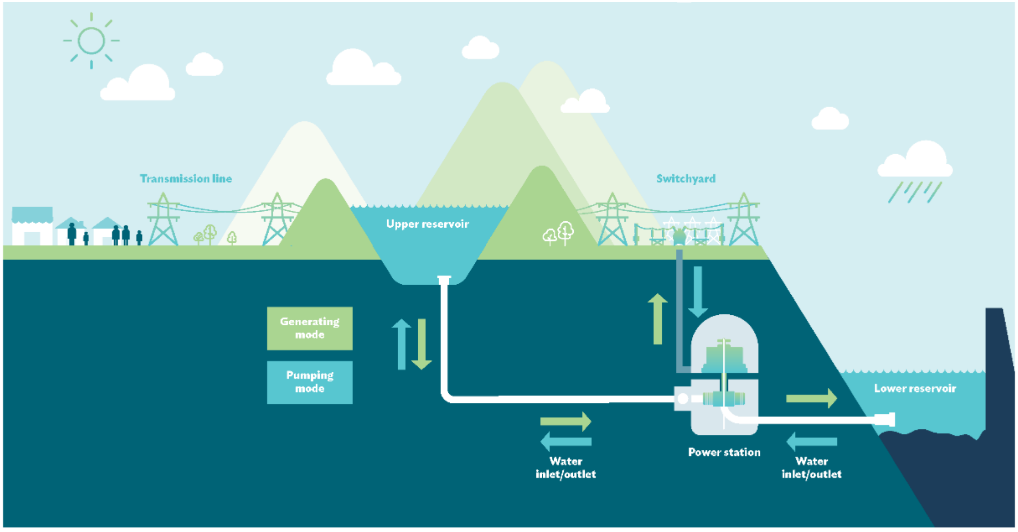


Figure 7: Diagram of the operation of pumped hydroelectric storage system
Source: Hydro.com.au

<u>Compressed Air Energy Storage systems (CAES)</u>

CAES-type storage systems are equally valid. They store surplus electricity by converting it into compressed air, which can be stored in underground and hermetic caverns, such as disused natural gas or salt quarries.

This system, depending on its declination, adiabatic or not, can also be integrated with fossil fuel for a surplus of power during the return phase.

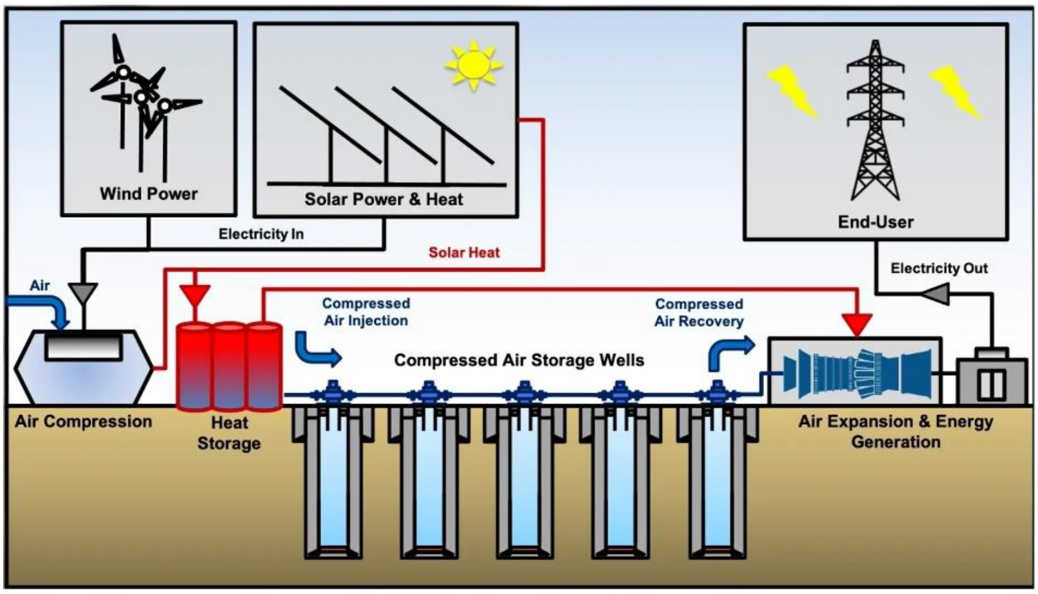


Figure 8: Diagram of the operation of CAES
Source: lakesblueenergy.com.au

Flywheel Energy Storage (FES)

FES systems are useful for quickly dampening fluctuations in energy produced by wind and photovoltaic farms, but they are not suitable for long-duration storage.

They are used in cases of rapid response and in aid of grid stability due to their economic nature.

The energy is stored in the form of kinetic energy.

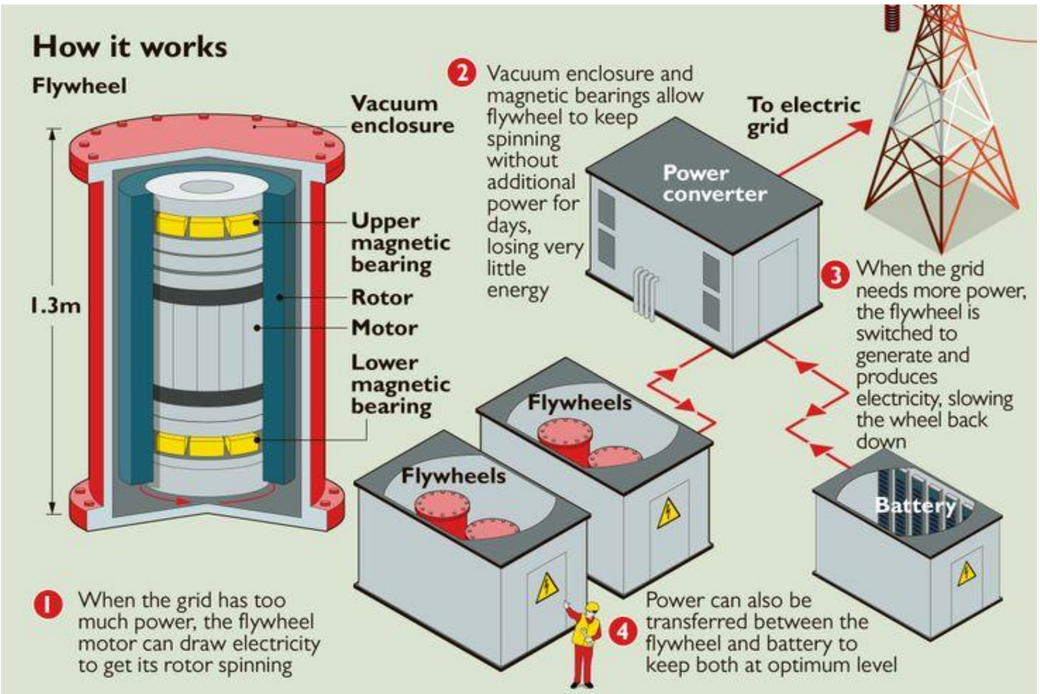


Figure 9: Diagram of the operation of flywheel energy storage system

Source: thetimes.co.uk

2.2.2 CHEMICAL STORAGE

Power-to-Gas

Power-to-Gas is a promising technology that uses electricity to produce a gaseous fuel.

This technology allows for the direct exploitation of renewable resources, both programmable (biomass of plant or animal origin) and non-programmable (wind and photovoltaic), through the production of hydrogen and synthetic methane.

The system is fundamental because it enables us to depend on methane produced solely from renewable sources. This methane can be used to generate electricity and can also be transported through existing gas networks.

Therefore, it is possible to generate electricity from renewable sources by relying on two essential elements: a potentially infinite storage capacity provided by the gas network and the ability to transport electricity production in a relatively simple way, utilizing existing infrastructures.

Although its efficiency is currently low, it has high potential for a full energy transition.

2.2.3 ELECTRICAL STORAGE

Supercapacitors

Supercapacitors are electrochemical energy storage devices that can be fully charged or discharged in seconds.

They have attracted significant research attention over the past decade due to their higher power density, low maintenance cost, wide thermal operating range, and extended lifecycle compared to secondary batteries. Additionally, they have a higher energy density compared to conventional dielectric capacitors.

The storage capacity of a supercapacitor is determined by the electrostatic separation between electrolyte ions and high surface area electrodes. However, their lower energy density compared to Li-ion batteries impedes their widespread use.

To meet the demands of future systems, from portable electronics to hybrid electric vehicles and large industrial equipment, improvements in supercapacitor performance are necessary.

Magnetic storage

Superconducting magnetic energy storage (SMES) systems store energy in a magnetic field generated by a DC current traveling through a superconducting coil.

Unlike normal wires, which lose energy as heat due to electric resistance, the wire in a SMES system is made from a superconducting material that has been cryogenically cooled below its critical temperature. Electric current can pass through the wire with almost no resistance, allowing energy to be stored for a longer period of time. Common superconducting materials, such as mercury, vanadium, and niobium-titanium, are used.

To discharge the energy stored, an AC power converter is connected to the conductive coil.

SMES systems are highly efficient, but have very low energy densities and are still far from being economically viable.

2.2.4 ELECTROCHEMICAL STORAGE

In the field of energy storage systems, batteries are playing an increasingly significant role.

There are various types of batteries available, each with unique characteristics, ranging from lithium solutions to flow batteries. The latter, in particular, are considered the most advanced technology and subject of extensive research.

Li-ion batteries

Li-ion battery technology has been present for decades in portable electronic devices and power tools. Recently, it has gained popularity in large-scale grid applications, with significant research aimed at improving energy density, reducing costs, increasing charging speed, and enhancing safety.

Furthermore, there are constant advances being made in the system level of large-scale batteries in order to enhance overall efficiency and the performance of control systems, power electronics, and HVAC (Heating, Ventilating and Air Conditioning).

This section focuses on the advantages and properties of Li-ion cells, the general layout of large-scale BESS, and the possible applications for stationary energy storage, considering the present status of the technology.

Li-ion cells operate on the same principle as most electrochemical batteries, consisting of a cathode, anode, separator, and electrolyte.

The cathode is made up of a lithium metal oxide, while the anode is primarily composed of graphite. The separator is a porous polymeric material, and the electrolyte is a lithium salt dissolved in an organic solvent.

Li-ion cell types are differentiated based on the lithium-ion donator in the cathode, which determines the cell properties. Compared to other metals used in energy storage technologies, lithium offers benefits such as being non-toxic, lightweight, and electropositive. However, its high reactivity creates severe safety issues.

Table 3 presents the main benefits and drawbacks of Li-ion cells.

Table 3: Strengths and weaknesses of Li-ion batteries

Strengths	Weaknesses
• High specific energy and power • Long calendar and cycle life • High round-trip efficiency • Adequate operational temperature range • High reliability • Diversity with distinct chemistry • Low self-discharge rate • Satisfactory charging speed	• High capital cost • Advanced BMS (Battery Management System) required • Safety incidents with thermal runaway • Material bottleneck • Weak recovery and recycling

Undoubtedly, Li-ion batteries are advantageous due to their high specific energy, which can reach up to 250 kWh/kg for commercially available products. This allows for significant size reduction, making them highly beneficial for portable devices.

Additionally, when combined with their high power capability, this technology has proven to be suitable for electric vehicles (EVs) and energy applications, both grid-tied and off-grid.

Despite the technological advantages, Li-ion BESS have two very significant drawbacks:

- Li-ion batteries are expensive, and although the cost has decreased drastically in recent years, it remains high, making many large-scale energy applications non-viable;
- Building safe battery cells that contain lithium is complex, and additional measures are required to protect against thermal runaway incidents. To avoid using metallic lithium, compounds that donate lithium ions are utilized.

<u>Li-ion stationary storage system's composition</u>

The layout of a large-scale Li-ion BESS consists of several subsystems that enable operation, control, thermal management, and grid integration based on a modular configuration.

The main elements include the battery system, the system coupling, and grid connection, as shown in *Fig. 10*. Appropriate sizing is crucial to optimize overall performance and revenues.

Furthermore, due to the degradation of Li-ion cells over time, large-scale BESS often need to be oversized and/or include the possibility of re-stacking. Therefore, the modularity of individual components is indispensable.

It is important to note that the implementation scope of each subsystem can vary depending on the BESS manufacturer, the engineering, procurement and construction (EPC) contractor, and the project environment.

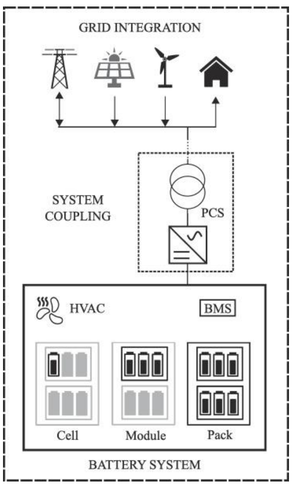


***Figure 10*: Illustrative layout of a Li-ion stationary storage system**
***Source*: Science direct**

The Battery System's core consists of **battery packs**, which are typically the smallest commercially available modular battery component. Each battery pack contains several **modules** set up at the same voltage level, each containing hundreds of small Li-ion cells.

The **HVAC system** is responsible for maintaining the battery packs within the permitted operational temperature range. The energy required to operate the HVAC can significantly impact the efficiency and performance of the BESS.

The **Battery Management System** (BMS) is responsible for managing the battery's energy, including charge/discharge rate, state of charge (SoC) limitations, balance of plant (BoP), status monitoring, and internal power electronics if applicable.

The **System Coupling** consists of a power conversion system (PCS) that is necessary to adjust the output signal of the Battery System to the point of interconnection (PoI) with the grid.
This typically involves a DC/AC power inverter, as well as a transformer to increase the voltage if the PoI is at medium voltage (MV) or higher.
The inverter may be integrated directly into the battery system or deployed externally, depending on the BESS architecture, which can be either module-integrated or centralized. The step-up transformer is typically outside the enclosed battery system.
In addition to the PCS, the System Coupling also includes all physical lines and/or cables, as well as protection schemes.

Grid integration refers to all the components that enable the interaction with adjacent systems. These include, for example, directly connected loads, renewable energy sources like PV plants and wind farms, and distribution or transmission grids in large electric networks, as well as entire micro-grids.

The elements that facilitate grid integration are centered around data acquisition, monitoring, and control of all involved components. This can be achieved through the use of metering units and SCADA systems (Supervisory Control and Data Acquisition), overall system-level control to improve energy dispatch of one or more applications, and potential operational optimization to maximize revenue streams and enhance market participation.

In this context, researchers have explored alternative solutions, such as reducing the percentage of cobalt or combining lithium with more readily available elements like silicon or even oxygen.

In addition to the challenge of sourcing certain materials, particularly cobalt, and the socio-political issues, lithium degradation is also a significant concern, resulting in a decrease in battery performance and storage capacity. In fact, the battery's performance decay accelerates with each complete and deep cycle it performs. Additionally, poorly managed temperatures during use can accelerate degradation, which is inevitable but can be slowed down with proper precautions.

Frequently, a battery is introduced to the market with incentives that require specific operating obligations. In certain situations, these obligations may necessitate a battery performance that consistently remains above a specific threshold. This can be achieved by either initially oversizing the battery (e.g. designing it to guarantee 2.5 hours instead of 2) or periodically increasing its capacity by adding cells every x years. This augmentation can be done without having to replace the inverter.

Furthermore, there is a growing emphasis on end-of-life management by studying processes that enable the production cycle to be 'closed' by improving the recycling of critical materials. According to data from the Global Battery Alliance, 11 million tons of lithium-ion batteries will reach the end of their life by 2030.

Various possibilities are being studied for reusing lithium batteries to create a virtuous circular economy process.

<u>Useful life</u>

The useful life of a battery energy storage system refers to the period during which it can reliably charge, store, and discharge energy for a specific application.

If a battery is used beyond its useful life, it will degrade unpredictably and lose its ability to store energy at an accelerated rate, eventually becoming unable to hold a charge.

The lifespan of a BESS depends on the lifespan of each individual battery cell, and its performance is determined by how the cells are integrated, operated, maintained, and balanced. If the cells degrade at different rates, it can significantly reduce the system's energy capacity or, in the worst case, cause the cell to overheat and fail.

The transition from predictable (generally linear) to accelerated degradation is often referred to as the "knee" or "shoulder" in the degradation curve and should be avoided. Predicting the knee in a BESS degradation curve is challenging due to the multiple factors involved in integrating and controlling the batteries to meet project-specific requirements.

Manufacturers and integrators typically limit daily and/or annual usage of a battery, known as 'throughput', to convert its useful life into years. This is necessary when developing a maintenance and replacement schedule for a project, as a battery's useful life is highly dependent on its use case.

Although stationary BESS typically have warranties ranging from 10 to 25 years, these warranty periods are usually achieved by augmenting the system with batteries during operations. Currently, there are very few stationary batteries on the market that have been operating for 15+ years, despite many new storage projects having warranty periods that exceed this.

The useful life of an individual battery may be shorter than the warranty period, depending on its application. According to DNV[7], the useful life of individual batteries is considered to be 10 to 20 years or when the batteries have degraded to 60-65% of their initial energy capacity, whichever comes first.

Battery safety

The safety features of the design are crucial and require thorough vetting, just like performance.

Safety is a critical aspect of an energy storage system, starting from the battery cell and extending to every stage of the product's lifecycle. This is based on both code requirements and best practices.

[7] DNV is an international accredited registrar and classification society that provides services for several industries, including renewable energy.

Battery safety has become a central focus in evaluating battery products and projects due to high-profile battery fires that have made global news, such as the Victoria Big Battery fire in July 2021 and London Buses in May 2022.

The industry is learning from these events, with root cause analyses becoming more commonly publicly released.

With wider deployment, the industry must continue to reduce failures to avoid widespread loss of equipment, environmental impact, or worse, and in turn, lose confidence from consumers and regulators.

Industry-standard test methods, such as UL 9540A (Test Method for Evaluating Thermal Runaway Propagation in Battery Energy Storage Systems), are critical for obtaining approval from permitting authorities for stationary storage applications.

UL 9540A is a test method, not a standard for determining whether a battery passes or fails. Instead, the test results provide essential information for system design, spacing, siting decisions, and emergency response plans. The method involves a series of tests, starting from individual cells to modules, units, and installations, as shown in *Figure 11*.

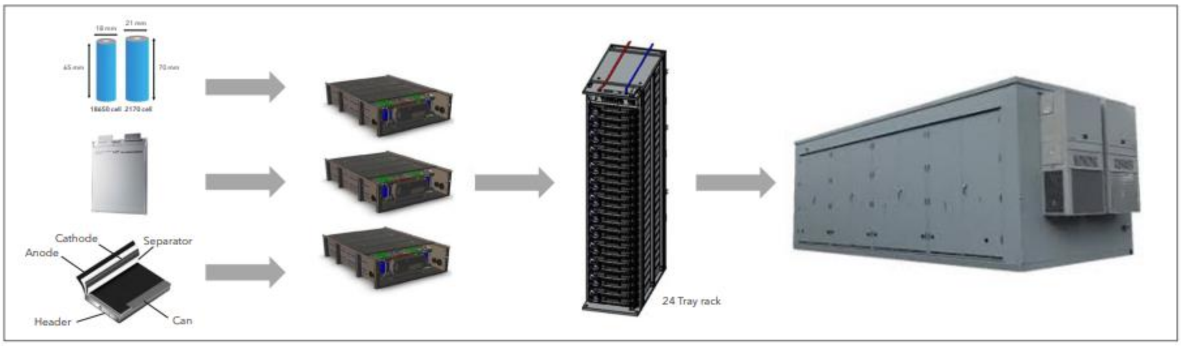


Figure 11: UL9540 testing is conducted at the cell, module, unit (racks), and installation (system level)

Source: DNV 2022 Battery scorecard

Redox flow batteries

Flow batteries are considered one of the most promising solutions for future storage systems connected to renewables.

Unlike lithium batteries, which use solid electrolytes, flow batteries utilize liquid electrolytes that are contained in special tanks. There is no degradation issue as it is easier to renew the electrolytes to maintain a constant charge in the system. However, this method requires more space and uses substances that are considered more toxic. Liquid electrolytes, for example, contain vanadium. As a result, obtaining authorization for this method may become more complex.

Flow battery storage systems are constructed using raw materials that are less critical in terms of availability and have a limited environmental impact compared to lithium batteries, making them more sustainable.

In terms of their potential in the service market, both lithium and redox flow batteries have similar capabilities due to their fast response times.

Flow batteries have a unique technology that allows for unconstrained stored energy and power delivery. This makes them an ideal choice for storage systems connected to renewables, particularly for uses with long discharge durations and energy-intensive services rather than power-intensive ones.

Flow batteries are currently considered a technology in the growth phase. Further developments are necessary to reduce their cost and increase their overall efficiency compared to the standards guaranteed by lithium systems.

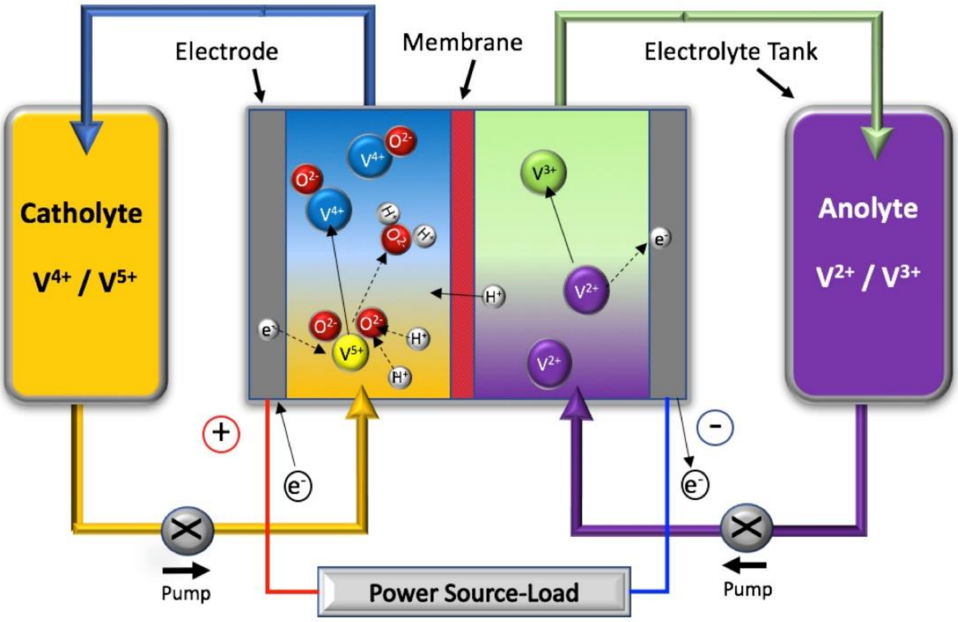


Figure 12: Diagram of operation of a redox flow battery
Source: nockemann-lab.org

Associated Risks

There are supply chain issues related to batteries, as most major suppliers are concentrated in Asia, particularly China. This creates a heavy reliance on these suppliers, with limited global distribution.

The possibility of a repeat of the situation that occurred with gas is being considered. For decades, the gas market was heavily reliant on Russia, but a negative shift in the geopolitical situation had a detrimental impact. Therefore, a shift towards batteries could result in dependence on third-party countries for the supply of energy and raw materials necessary for asset development.

Furthermore, the extraction of battery raw materials is not always conducted with a sustainable approach. Specifically, lithium extraction in certain regions of South America involves the use of significant amounts of water diverted from other economic sectors or sources of livelihood for local populations. This can have negative impacts on the environment and the community. It is important to consider the sustainability of these activities.

Then, there are risks related to the chemical composition, such as potential leaks of pollutants. For example, the rupture of a tank of a redox battery could result in the release of toxic liquids into the environment. Lithium batteries also pose risks related to overheating and fire, known as *thermal runaway*. This is a self-sustaining process that, if not properly treated and controlled, can accelerate the asset's degradation and lead to serious damages and accidents to the plant or to people and things working with the battery itself.

Safety

Batteries that are exposed to overheating, short circuits, or internal faults may release gases and, in some cases, reach **thermal runaway**. It is crucial to comprehend the temperatures at which venting and thermal runaway occur, as well as the composition of the vent gases, to ensure safe design and operation.

When considering thermal runaway, two temperatures are of utmost importance. The first is the cell venting temperature, which is the temperature at which gases build up within the cell and are released through the pressure release vent to prevent the cell's casing from rupturing. The second temperature is the onset temperature, which is the point of no return for the cell. At this temperature, uncontrollable self-propagating reactions involved in thermal runaway begin.

Although cells may reach temperatures as high as 1000 °C, it is important to monitor and control the temperature at which these reactions begin to avoid thermal runaway. This will help determine the necessary mechanisms for avoiding thermal runaway altogether.

Preventing cascading effects of one cell’s thermal runaway causing other cells to also reach thermal runaway is a key aspect of battery system design and control mechanism.

Figure 13 shows that cells from different manufacturers and chemistries have vastly different venting and thermal runaway onset temperatures.

It is generally recommended to maintain a higher degree of separation between the gas venting and thermal runaway onset temperatures, particularly if gas detection is available within the energy storage system. Early detection of gas provides more time to catch an overheating cell and prevent thermal runaway from occurring altogether. If the venting and runaway temperatures are closer together, there is less time available to prevent thermal runaway using gas detection.

In addition, it is preferable to have higher thermal runaway temperatures. This indicates that the cell requires more energy to reach that temperature and enter into runaway.

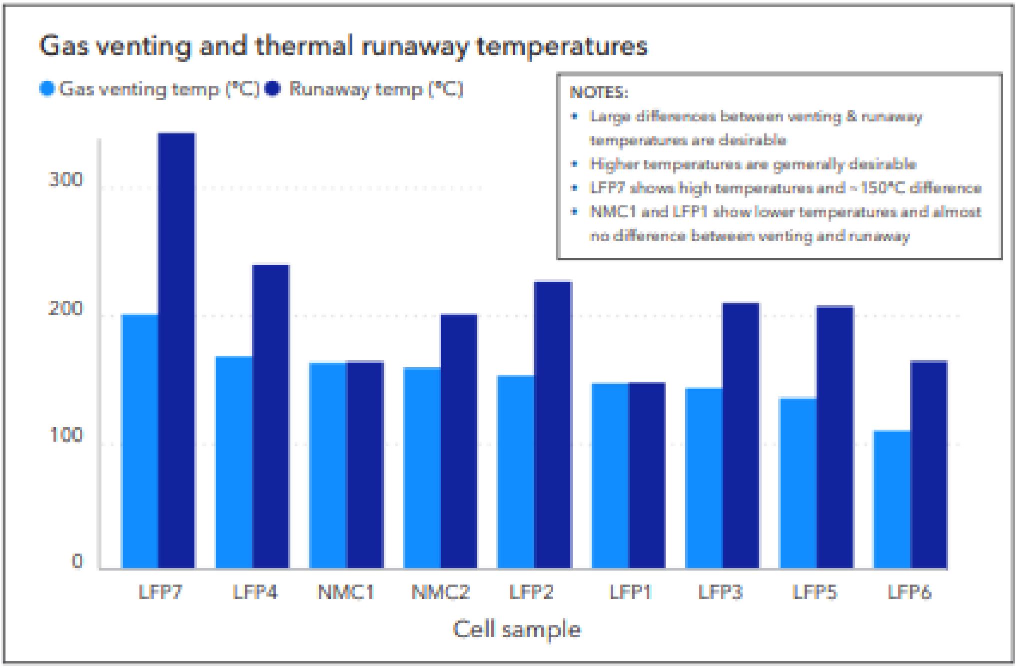


Figure 13: Venting and thermal runaway onset temperatures for various cells across chemistries
Source: DNV 2022 Battery scorecard

<u>Off-gas flammability</u>

During thermal runaway, the cell produces gases that are vented and measured during cell-level UL 9540A testing to determine flammability and other characteristics.

The off-gas typically includes hydrogen, carbon dioxide, carbon monoxide, and various hydrocarbons, which are all flammable gases that can contribute as a fuel source for a fire. If hydrogen is not burned upon emission, it can contribute to the explosiveness of the off-gas. The more hydrogen present, the more energetic the explosion can be.

Other hazardous considerations for the gas composition include carbon monoxide as a toxic gas and carbon dioxide as an asphyxiant.

The volume and ratio of gases depend largely on the materials used inside the cell, such as the cathode, electrolyte, and anode. A cell of identical chemistry and size may have a different composition ratio due to other components within the cell. *Figure 14* shows the average off-gas composition from UL 9540A data collected for various cells across different chemistries and manufacturers.

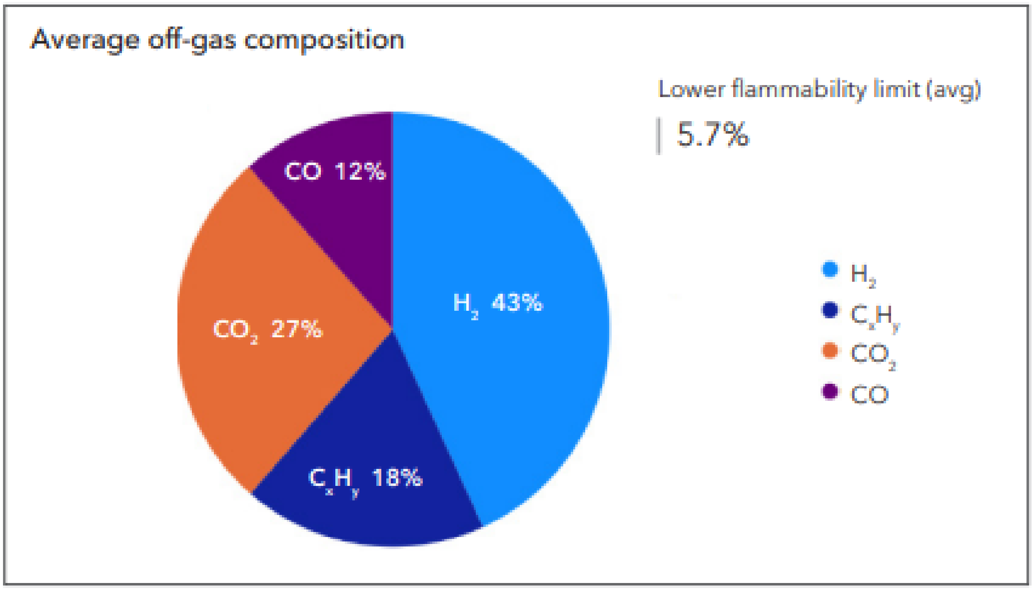


Figure 14: Off-gas composition of gas released during thermal runaway
Source: DNV 2022 Battery scorecard

Battery Management System

Battery cells are usually assembled into modules or packs with an integrated battery management system (BMS). The BMS controls the upper and lower voltage limits of the cells during charging and discharging, among other things.

Manufacturers can adjust their BMS to allow for wider voltage limits to capture more energy per charge/discharge cycle. The BMS can also establish more conservative voltage limits to avoid upper and/or lower charge states, with the aim of prolonging battery life.

It is critical to tune the BMS to optimize the tradeoff between maximizing short-term capacity and not unduly sacrificing long-term performance, as all cells degrade rapidly if operated outside of their preferred voltage range.

2023 AND BEYOND

Driven primarily by the growth in electric vehicle demand, today's lithium batteries will continue to see advances that benefit the EV sector and, to a lesser degree, the stationary energy storage sector.

In the short- and mid-term, lithium batteries will dominate the stationary storage market due to their versatility, durability, and decreasing cost. Improvements are expected in energy density, durability, performance, and safety, as discussed below.

As previously mentioned, Li-ion batteries are composed of several components, including an anode, cathode, electrolyte, separator, and the cell casing.

The anode and cathode are the electrochemically active components that store lithium ions when charging and discharging. Efforts have been made to reduce the cost of the cells by increasing energy density, improving the reliability and safety of the anode and cathode, increasing the ability to charge quickly, and reducing inactive materials.

Li-ion battery improvements

- CATHODE

Regarding the cathode, most electric vehicle batteries use a combination of lithium with cobalt, magnesium, aluminum, and nickel to create either NMC (nickel manganese cobalt oxide) or NCA (nickel cobalt aluminum oxide) chemistry. These metals, especially cobalt and lithium, have become more expensive in the past year due to increased demand, supply constraints, or both.

Lower range EVs and stationary storage applications use lithium combined with iron to form the LFP (lithium iron phosphate) battery chemistry. LFP is cheaper and generally has a higher temperature threshold for entering thermal runaway than NMC and NCA. However, it sacrifices energy density, so it takes up more space in the vehicle or project site for the same amount of storage capacity.

The relative costs of different battery chemistries are uncertain due to rapid growth and material supply constraints. Sulfur is being considered as a replacement for the layered oxide class used by NMC and NCA due to its high energy density, but no commercial products are currently available.

- ELECTROLYTE

Advancements are also expected in electrolytes, which facilitate the flow of ions from anode to cathode and back again.

In conventional automotive lead-acid starter batteries, for example, the acid serves as a liquid electrolyte.

In lithium batteries, the electrolyte is typically an organic-based compound or solvent that interfaces with the cathode and anode and permeates a separator. Most Li-ion battery electrolytes are liquid, but polymer and solid electrolytes are also used.

Solid electrolytes are particularly interesting due to their non-flammable nature, which provides a significant safety advantage over organic polymer and liquid electrolytes.

Solid-electrolyte batteries have also potential advantages such as higher energy density, longevity, and stability. However, these claims need to be proven before commercialization.

- ANODE

Anodes used today are usually made of graphite, a form of carbon with a structure that allows reversible insertion (intercalation) of lithium ions between the carbon layers.

Although graphite is a suitable anode material, silicon is being considered as a replacement because it can hold ten times more lithium than graphite. However, silicon swells more than graphite when lithium ions are inserted, which can damage the cell.

A possible solution is to utilize a combination of graphite and silicon, which has been observed to decrease swelling while sacrificing some density improvements.

Non-lithium technology

Several non-lithium technologies are ready to enter the stationary sector. Pumped-hydro, for instance, already has a dominant market share.

The China Energy Storage Alliance (CNESA) reported that as of the end of 2021, pumped-hydro accounted for 86.2% of the 209.4 GW of electrical energy storage deployed globally, followed by Li-ion at 11.0%, and then a variety of other non-lithium technologies making up the remaining 2.8% (CNESA, 2022).

The different types of energy storage can be broadly classified into electrochemical storage, mechanical storage, and thermal storage. These types of storage convert energy into heat and either directly or indirectly use that heat to replace electricity.

Additionally, there is significant focus on hydrogen, which can be classified as chemical energy storage. It can play a role in long-duration storage applications and industrial use in other markets such as fertilizer production and steel processing.

Non-lithium energy storage technologies are often categorized as 'long-duration', meaning they have a storage capacity of 10+ hours at rated power, according to the U.S. Department of Energy (DOE).

In contrast, Li-ion technologies typically operate for 6 hours or less at rated power. Long-duration energy storage is an emerging focus area that many believe is necessary for complete decarbonization of the electricity grid.

To be viable, the market for long-duration storage must meet the following criteria:

- The capital cost of long-duration storage equipment must be significantly lower than Li-ion on an average $/kWh basis (targeting $20/kWh or less), with comparable operation and maintenance (O&M) costs and useful life;
- Off-takers, including utilities and commercial and industrial partners, must place sufficient value on the service of long-duration storage to compensate project owners for the cost of operating these assets;
- Long-duration storage equipment must be as safe or safer than lithium-ion technology;

- The performance and safety of long-duration storage equipment must be tested and verified by third parties to build broader confidence in the technology.

Many long-duration storage technologies 'decouple' power and energy, meaning that they increase duration (MWh) at relatively low cost without increasing power (MW).
This is different from conventional batteries, which require proportional increases in power and duration because all DC energy storage components are contained within a single cell.

Another advantage of many long-duration technologies is their reduced fire safety risk and low degradation potential.

Long-duration energy storage technologies also have several disadvantages compared to Li-ion batteries, including:

- Round-trip efficiency is limited to about 50%-70%, depending on the technology, as opposed to Li-ion, which often exceeds 90%;
- Ramp rate can be limited for some technologies, which means they are not well suited for shorter durations below 4 hours;
- They can have moderately to significantly lower energy densities than Li-ion, which means they are almost always larger and heavier and not well suited for mobile applications;
- With the notable exception of hydropower, which has been around for centuries, many long-duration energy storage technologies are less proven, although this is beginning to change as investment flows into the sector.

Non-lithium and long-duration energy storage technologies are expected to gradually expand into niche markets over the next 3-5 years, with growth accelerating as renewable energy penetration rises above 50%. Local and federal mandates and incentives will also drive the long-duration energy storage market to broader adoption.

2.3 Cost analysis

Capital Expenditure (**CAPEX**) is the investment in capital or fixed assets that a business makes, whether to acquire, maintain or improve its non-current assets. In other words, it is the investment required to maintain or expand capital assets (factories, machinery, vehicles, etc.) and it is very important within the activity of a company and its evolution.

The future of a company, its growth and the cash flows it generates will depend on the investments made. Therefore, Capex is an element of great relevance because it provides insight into whether the company is investing to continue growing or simply to maintain itself.

Capital Expenditure is precisely that expenditure that a company makes on capital goods and that will generate benefits; it can be applied through the acquisition of new fixed assets or through the increase in the value of existing fixed assets.

In other words, it works like the money that the company uses to keep its assets in the best production condition to achieve stable operation, which also allows the particular business of the company to be maintained.

In accounting terms, the exact expenses to meet all the investments made are capitalized if the useful value of the asset has increased, and it is the duty of the company to distribute this capitalized expense fairly over its useful life. If the case is that the expense was made solely to keep the asset in optimal condition, the expense is not capitalized and will become a deductible expense.

Regarding BESS projects, in particular, these costs can vary greatly based on several factors, such as the size of the plant, the technology of the batteries used, the geographical location, and other project-specific parameters.

- Cost of batteries: the cost of batteries is one of the main elements. For example, the cost of lithium-ion batteries, commonly used in BESS plants, can range between €150 and €300 per kilowatt-hour (€/kWh). Considering a 10 MWh plant, the cost of batteries could vary between 1.5 million and 3 million euros;

- Electrical and mechanical infrastructure: it includes the cost of all necessary infrastructure elements, such as thermal management systems, inverter, transformers, electrical control systems, etc. This can vary depending on the complexity of the plant, but could account for a significant portion of the investment;
- EPC Costs: this involves the costs associated with the design, procurement, and construction of the plant. These costs can account for a significant percentage of total investments;
- Land and building costs: if the plant requires a physical structure, you need to consider the costs of the land, the building, and its construction.

Numerical example

A CAPEX cost assessment for a 65 MW BESS stand-alone project, for example, may include the following works and their respective costs.

It is important to note that the information provided here is indicative and based on general estimates.

Table 4: Numerical example of CAPEX from a known project

Works	Description	Total CAPEX [€]
ELECTRICAL WORKS	BESS systems (Li-ion batteries and related monitoring and management systems)	54.600.000,00
	Power station unit	3.250.000,00
	LV cables	49.920,00
	MV cables	67.260,00
	Collection cabin 36kV	280.000,00
	Ground system	50.000,00
	Generator	100.00,00
CIVIL WORKS	Soil preparation	4.200,00
	Excavations	44.257,50
	Internal roads and cabin yards	49.500,00
	Foundation works	1.560.000,00
	Fences	21.505,00
	Gates	5.000,00
PLANT AUXILIARIES	Control cabin	80.000,00
	Video security system	30.000,00
	Local deposit cabin	50.000,00
FIRE PREVENTION WORKS	Fire prevention networks	371.955,50
CONNECTION WORKS	Network works	5.725.000,00
TECHNICAL AND PROVISIONAL EXPENSES	Engineering	1.093.000,00
TOTAL		**67.431.598,00**

Operating Expenditure (**OPEX**) are the costs that a company incurs while performing its normal operational activities, i.e. those tasks that must be undertaken from day to day to operate the business and generate revenue.

Operating expenses can differ according to what a company does. In fact, some activities (and expenses) might be considered operational in one industry but not so in another.
It's important to understand the distinction due to their tax-deductibility.

Some common types of OPEX include:

- Rent;
- Salaries and wages;
- Accounting and legal fees;
- Bank charges;
- Sales and marketing fees;
- Office supplies;
- Repairs;
- Utilities expenses;
- Cost of goods sold.

One of the responsibilities that management must contend with is determining how to reduce operating expenses without significantly affecting a firm's ability to compete with its competitors.

They are necessary and unavoidable for most businesses. Some firms successfully reduce them to gain a competitive advantage and increase earnings. However, reducing operating expenses can also compromise the integrity and quality of operations.

Finding the right balance can be difficult but can yield significant rewards.

Specifically for BESS systems, it is possible to find this type of expenses listed below:

- Maintenance: includes routine expenses for the maintenance of batteries, inverters, and other system components. It is crucial to ensure the durability and efficiency of the plant;
- Energy Costs: the expenses for the energy required to charge the batteries and any energy losses during the charge/discharge cycle;
- Insurance costs: insurance coverage for the plant and equipment;

- Personnel costs: if necessary, the costs related to the personnel dedicated to the management and supervision of the plant;
- IT Operational and Monitoring Costs: expenses for plant monitoring, control, and management systems.

Numerical example

An OPEX cost assessment for a BESS stand-alone project, for example, may include the following voices and their respective costs.

It is important to note that the information provided here is indicative and based on general estimates.

Table 5: Numerical example of OPEX from a known project

Description	**OPEX (per MWn) [€]**
Rent (construction and operation)	1.500,00
Asset management (construction)	5.000,00
IMU[8] (construction and operation)	10,00
Asset management (operation)	2.000,00
O&M	7.500,00
Insurance	6.000,00
Accounting and audit	500,00
IRAP[9]	3.9%
TOTAL (per annum during construction)	**13.010,00**
TOTAL (per annum during operation)	**17.510,00**
Maintenance provision (per annum)	**9.760,00**

Finally, the assessment of CAPEX and OPEX takes the form of calculating the IRR (Internal Rate of Return) index.

[8] *"Imposta Municipale Unica"*, Single Municipal Tax.
[9] *"Imposta Regionale sulle Attività Produttive"*, Regional Tax on Productive Activities.

The IRR is a metric used to evaluate the profitability of an investment, taking into account the time value of money and the cash flows associated with the investment. It can be calculated using a mathematical formula or specialized software such as Excel.

$$\sum_{t=0}^{n} \frac{CF_t}{(1+i)^t} = 0$$

Where CF = cash flow over a given period, i = interest rate to be determined; t = period in which cash flow occurs.

The Internal Rate of Return is important for evaluating investment profitability, comparing investment alternatives, analyzing risk, and monitoring performance.

If the IRR exceeds the acceptance rate, which is a threshold rate of return, then the investment is considered worthwhile.

Based on this information, I attempted to compose an approximate cost study for the development of a BESS plant based on an analysis of the documentation of several projects developed in Italy, including capital expenditure estimates.

Estimates are used because data are difficult to find due to the emerging nature of the technology and various factors causing variability and uncertainty.

Table 6: Available data for CAPEX of known projects

PROJECTS	CAPACITY [MW]	BATTERY SIZE [h]	MWh	TOTAL	TOTAL [per MW]	k€/MWh
Poject 1	15,5	1	16	6.619.000,00	427.032,26	427,03
(2021)	15,5	4	62	13.346.800,00	861.083,87	215,27
Project 2	4,5	1	5	2.257.000,00	501.555,56	501,56
(2021)	4,5	4	18	4.216.500,00	937.000,00	234,25
Project 3 (2022)	9,6	4	38	10.000.000,00	1.041.666,67	260,42
Project 4 (2023)	396	4	1584	360.360.000,00	910.000,00	227,50
Project 5 (2023)	198	4	792	190.080.000,00	960.000,00	240,00
Project 6 (2023)	198	4	792	188.100.000,00	950.000,00	237,50
Project 7 (2023)	65	4	260	67.431.598,00	1.037.409,20	259,35
Project 8 (2023)	95	8,8	836,6	214.057.775,00	2.253.239,74	255,86
Project 9 (2023)	95	8,8	836,6	213.955.588,00	2.252.164,08	255,74

Based on the limited data available, collected in *Table 6*, the CAPEX for BESS with 4-hour batteries ranges from 215 to 260 k€/MWh. This is consistent with the literature, which reports a CAPEX of approximately 250 k€/MWh. While the Annual OPEX may vary between 2% and 5% of the initial investment.

This study demonstrates the cost differences between various projects, specifically in regards to battery duration. The cost of using 4-hour batteries is significantly higher than using 1-hour batteries when considering the total amount. However, with the same installed power, the cost in terms of k€/MWh for 1-hour batteries is approximately twice as high as for 4-hour batteries, which is understandable. And for the same reason, 8-hour batteries are even more expensive overall.

The year of project development is another factor that caused disparities in the analyzed data. It is important to note that BESS is a recent and emerging technology, and therefore costs have undergone significant variations in just a few years.

This disparity is also a result of the increasing number of independent projects being developed with higher capacity compared to the clusters of a few MW that were initially constructed, possibly coupled with existing renewable energy source plants.

In conclusion, this confirms the challenge in accurately estimating costs at present, as they can vary significantly based on project-specific factors and market conditions.

3. REVENUE STREAM

Global energy storage market overview

Many factors affect the energy storage market, with some underlying drivers providing predictable growth trends. The ability of an energy storage system to stabilize the electricity grid and shift daytime solar energy into morning and evening hours has been a consistent driver of growth.

In general, early markets in new global regions are forming around ancillary services, which balance the power grid when consumption (load) is not perfectly matched to generation.
Ancillary services require fast-responding resources to provide "grid support" such as frequency and voltage regulation, and to add power capacity. Battery energy storage systems are particularly well-suited for this purpose.

Early success stories of battery energy storage can be found in commercial and industrial (C&I) behind-the-meter applications, such as demand charge reduction. In this application, batteries provide energy during periods of high prices, reducing peak power costs and saving money for C&I facility owners.

These types of systems can also be a source of resiliency, such as temporary backup power during a grid outage.

Other factors affecting the energy storage market are less predictable, and reliable information can be difficult to obtain. Government mandates and incentives, raw material prices, battery supply shortages, new disruptive technologies, and both regional and global politics can create uncertainty in the market.

After more than a decade of investment in electric vehicles, consumer electronics and, more recently, stationary energy storage, lithium-ion batteries have become the dominant battery on the market.

Within the broad category of Li-ion batteries, the NMC chemistry accounts for approximately 50% of the market, while LFP and NCA chemistries are rapidly gaining ground.

For the foreseeable future, Li-ion is likely to remain the dominant technology for both transportation and stationary energy storage, lasting at least three to seven years. However, next-generation technologies, including silicon, sodium, and lithium metal anodes, solid-state electrolytes, new cathode materials and cell manufacturing processes, flow batteries, and other non-lithium technologies, may play a crucial role in enabling these price reductions.

Current price volatility

In 2010, the average price of a lithium-ion battery pack prices across various battery end uses was over $1,200 per kilowatt-hour.

According to Bloomberg New Energy Finance (BloombergNEF, 2021) these prices have fallen by 89% to $132/kWh in 2021, which is a 6% decline from $140/kWh in 2020.

However, costs are expected to rise sharply by the end of 2021 and the first half of 2022. This is mainly due to the increasing cost of lithium and other raw materials, global supply constraints, broader inflation, and production curbs in China.

Although the coveted $100/kWh battery remains achievable in the longer-term, battery costs are significantly higher than this in many regions. For instance, project developers in North America have received quotes from battery manufacturers of up to nearly $500/kWh by mid-2022.

In 2021, battery costs were lower on average, although there was an imbalance across regions. The lowest costs were found in China, at $111/kWh. However, packs in the U.S. and Europe will cost 40% and 60% more, respectively, according to BNEF.

Prices have fallen as the adoption of LFP has increased and the use of expensive cobalt in nickel-based cathodes has decreased. On average, LFP cells were almost 30% cheaper than NMC cells.

This volatility has impacted project financials, and the market is already responding.

In the U.S., which is a leading market for grid-scale energy storage, the market is being driven by new state-level storage mandates and supportive federal policies such as the Federal Energy Regulatory Commission's Order no.2222.

The U.S. energy storage market is expected to expand from an annual deployment of 5 GW/14 GWh in 2022 to 14 GW/50 GWh in 2026, according to Wood Mackenzie[10] projections (2023).

Buyers are renegotiating purchase agreements to better reflect the cost of procuring energy when they need it, and they are paying more for it.

COVID-19 has challenged the evolution of the storage sector in some countries, but deployment in the U.S. has been strong, with new hybrid solar-plus-storage systems driving growth in sunnier regions.

China will compete with the U.S. for the largest volume of lithium batteries deployment in the coming years, and Chinese lithium batteries suppliers are poised to offer the lowest-cost products.
China is set to emerge as the world leader in storage capacity by 2024.

[10] Wood Mackenzie is a global insight business for renewables, energy and natural resources.

3.1 Italian market size

The Italian government has demonstrated its willingness to integrate battery storage into the energy system through recent policy developments.

In 2014, ARERA began integrating BESS into the Italian electricity system by allowing them to participate in the MGP – *"Mercato del Giorno Prima"* (Day-ahead Market). From 2017, they were also allowed to participate in the MSD – *"Mercato del Servizio di Dispacciamento"* (Dispatching Service Market) through several **Pilot Projects**.

Although the first pilot project open to BESS was **UVAM**[11] (Res. 422/2018/R/eel), the most significant is probably the **Fast Reserve Unit** (FRU, Res. 200/2020/R/eel). This scheme was the first auction scheme actually tailored to BESS , and can be considered particularly successful, as it received 1.3 GW of requests and awarded 250 MW of capacity (the allowed contingency).

The amendments made by ARERA and Terna are aimed at integrating BESS into the grid, aligning the regulations with European standards and incorporating the experience and innovations gained from the pilot projects.

Pursuant to Article 18 of Decree Law 210/2021, ARERA, Terna and GSE are developing the "***Grandi Accumuli***" scheme to create 71 GWh of new storage capacity by 2030.

Italy is rapidly transitioning from a state of no batteries to having approximately 2 GW of power, equivalent to 8 GWh of storage capacity, by the end of 2024.

This progress is also due to the **Capacity Market** mechanism and its implementation over the next year.

The 2022/2023 auctions have stimulated the entry of storage facilities through the allocation of long-term capacity contracts at values that guarantee the convenience of the investment in storage.

It is anticipated that this sector will continue to expand in the future, as its presence in the system will become increasingly necessary due to the ongoing energy transition.

[11] *"Unità Virtuali Abilitate Miste"*, Mixed Enabled Virtual Units.

Even with regard to Terna's position on the issue, it is evident that a significant amount of storage will be required in the near future.

Terna has set a target of approximately 95 GWh of storage capacity by 2030. This includes 8 GWh already foreseen for the CM auctions, as well as approximately 71 GWh of large-scale storage and 16 GWh of small-scale storage. Small-scale batteries coupled to generation units were already available, but there are currently no large-scale batteries on the market.

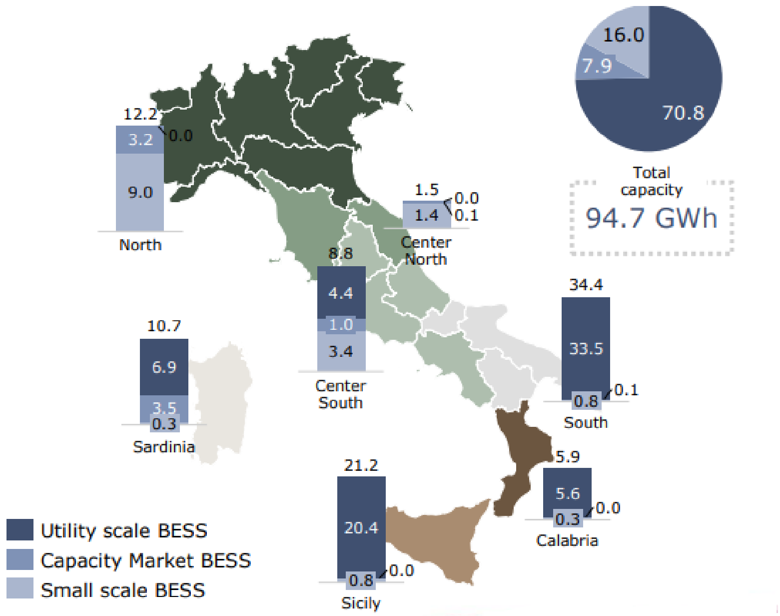


Figure 15: 2030 Terna Storage additional capacity targets

Source: Terna

Currently, Italy has a combined pipeline of about 6.5 GW storage capacity, 40% of which has been authorized or is in final authorization stage.

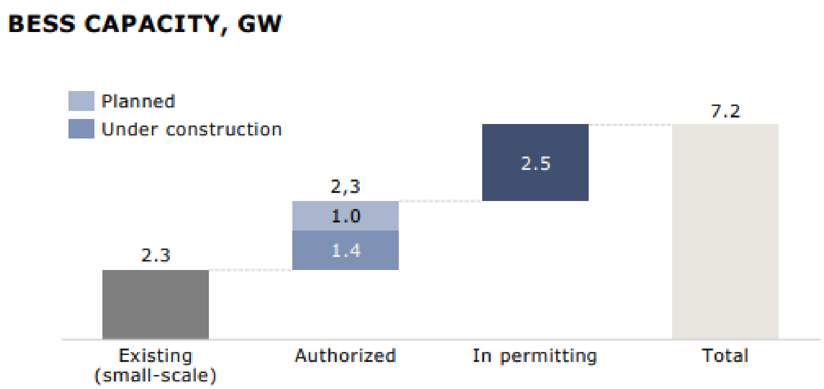


Figure 16: BESS capacity divided into existing, authorized and in permitting

Source: AFRY analysis

– In March 2023, 2.3 GW of small-scale storage systems were installed in more than 310k plants.

– About 55 large-scale BESS plants are currently approved, with a total capacity of around 2.4 GW. Of these, about 60% are under construction, having been awarded projects in the Capacity Market and Fast Reserve Unit, and are expected to be online by 2024.

– Approximately 30 projects totaling 2.5 GW are under analysis for authorization.

Market operators have shown a visible interest in this situation, as Terna's published data indicates at least 80 GW of connection applications.

The message is that there is a strong interest, materialized in many requests from operators, most of which are for stand-alone batteries, while a smaller part is as assets coupled with renewable generation. Out of the total 82.6 GW, 54 GW are for stand-alone batteries, 20 GW are for batteries coupled with renewable generation plants, and approximately 8 GW are related to new pumped-hydro projects.

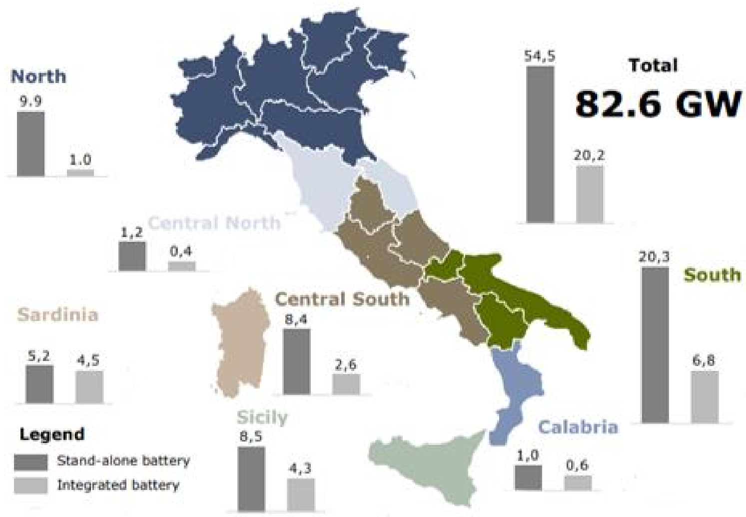


Figure 17: Localization of connection requests in the Italian territory

Source: Terna

The storage capacity must be developed in accordance with the anticipated growth of renewable energy sources, particularly in the southern regions and on the islands where wind and solar resources are abundant. Additionally, the expected expansion of the electricity grid must be taken into consideration.

At this moment, Enel is the leading player in Italy's storage sector, having secured 1.7 GW in the last CM auctions. Other companies, such as Edison, Aura, and Whysol, are also involved.

3.1.1 MARKET ASSESSMENT

The Italian electricity market was established by Legislative Decree No. 79/99 on March 16th 1999, as part of the process of transposing the EU Directive 96/92/EC on the creation of an internal energy market. The purpose of creating an electricity market is to promote competition in the production and sale of energy and electricity in a neutral, transparent, and objective manner. This is achieved through the establishment of an electricity exchange. Additionally, the market ensures the economic management of adequate availability of dispatching services.

The Italian electricity market is managed by the Energy Markets Operator (GME – *"Gestore dei Mercati Energetici"*), a subsidiary of the Energy Services Manager (GSE). It is divided into two markets: the Spot Electricity Market (MPE - *"Mercato Elettrico a Pronti"*) and the Future Electricity Market (MTE - *"Mercato Elettrico a Termine"*).

The MPE comprises four submarkets.

The **Day-Ahead Market**, where hourly blocks of energy for the next day are exchanged. Operators participate by submitting offers to sell or buy electricity. The **Intraday Market** (MI – *"Mercato Infragiornaliero"*) allows operators to modify the input and withdrawal schedules determined on the MGP. The **Daily Products Market** (MPEG – *"Mercato dei Prodotti Giornalieri"*) is the venue for the trading of daily products with an obligation to deliver energy. Finally, the **Dispatching Service Market** (MSD) is where Terna procures its supplies to provide dispatching services necessary for the management and control of the electricity system.

The MGP considers day-after time blocks, feed-in and withdrawal schedules, and transit limits between zones when negotiating electricity prices and quantities based on economic merit. The MGP is an auction market for wholesale electricity trading.

The Intraday Market enables operators to modify schedules outlined in the MGP by submitting additional purchase or sale proposals. Transactions in the MI occur through three auction sessions and one continuous trading session. During the auction sessions, while the negotiations for the purchase and sale take place, the intraday interconnection capacity between all the areas of the Italian market and the other interconnected geographical regions is assigned.

Terna uses the MSD to acquire the resources needed to resolve intra-zonal congestion, create energy reserves, and balance in real-time. The MSD is divided into MSD *ex-ante* and MB.

The MSD *ex-ante* consists of six programming sub-phases. Terna accepts offers for the purchase and sale of energy to resolve residual congestion and build up reserve margins. On the other hand, the Balancing Market (MB) is where buy and sell offers are selected for the periods of the calendar day when the MB sessions are held.

The MB enables Terna to perform the secondary regulation service and maintain a real-time balance between energy injection and withdrawals on the grid.

In conclusion, the MTE is the platform for negotiating electricity futures contracts with delivery and withdrawal obligations. Operators participate by submitting proposals that specify the type and period of contract delivery, the number of contracts, and the price at which they are willing to buy or sell.

It is important to note that the demand for electricity fluctuates throughout the day. Managing this shift in demand, especially during peak times, is a crucial challenge for electricity service providers. The challenge of uneven energy demand can be addressed by implementing an electricity storage system that utilizes load leveling. This involves storing excess energy during periods of low demand and then delivering it during times of high demand, effectively reducing peak shaving phenomenon.

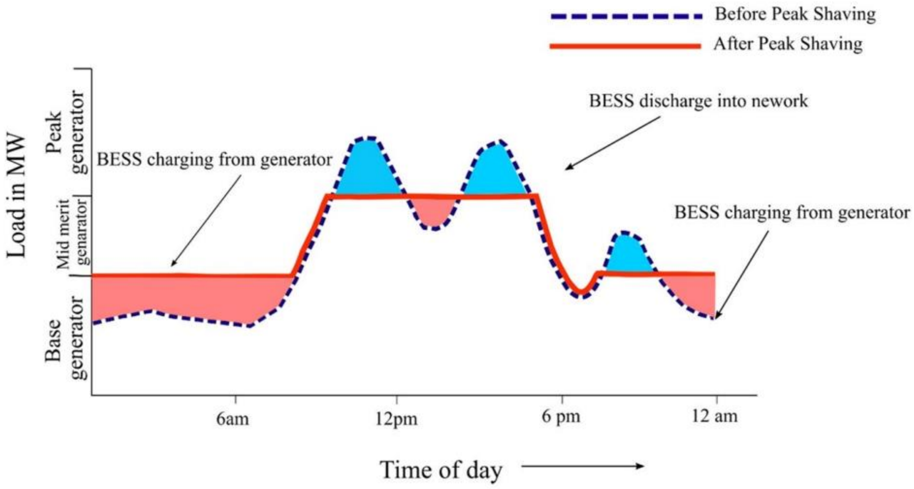


Figure 18: Peak load reduction using a storage system
Source: G. Comodi, "Appunti Sistemi di Accumulo e loro Gestione - Sistemi di accumulo elettrochimico (batterie)" 2022

Furthermore, storage systems can be utilized to alleviate congestion issues on the grid. Transmission line congestion arises when distributed electricity cannot be delivered to all or some loads due to undersized transmission facilities for power supply.

During periods of high energy demand, the costs of expanding transmission capacity and transmission access tariffs increase. Congestion in the transmission grid can prevent efficient generation plants from producing as much energy as they could, resulting in a zoning of the national territory into areas with different energy selling prices.

Storage systems are installed downstream of the grid element near congestion to store energy when the grid is not overloaded. During times of congestion, the stored energy is released directly to the grid element. If congestion is due to excess generation, it may be more effective to install a storage system upstream of the congested section.

The main concept is that a small amount of stored energy can offer enough additional capacity to delay more costly investments in electric drivetrains. This reduces overall costs for taxpayers, enhances resource efficiency, frees up capital for other projects, and mitigates the financial risk associated with proposed investments.

The price arbitrage service involves exploiting price differences by storing energy during periods of low prices and releasing it during periods of high prices. The daily revenue generated by the energy storage system through arbitrage is calculated as the difference between the income from selling electricity during discharge and the cost of purchasing electricity during charging. Therefore, from an economic perspective, energy storage systems can help reduce and stabilize electricity market costs. This is because these systems separate electricity generation from the fluctuations and uncertainties of fossil fuel prices, thus avoiding speculative influences.

In terms of BESS's capabilities in the Italian electricity market, it is primarily concerned with time shifting, balancing market and the provision of secondary reserves.

Time Shifting

Storage systems in the Italian electricity market can withdraw energy from the grid without incurring grid fees and system charges.

This allows BESS to seek arbitrages and perform time shifting on energy markets, such as Day-Ahead and Intraday, by buying energy during cheaper hours (usually at night or when renewable production is significant) and selling it when prices rise.

The regulation does not penalize storage facilities based on their rated power or location. Each asset can participate in the Day-Ahead market without significant constraints.

However, the location of power plants can impact market revenues. The Italian electricity market is divided into market zones, which may have varying prices depending on fundamentals and transfer capacity constraints.

Balancing

Due to their flexibility, storages can provide ancillary services to the TSO[12] for balancing production and load.

The Italian Balancing Market operates on a central dispatch model, and the TSO selects the unit that must modify its injection profile based on its nodal location and technical constraints.

Until 2017, this market was only open to thermoelectric and hydro power units with a rated power higher than 10 MW. However, due to pilot projects, participation has been extended to include further technologies, including storage, also through aggregates (UVAM).

Terna recently carried out a consultation process to significantly reform MSD regulations. This new regulation revises technical requirements for market participation with the aim of expanding the number of active units in the MSD. It also makes smaller units (power<10 MW), intermittent resources, and storages eligible to provide ancillary services.

Secondary Reserve

Secondary reserve is a frequency control service used to restore the frequency rated value after deviations.

The TSO creates reserve margins on the automated security management system. The selected resources make available to the TSO a power bandwidth (at least equal to the maximum between 6% of rated power and 10 MW for thermal units and 15% of rated power for hydro).If activated in real-time, the TSO can automatically modify the output of the unit through a real-time signal.

For the provision of secondary reserve, the national grid is divided into three market zones: continental Italy, Sicily, and Sardinia.

Currently, only conventional and hydro units with a power higher than 10 MW are eligible to provide this service. However, a pilot project has made it possible for smaller units and UVAM to also provide this service.

[12] The TSO is the Transmission System Operator, an entity responsible for the transmission of energy, using appropriate infrastructures, at national or regional level.

3.2 Regulatory Framework

BESS is believed to have a great potential in Italy and to play a pivotal role in the energy transition by meeting the increasing demand for flexibility.

Since 2014, ARERA and Terna have been working towards a more complete integration of BESS into the Italian electricity system, first by opening the MGP to both stand-alone batteries and aggregations, and then by gradually allowing BESS to participate to the MSD through the pilot projects launched by Res. 300/2017/R/eel.

As already mentioned in the previous paragraph, this process of integration is crystallizing through the amendments of the main regulations, such as the TIDE[13] and Terna's Grid Code, last updated in 2023.

In 2021, the Italian authorities modified the Capacity Market mechanism in order to allow the full participation of BESS in the incentive system.

The new provisions apply to the 2024 and 2025 auction rounds. The 2024 round was held in 2022, while the 2025 round has not yet been called; however, the extension of the mechanism post-2025 is still highly uncertain.

Article 18 of Decree Law 210/2021 provides for the introduction of a new system for the forward supply of resources for the storage of electricity. Following the consultation process launched in 2022 (Dco 393/2022), the general rules governing this mechanism, defined as the "*Grandi Accumuli*" scheme, were defined by ARERA in 2023 through Resolution 247/2023/R/eel.

In August 2023, Terna launched the consultation on the study detailing the technologies to be admitted to the scheme and, on October 31st, it opened a further consultation on the expected auctions for batteries and other storage systems to be put at the service of the electricity system.

[13] "*Testo Integrato del Dispacciamento Elettrico"*, Integrated Text of Electricity Dispatching.

3.2.1 ACCESS TO MARKET

To date, according to what the market says, a battery operated only on the energy markets does not have enough keys to guarantee the actual convenience of the investment, some form of support, mounted on market revenues, is needed to make the investment in the battery fully profitable.

Indeed, batteries are still very expensive, being a relatively new technology, and until the cost decreases, support will be essential.

It is thought that they will follow a similar path as renewables did a few years ago: to come to the market they needed a significant incentive, after 10 years the cost has dropped and the plant can now operate on a merchant basis, so something similar can be achieved with batteries over the next 10/15 years, with cost reductions and an expected potential for increased revenues from market operations.

So what can be envisaged for batteries is that in a more or less long time, prices and revenues are going to trend upwards, leading to less and less need for incentives.

At present, without incentives or support, batteries cannot be produced, according to the market outcome, for the reason that there are no pure merchant batteries, either stand-alone or coupled; the batteries that have reached an effective investment decision are those that have received some of the incentive mechanisms in recent years (Fast Reserve and CM).

In the future it is expected that this role will also be played by the mechanism of "*Grandi Accumuli*".

From a regulatory point of view, the path towards the integration of batteries in the market is complete.

In 2014, Resolution 574/2014/R/eel established that batteries and pumped-hydro would have equal participation in the day-ahead and intraday markets. The resolution allowed both stand-alone storage systems and RES coupled with storage to participate in wholesale markets, considering storage systems as a single production unit or part of a generation group.

So they are already fully integrated from that perspective.

As far as the MSD is concerned, the situation is a bit more complex and requires a distinction between the different frequency reserves; their integration started more recently in 2017 with the famous Resolution 300 which triggered the so-called **pilot projects**.

- Frequency Primary Reserve should be provided in accordance with the Grid Code;
- FRU pilot project - Res. 200/2020/R/eel, refers to fast frequency/power regulation, supporting the primary control, and allows the participation of both stand-alone batteries and aggregated units;
- Frequency Secondary Reserve has been introduced with aFRR (automatic Frequency Restoration Reserve) pilot project - Res. 215/2021/R/eel in May 2021, with the purpose of enabling relevant renewable facilities, storage systems and UVAM systems to participate in MSD's secondary reserve;
- Frequency Tertiary Reserve with UPR[14] pilot projects - Res. 383/2018/R/eel, which allows relevant production units, including stand-alone storage systems and RES coupled with storage, to benefit from it;
- UVAM pilot project - Res. 422/2018/R/eel, regarding secondary reserve, tertiary rotating and replacement reserves and the participation for aggregated units of both production (including batteries) and demand.

The pilot projects are nothing more than attempts to propose provisional regulations for specific services. They aim to define innovative participation possibilities based on softer requirements than those present in the basic Grid Code, which until last year only enabled thermal plants to participate in the services market. In recent years, it has been accepted that a plant can provide services to the system. This expands the pool of technologies that can offer services to the system.

Therefore, the idea is to give the possibility to the different plants to qualify themselves only in certain services or in certain directions, and the batteries will also find their place within these projects.

At the beginning of 2023, in connection with the entry of batteries into the market, Resolution 98/2023 approved amendments to Terna's Grid Code that better define the possibility for storage to participate in the services market.

[14] *"Unità di Produzione Rilevanti"*, Relevant Production Units.

The main changes introduced by Terna are:

- The definition of relevant production units as those UPs having a total maximum net capacity equal or greater than 10 MW;
- The possibility for a single section of a production plant to constitute a UP, provided that the maximum net capacity of the section is equal to or greater than 10 MW; this provision also applies to storage systems;
- The possibility for installations with the following configuration to form specific UPs:

  A combination of a storage system other than pumped-hydro storage and an electricity generation module powered by renewable energy sources; in the case of non-programmable renewable energy sources, the UP is considered programmable if the energy to power ratio is of at least 2 hours or if the ratio between the storage system and the electricity generation module is higher than 20%;

- A combination of a storage system other than pumped-hydro storage and an electricity generating module powered by non-renewable sources.

Regarding ancillary services, Terna introduces the following updates:

- Primary Reserve: storage systems are eligible for the provision of primary reserve services, subject to certain conditions specified in the Grid Code. If the storage system is included in an eligible unit, it is obliged to provide such services;
- Secondary Reserve: Terna proposes to revise the minimum bandwidth of the secondary reserve in order to qualify for the provision of the service;
- Tertiary Reserve: Terna modifies the duration requirements for substitution tertiary reserve services by eliminating the unlimited duration requirement; such service can in fact be provided within 2 hours from the request and can be performed without any time limit;
- MSD *ex-ante* and MB: Terna proposes the introduction of a specific algorithm for the selection of offers related to activated storage units in order to respect the effective state of charge, and the elimination of imbalances for safety reasons deriving from operations on the MB.

In terms of functionality, batteries can perform a wide range of tasks. The removal of stringent limitations related to durability and activation time maintenance has expanded their potential as backup services for the system.

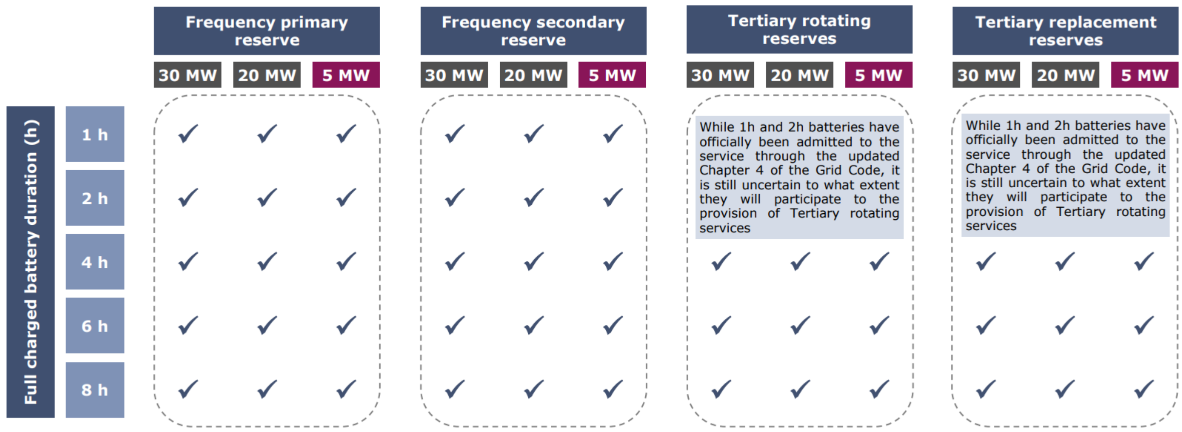


Figure 19: Services provided by batteries of any duration

Source: AFRY analysis

Figure 19 shows that batteries of any duration can provide all services, as also confirmed by. Resolution 98/2023. Short-duration batteries may be more challenging to use for tertiary regulation services, while batteries with a duration of at least 4 hours have no limitations.

Terna will develop algorithms for the effective inclusion of batteries in the *ex-ante* and MB market, taking into account their state of charge.

As far as the Primary Reserve is concerned, the supply obligation for batteries has been better explained, with some discussions still in progress, as it appears to be a bit strict for the way it has been defined in the most recent Resolutions.

Batteries are subject to the same capacity obligation as thermal installations, requiring them to reserve 1.5% of their nominal capacity for primary regulation, which is extended to 10% in the islands. Additionally, batteries must reserve a portion of their energy storage capacity for primary supply to ensure the modulation of 1.5 or 10% is guaranteed for at least 30 minutes. This means that there must always be some energy available.

The minimum energy reserve is defined as a percentage of storage capacity (1.5% for the continent and 10% for islands) to be reserved for a 60-minute period.

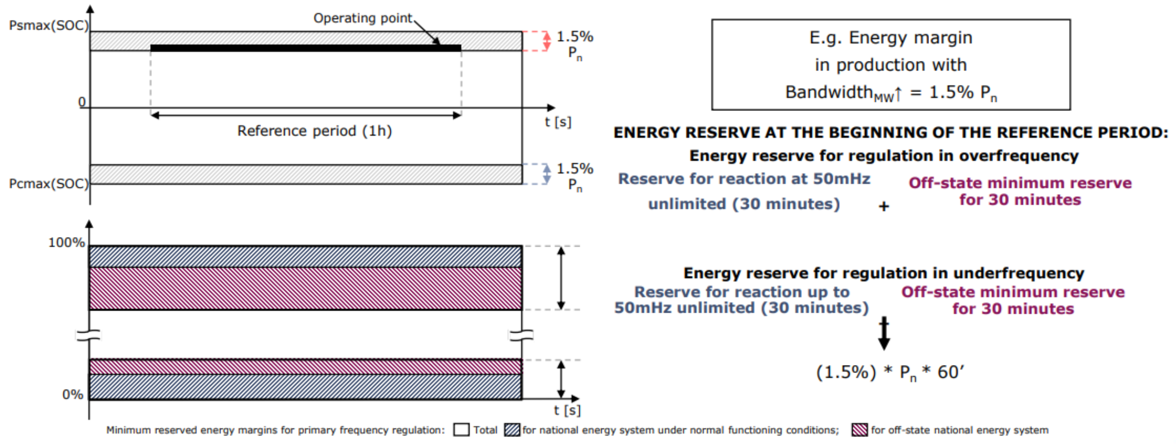


***Figure 20**: Calculation of the minimum reserved energy margins for primary frequency regulation*

***Source**: Terna*

This is the primary reserve obligation. It could be significant and burdensome, particularly in the islands, but there is also progress on the TIDE side and, ideally, from the proposals that have come out of ARERA, the procurement paradigm will change.

The aim is to adopt a mechanism similar to that of other European countries, like Germany, where the primary reserve is procured *ex-ante*. This will lead to a gradual reduction of the obligation to provide this service until it becomes a remunerated procurement.

In conclusion, what is currently a challenging constraint for a battery to meet will be removed or turned into an opportunity to increase revenues in a few years.

3.3 Incentive schemes

The prevailing belief is that a battery cannot survive solely on the market; it requires an additional source of revenue to make up for the shortfall and achieve full profitability of the investment.

In Italy, three major incentive mechanisms suitable for BESS have been adopted in recent years: Fast Reserve Unit (FRU), Capacity Market (CM), and DGA ("*Decreto Grandi Accumuli*").
Currently, only CM and DGA are available.

3.3.1 FAST RESERVE UNIT

Introduced with Resolution 200/2020/R/eel, this pilot project has been particularly successful, with requests for a total of 1.3 GW and a total awarded capacity of 250 MW.

It was created as an incentive mechanism for the development of storage, formally disguised as an auction to procure batteries. Ideally, it was designed to stipulate multi-year supply contracts for a Fast Reserve service, for which about 250 MW had been auctioned.
The storage facilities were the only ones that met the requirements to obtain these contracts, as Terna required a very rapid response to any activations.

The Fast Reserve contract does not require continuous service throughout the year. Instead, it obligates the provider to offer a bandwidth equal to the contracted capacity for 1000 hours annually. During the remaining hours, the plant can operate in other markets and keep the revenues generated.

Thus, the incentive scheme was designed as a payment in €/MW based on the plant's existing revenues from the day-ahead market and service provision.

However, no new auction round has been scheduled. This decision may be reviewed following the revision of the TIDE after 2027 when the contracts awarded in last year's auctions expire. The new contracts will be shorter than the current five-year ones.

The strong participation in the Fast Reserve Unit auctions demonstrated high interest in the battery storage business, which has 249.9 MW of assigned capacity distributed as follows.

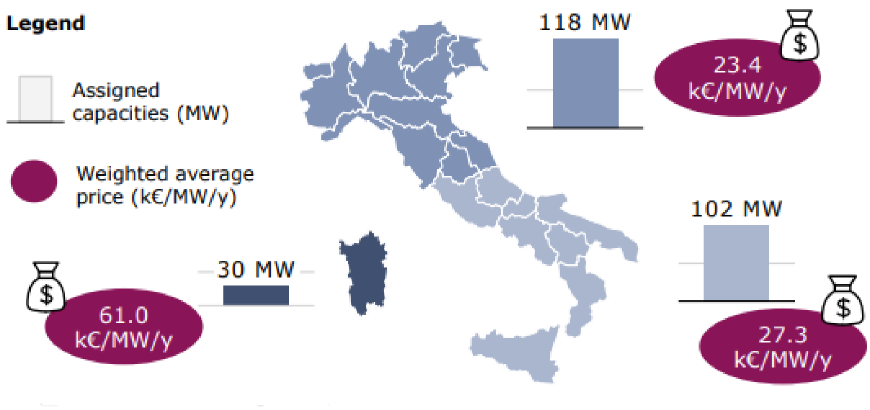


Figure 21: Breakdown of assigned capacity per area

Source: Terna

During the auction, there was intense competition among operators, with many adopting an aggressive attitude and requesting significant discounts on the auction base price of 80 k€/MW.

Ultimately, the auctions closed with an average price of 61 k€/MW/y in the islands. On the continent, the discounts were even more significant, with weighted average prices of 23.4 k€/MW/y in the north and 27.3 k€/MW/y in the south. It is important to note that these are weighted averages and that there are also lower contract values.

In summary, the Fast Reserve was an initial attempt that generated strong interest from market participants. However, it ultimately resulted in very low premiums. Some operators may have speculated on a reduction in prices or a faster change in market conditions that did not materialize. These factors are also contributing to delays in the implementation of the initial projects.

3.3.2 CAPACITY MARKET

Terna introduced the Capacity Market to address the decommissioning of old thermal plants and the resulting decrease in system adequacy. The CM provides price signals to investors in flexible capacity through long-term procurement contracts awarded via competitive bidding.

This tool is also permitted in the European regulatory context to ensure system adequacy, or sufficient capacity in a generation system to cover peak demand.

The scheme is designed to meet this need. Batteries are flexible assets that can contribute to this purpose, and they have found a place within the scheme. Their presence was not contemplated in the two previous auctions, but they will be included starting in 2024.

Thus, although it was not designed for storage development, it has contributed to its advancement.

The CM assigns a premium in €/MW/y, determined through competitive auctions, lasting one year for existing plants. New entrants are awarded a 15-year contract, typically with higher premiums.

Existing plants will receive a premium equal to the lower of the auction marginal price and the cap for existing plants (€33,000/MW*[15]).

New plants will receive a premium equal to the lower of the auction marginal price and the cap for new plants (€70-75,000/MW*).

The payment capacity in euros per megawatt (€/MW) refers to the derated capacity, which is the capacity available during tight hours. This is obtained by applying a derating factor to the nameplate capacity.

$$Derated\ capacity = Nameplate\ capacity * (1 - derating\ factor)$$

For the same nameplate capacity, a plant with a lower derating factor will receive a higher total capacity payment.

The derating factor depends on the technology: the more programmable and available at peak times a technology is, the lower the derating factor. For example, a thermal power plant has a low derating factor, while solar and wind have a very high derating factor. This system goes a long way toward penalizing technologies that have a low predictable contribution to the system.

In the last auctions, the derating has been made a function of battery life and energy/power ratio, with a very high derating assigned to 1 hour batteries, and gradually decreasing to a very low derating for 8 hour batteries (equivalent to a combined cycle).

[15] *payment is referred to the 'de-rated' capacity.

The more the derating is reduced, the more the cost increases significantly, so the issue is to find the best duration that reaches a balance, an optimal point between the revenues that can be made in the market, what can be added with the CM and what has to be paid to build these plants.
And based on the market results so far, the winning duration is the 4-hour batteries, which is a good compromise between these factors.

The updated Capacity Market discipline has introduced specific rules for BESS participation that were not explicitly considered in previous auctions, triggering 3.8 GW of new investment in capacity to be awarded in 2024 CM auctions, of which 1.1 GW derated of BESS, consisting mostly of 4-hour batteries.

Key features of the new Capacity Market discipline for BESS are:

- BESS classification, which considers three configurations:
  - Storage coupled with renewable power plants, which is considered as FRNP[16];
  - Storage coupled with thermoelectric plants, which is considered as non FRNP;
  - Stand-alone systems: which are also considered as non FRNP;
- CDP[17] calculation: the CDP of storage is dependent on the energy/power ratio. If storage is coupled with other generation units, the total CDP is the sum of the two systems separately;
- Derating factor, which considers the effect of the E/P ratio and penalizes batteries with a lower E/P ratio;
- Battery Obligation: the battery will be subject to a bidding obligation; which may vary depending on the type of configuration in which the BESS is installed. Additionally, there are specific limitations on the amount of capacity that storage systems can offer in the MSD market to meet the bidding obligation;
- Charging period: the charging period of the battery should be programmed during the night, as the CDP offered on the MSD depends on the maximum amount of energy that can be produced daily, calculated at 8:00 a.m.

[16] *"Fonte rinnovabile Non Programmabile"*, Non-Programmable Renewable Source.
[17] Capacity Derated Payment.

In conclusion, Terna uses the Capacity Market as a mechanism to procure capacity through long-term contracts awarded through competitive bidding. The mechanism is based on downward auctions open to operators on a voluntary basis, offering generation capacity at a specific price. The TSO acts as the central counterparty of the mechanism.

3.3.3 DECRETO GRANDI ACCUMULI

The new "*Grandi Accumuli*" mechanism has a completely different idea.

The mechanism does not involve adding features to batteries as in other markets. It aims to transform the battery into a semi-regulated asset, where investing in a battery is equivalent to investing in an interconnector. This investment yields a return and grants access to third parties.

Terna aims to achieve its development objectives for storage assets while maintaining control over their location. This ensures investments are made efficiently and effectively from a geographical standpoint.

The plants participate in competitive auctions and, according to the latest updates of the legislation, will be *pay as bid*. Participants will offer a premium in €/MWh/y, and the assignees of these contracts will receive payment in €/MW. This payment should ideally cover the costs of the investment and guarantee a certain return.

However, in exchange, the operator will be obligated to maintain the plant in optimal operating conditions and will not have the ability to directly dispatch the plant to the energy market. The contracted capacity will be aggregated on a zonal basis by Terna and GME and dispatched to the market through the sale of time-shifting products to operators who can use them as virtual batteries.

The concept is that market participants can purchase time-shifting products from a specialized platform, which they can then utilize and allocate to the market. Following the closure of the day-ahead market, there will be a virtual dispatch of these products, which will be translated into physical dispatch and partially assigned to Terna and to the various batteries participating in the large storage mechanism across different market areas.

The operator does not receive any revenue directly from the energy market. Instead, the owner of the asset receives payment from Terna in €/MWh/y. Terna covers part of the costs of this incentive with the revenues it obtains from the sale of time-shifting products to traders in the electricity market. The remaining cost is then passed on to end-users through their electricity tariff.

The idea behind the "*Grandi Accumuli*" mechanism is that the participants receive a fixed annual amount and do not take anything from the energy exchange.

The situation is slightly different on the services market.

In contrast to the day-ahead market, the services market requires individual asset owners to handle dispatching. However, operators are still expected to receive a portion of the revenue generated from MSD operations. Price collars will be implemented for participation in the MSD, ensuring offers are neither too high nor too low.

In particular, the recent Resolution 247/2023 has superseded the previous Dco 393/2022, which had set a maximum upward and downward bid price. The new resolution specifies that Terna will determine a price collar for the MSD offers:

- Terna will have greater flexibility in defining standard contracts;
- For standard contracts with contractually agreed capacity that have a useful life exceeding the delivery period, Terna may extend the contractual obligations period and revise the premium;
- The system provider can submit offers on the MSD within a price collar defined by Terna in the regulations, which may differ from what was envisaged by the Dco;
- A portion of the margins on the MSD will be retained by Terna in order to reduce the net burden of the incentive mechanism, while the remainder will stay with the system provider;
- The premium valuation will follow a *pay as bid* logic, and the offer will be characterized by a quantity of energy in MWh and a premium in €/MWh;
- Penalties will be defined by Terna based on the maximum premium applied to the specific technology, rather than the actual annual premium received.

This support mechanism is complex, but it presents an opportunity for both industrial market players and infrastructure funds. This is because asset management requires a lower operational commitment.

The mechanism can support the profitability objectives of storage investments. However, it is important to consider the downsides as well.

Competition in the storage industry is increasing, as non-industrial entities may also be interested in entering the sector, even with lower return expectations.

Another potential risk is the cannibalization of the MSD market, as these assets would be in a position similar to that of an essential asset. This would make them less expensive to activate than another non-market entity. Therefore, the price caps imposed on these "*Grandi Accumuli*", which will ideally be several GW of capacity in the system, could lead to a squeeze on the capacities of other players in the services market.

Terna aims to install 71 GWh of utility-scale storage by 2030, in addition to what is already contracted in the Capacity Market.

In conclusion, the storage of "*Grandi Accumuli*" is not well defined, including the timing. If confirmed, it is expected to begin in 2025, and the auction planning will depend on the technologies involved. Terna aims to develop high energy/power ratio storage construction, specifically 8-hour batteries.

3.3.4 LATEST UPDATES

On October 31st 2023, Terna initiated the consultation for the much-awaited auctions for batteries and other storage systems to be utilized by the Italian electricity system. This mechanism was introduced by Decree 210/21 and is subject to ARERA's Resolution 247 of 2023, as previously discussed.

The decree and resolution outline a system that includes two categories of auctions involving different market operators. Terna acts as a counterparty on the demand side in a primary auction for storage and on the supply side in an auction for time-shifting products.

In summary, the subjects selected at the end of the auction have:

- the obligation to build the plant;
- the obligation to make storage capacity available to third-party market participants for its use in the energy market through a platform managed by GME;
- the obligation to offer such capacity on the MSD;
- the right to receive a fixed annual premium from Terna.

The consultation publication states that the initial insolvency procedure will procure lithium-ion batteries and pumped hydropower, providing:

- a contractual duration of 12 to 14 years for lithium-ion batteries, while the contracts for pumped hydroelectric plants will have a maximum duration of 30 years. The actual advance will be disclosed, along with other technical parameters identified in the study put out for consultation, at least 180 days before the auction;
- an advance of the auction date by at least 1/3 years for lithium-ion batteries and 5/7 years for pumped-hydro storage, in comparison to the date of entry into operation. The actual advance will be disclosed, along with other technical parameters identified in the study put out for consultation, at least 180 days before the auction.

Other storage technologies may also be included in the Procedure, but their allocation will be limited to 10% of the total.

The first auctions will not take place until at least 6 months after the approval of the mechanism according to Article 18 of Legislative Decree 210/2021.

Assuming a swift approval of the regulation by the MASE (the consultation ended on November 30th), the earliest possible date for the first auction would be July 2024.

Furthermore, the consultation document states that Terna will publish a 'Technical Report' containing all technical parameters related to the reference technologies 180 days prior to the first auction.

To meet this requirement, the document should have been published by the end of 2023. However, this has not occurred, and given the ongoing similar proceedings, it seems unlikely to happen soon.

This longer-than-technically-possible timeline scenario would not benefit the market. The market has been preparing for these auctions for some time. The first auction was initially expected as early as 2023. However, the lack of these technical parameters currently makes it challenging to accurately size an electrochemical storage system and determine its profitability.

Additionally, the allocation of only 10% of the capacity in the first auction to technologies other than Li-ion batteries and pumped hydroelectric power is a limiting and unclear factor.

It may be too conservative to consider Li-ion as the only mature technology for stationary storage systems, apart from pumped-hydro. Other solutions are currently technologically mature and should also be considered in a 'technologically neutral' auction.

For instance, unlike Li-ion batteries, flow batteries or mechanical and thermomechanical storage systems (such as CAES, CO2 or gravitational) would involve the national industry more extensively.

A more courageous approach in this regard would have stimulated a healthy competitive environment and a greater plurality of initiatives. It is important to clarify as soon as possible which technologies will be allowed to compete for the 10% of the allocated capacity.

In conclusion, the publication (Terna, 2023) of the MACSE – *"Meccanismo di Approvvigionamento di Capacità di Stoccaggio Elettrico"* (Electricity Storage Capacity Supply Mechanism) is an obligatory step that is welcomed by operators in the sector. They have already been in full activity for several months for the development of storage projects. To participate in the auctions, the projects must have construction and operating authorizations in advance.

The development and permitting of projects is a complex process that requires significant investment and specialized human resources. Operators have invested heavily in this important market, making visibility, continuity, and certainty in the process essential.

On December 21st 2023, the European Commission announced the approval of the Terna auction on centralized storage systems, in line with state aid rules. The measure is worth €17.7 billion and incentivizes the development of electricity storage capacity of 9 GW and 71 GWh for ten years. This is the MACSE, and it will last until December 31st 2033.

The measure supports the goals of the *European Green Deal* and the *Fit for 55* package by facilitating the integration of renewable energy sources into the Italian electricity system.

The note from the Commission (2023) clarifies that the aid provided under the scheme will consist of yearly payments to cover the investment and operating expenses of electricity storage system developers. The beneficiaries will be chosen through a transparent, non-discriminatory, and competitive bidding process, where developers will compete based on bids for the lowest amount of aid requested per unit of capacity offered.

The program is open to all technologies that meet the performance requirements set by the Italian transmission system operator and approved by the Italian energy regulatory authority. The list of eligible electricity storage technologies will be reviewed every two years to reflect technological developments. Currently, the eligible technologies include electrochemical lithium-ion storage and pumped-hydro storage facilities.

As part of this measure, a new 'time-shifting trading platform' will be established. The platform will pool storage capacity and offer it to third parties in the form of standardized time-shifting products. Beneficiaries of the measure will be required to make their storage assets available on the platform.

Each TSO will allocate physical storage resources to execute standard time-shifting contracts, optimizing the use of available storage resources. This platform enables renewable energy producers to use the storage assets supported by the measure to shift their electricity production from periods of overgeneration to periods of scarcity.

To summarize, the Commission has found the following:

- The measure aims to promote economic activity, specifically the development of electricity storage facilities. It is deemed necessary and appropriate to accelerate investments in this area and supports key EU policy initiatives, including the *European Green Deal* and the *Fit for 55* package;
- The proposed scheme is proportionate as the level of aid corresponds to the actual financing needs. The necessary safeguards will be put in place, including a competitive bidding process for the granting of aid, limiting it to the minimum necessary;
- The aid has an incentive effect, as the subsidized storage facilities would not be financially viable without public intervention;
- The aid has positive effects that outweigh any potential distortion of competition and trade in the EU.

On the basis of these considerations, the Italian scheme was approved by the Commission as being in line with EU state aid rules.

4 BESS PROJECTS IN EUROPE

In recent decades, the opening of electricity markets has created opportunities for the participation of Battery Energy Storage Systems, particularly in primary frequency regulation within ancillary services.

Additionally, the interest in commercial and industrial (C&I) applications is increasing due to high prices and/or penalties for peak demand periods, low photovoltaic costs, and potential aggregation programs. However, the layout of the market and regulatory frameworks vary by country, resulting in a lack of homogeneity in the presence of Li-ion battery projects across Europe.

The current market outlook in Europe is depicted in *Fig.22,* based on information from leading markets, existing implementations, and potential opportunities (data from 2019).

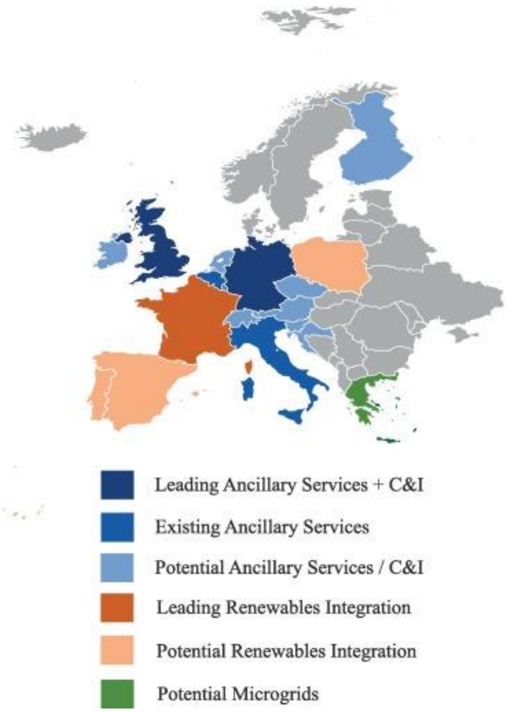


Figure 22: Li-ion BESS market overview of Europe
Source: Science direct

The UK and Germany are the leading countries for large-scale Li-ion BESS implementation for both ancillary services and C&I use-cases in Europe, with the largest installed energy storage units.

The UK is the first European country to have opened a fast frequency response market as part of its grid services (EFR - enhanced frequency response) in order to mitigate constant frequency deviations resulting from disconnection from the European continental electricity network. This is particularly favorable for BESS, as EFR requires asset activation within 1 second.

As a result, more than 200 MW of equivalent battery systems were awarded in tenders for EFR in 2018. In addition, the primary frequency regulation service (FFR - firm frequency response) requires a faster activation time compared to the rest of Europe. Specifically, it requires 10 seconds instead of 30 seconds.

Until very recently, the UK had a capacity market with long-term contracts. Clean Horizon[18] reports that over 500 MW of equivalent BESS contracts were awarded in 2020.

The UK has highly favorable conditions for batteries in C&I use-cases due to the high tariffs on peak demand periods based on triad mechanisms[19].

On the other hand, Germany has a well-functioning market for primary frequency regulation. This is due in part to the country's open cooperation with neighboring countries such as France, Austria, Switzerland, Belgium, and the Netherlands. This cooperation has led to the implementation of more than 150 MW of equivalent storage systems during the last three years.

France is the third most important European market for renewable energy integration due to its numerous isolated islands and remote locations, many of which are former colonies. Conventional energy resources based on fossil fuels can be very expensive in these areas, making the integration of renewable energy, enhanced by BESS, a positive environmental solution that can reduce the present levelized cost of electricity (LCOE).

Several tenders have been awarded for the implementation of storage on islands, totaling more than 60 MW. These tenders include Corsica, Guadeloupe, Guyana, La Reunion, Martinique, and Mayotte, which are overseas regions administered by the French government.

[18] Clean Horizon is a company that helps its clients monetize energy storage projects by offering technical consulting, market analysis and project management.

[19] A triad in electricity refers to the three half-hour settlement periods of highest demand on the Great Britain electricity transmission system between November and February (inclusive) each year, separated by at least ten clear days.

Other European countries and regions also have existing and/or potential Li-ion storage solutions. For instance, both Belgium and Italy have implemented large-scale BESS to provide primary frequency regulation.

Besides, there are several emerging markets where Li-ion BESS implementation is possible due to recent initiatives or changes in the energy market. These include the high imbalance prices in the Netherlands, the opening of the capacity market in Poland, promising ancillary services in Finland, island microgrid initiatives in Greece, and the *Sincrogrid* project in Slovenia/Croatia.

UK

The battery storage market in the UK is expected to experience significant growth in the next few years, with a projected capacity of 24 GW by the end of the decade.

These utility-scale battery systems "will attract investments of up to $20 billion and have enough combined energy reserves to power 18 million homes for a year", Rystad Energy analysis (2023) shows. Due to its rapid expansion, the UK will account for almost 9% of all global capacity installations, ranking fourth behind China, the US, and Germany.

As the UK installs more solar and wind energy infrastructure, the need for reliable storage solutions increases due to the intermittent nature of these renewable sources. Consequently, the UK government has set ambitious targets for energy storage requirements, aiming to achieve 30 GW of capacity by 2030, including batteries, flywheels, pumped-hydro, and liquid air energy storage.

It is projected that the UK will meet and even surpass its target, but only if the government addresses some expected roadblocks. These include ensuring widespread grid connections for battery systems, mitigating supply chain issues and developing a policy framework for pumped-hydro projects.

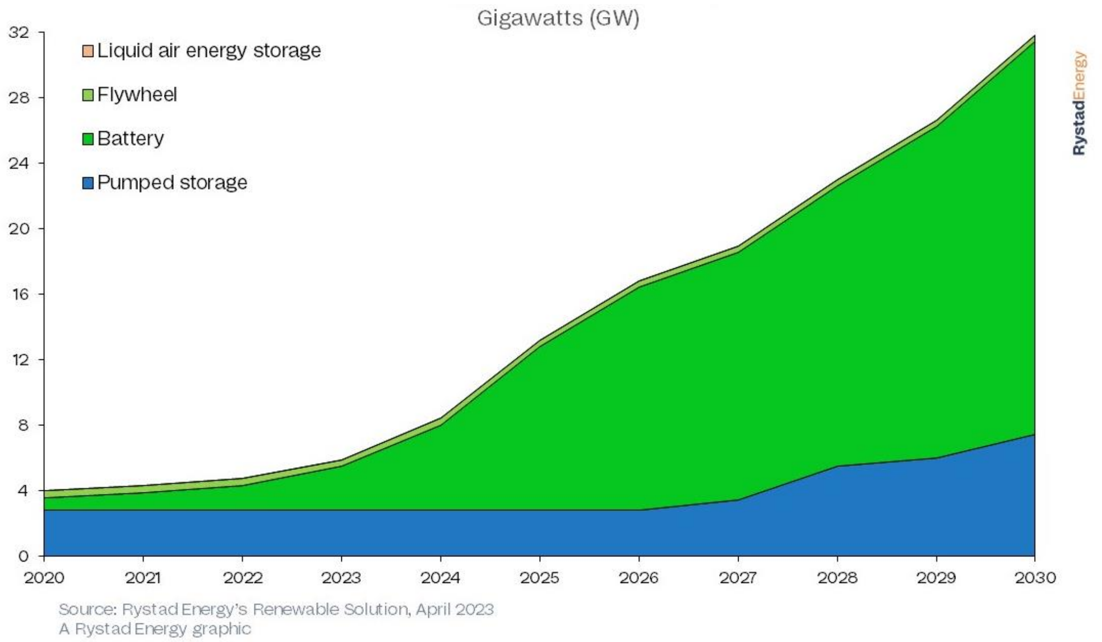


Figure 23: Installed energy storage capacity (in GW) in the UK

Out of the total 4.7 GW of installed energy storage capacity in the UK, only about 2.1 GW is accounted for by BESS.
The majority of the current capacity, 2.8 GW, is derived from pumped-hydro storage, which is a form of turbine-powered hydroelectric storage where water moves between two reservoirs at different heights.

Although these systems are efficient, the UK is unlikely to add new projects in the short term due to the financial and regulatory hurdles required to develop new capacity. However, the government plans to establish a strategy for Long-Duration Energy Storage (LDES) developments, such as pumped-hydro, by the end of 2024. This will boost capacity buildout in the long term.

Battery developments are also set to increase in number and scale due to the government's decision to lift size restrictions on project planning.

As a result, the most common size of BESS projects in the UK is expected to increase significantly, with some single projects even exceeding 1 GW. A battery project of this magnitude could require up to 55 acres of land, which is equivalent to more than 40 football fields.

BESS can play an essential role in the power grid by providing frequency regulation, voltage support, and power reserve, while also enhancing grid stability and reliability.

The National Grid has opened five revenue streams for BESS project investors to capitalize on in order to encourage developments.

Battery operators can generate significant revenues by selecting the appropriate revenue stream. For example, the deployment of battery energy storage is being driven by dynamic containment services for grid stability and capacity market auction schemes. However, meeting the technical requirements to participate in such schemes can be challenging.

Authority	Revenue streams	Details
National Grid	Capacity market auction	Mechanism to procure capacity by providing payments to generators to ensure sufficient generation on the system. Two auctions are held yearly under this scheme T-4, where it awards mostly projects to be delivered in four years time (with new projects able to secure 15-year agreements), and T-1 awards one-year contracts to existing generators to ensure delivery ahead of each year.
	Frequency response	Generators are awarded with payments at different contract durations to balance the supply and demand of electricity and manage frequency deviations on a minute-by-minute basis.
	Dynamic containment (DC), Dynamic moderation (DM), and Dynamic regulation (DR)	A new suite of products used by National Grid to provide fast-acting service (DC) for post-fault management and DM & DR for pre-fault events to ensure frequency remains around 50Hz in the event of sudden drop or surge in supply on the grid.
	Wholesale market	Wholesale electricity trading between generators and suppliers, mainly in day-ahead to intraday markets.
	Balancing mechanism	Primary market used by national Grid to provide real-time flexibility to the grid by using flexible technologies such as batteries and gas reciprocating engines during events including power station trips, demand surges and intermittent renewable generation.

RystadEnergy

Source: Rystad Energy's Renewable Solution, April 2023
A Rystad Energy graphic

Figure 24: Revenue streams available to battery storage project investors

Ten Point Plan for a Green Industrial Revolution (HM Government, 2020)

The plan aims to combine ambitious policies with substantial new public investment, while also striving to mobilize private investment. This has the potential to generate an estimated £42 billion of private investment by 2030 across various sectors, including energy, buildings, transport, innovation, and the natural environment. By positioning itself to take advantage of export opportunities presented by low-carbon technologies and services in emerging markets, the UK can create jobs and reinvigorate industrial heartlands.

It is important to unleash innovation and develop new sources of finance to further develop green technologies for net zero. The upcoming phase of green innovation aims to reduce the cost of the net zero transition, foster the creation of improved products and business models, and impact consumer behavior.

To expedite the commercialization of innovative low-carbon technologies, systems, and processes in the power, buildings, and industrial sectors, the Net Zero Innovation Portfolio, worth £1 billion, will be launched.

The portfolio will focus on ten priority areas that correspond with this Ten Point Plan, including:

- floating offshore wind;
- nuclear advanced modular reactors;
- **energy storage and flexibility;**
- bioenergy;
- hydrogen;
- homes;
- direct air capture and advanced CCUS[20];
- industrial fuel switching;
- disruptive technologies such as artificial intelligence for energy.

In particular, £100 million will be provided for Energy Storage and Flexibility innovation challenges.

UK projects

Trafford Battery Energy Storage System

The Trafford Battery Energy Storage System is a brownfield project that is ready to be built. It has a confirmed connection capacity of 1040 MWe onto the National Grid 400kV network in October 2025.

This project presents an opportunity to invest approximately £700 million in a large-scale, 1 GW MW, 2-hour duration BESS project that is at an advanced stage of development. Upon completion, it will connect to the National Grid's transmission system at 400kV, with the potential for further expansion up to more than 2 GW in subsequent phases.

Carlton Power, the developer, is offering to sell up to 100% of the project company, with a long-term lease for the site at Trafford Energy Park. The site is strategically located on the National Grid system for both the 400kV transmission network and high-pressure gas, as well as the low-pressure regional gas network. It is also in proximity to the proposed HyNet Hydrogen networks.

[20] Carbon Capture Utilization and Storage.

Detailed planning has been obtained for a 1040 MWe x 2 hour duration facility on the site, with grid capacity and land available for future expansion to 2080 MWe.

Figure 25: Render of the Trafford Battery Energy Storage System in Manchester
Source: great.gov.uk

<u>Vanadium Flow Battery Longer Duration Energy Asset Demonstrator ("VFB LEAD")</u>

Invinity is deploying the largest battery ever manufactured in the UK, a 30 MWh Vanadium Flow Battery, utilizing funding awarded by the UK Government's Department of Energy Security and Net Zero (DESNZ) as part of the Longer Duration Energy Storage Competition (LODES).

The Vanadium Flow Battery Longer Duration Energy Asset Demonstrator ("VFB LEAD") project will deploy a 30 MWh Invinity VFB system deployed at a key node on the National Grid.

The battery will be capable of delivering more than 7 MW of power on demand. It will utilize Invinity's battery technology, which has fast-response and high-throughput characteristics, to provide a broad range of services to the grid.

The battery's operation will provide flexibility to the UK electricity network and support the country's transition to a low-carbon energy system supplied by domestic energy sources like wind and solar power.

This battery, with a capacity equivalent to the daily energy use of over 3,500 homes, will be the largest ever to be manufactured in the UK.
The flow battery system at the Energy Superhub Oxford is approximately six times smaller than the one described here. This new system is expected to be one of the largest flow batteries in the world and the largest long duration battery asset connected to the UK grid, with the ability to deliver full power for over 4 hours.

Additionally, this technology is a superior option to the more commonly used lithium-ion batteries due to its enhanced safety (they are incapable of catching fire), increased durability (they do not degrade with use), and over 97% recyclability at the end of their 25+ year lifespan. This reduces environmental impact and disposal costs for project owners.

Figure 26*: *Invinity VFB system
Source*: *invinity.com

GERMANY

Germany's utility-scale BESS market is experiencing a resurgence, and it may accelerate further due to increasing national and European Union commitments to renewable energy.

The primary economic opportunities in Germany are for frequency regulation ancillary services and energy trading on the wholesale market. Although the market experienced a brief surge in the mid-2010s as an early adopter of battery storage for frequency regulation, opportunities in the primary control reserve (PCR) market quickly became saturated.

The fundamental drivers for battery storage have been amplified by growing shares of renewable energy and increasing volatility in electricity markets across Europe, which has resulted in higher gas prices due to the Russian invasion of Ukraine. Additionally, storage operators in Germany have been granted a three-year extension on the waiver of fees charged for their use of the grid.

In addition to PCR, there is now also a market for secondary reserve (aFRR), which is being rolled out across the grids of Europe.

An article featured in the quarterly journal "*PV Tech Power (Vol.32)*" last year examined whether Germany's utility-scale market was due for a revival. The article noted that only 32 MW of large-scale BESS had been deployed in 2021.

The German market experienced an increase in activity due to the introduction of Innovation Tenders, which are government-backed reserve auctions for projects that combine two low-carbon technologies. These tenders have resulted in contracts primarily for solar-plus-storage plants. Additionally, 'NetzBooster' (or 'GridBooster') projects have been deployed as individual large-scale battery assets to directly support the transmission network.

Fluence has been awarded three GridBoosters, with a total capacity of 450MW/450MWh. The first GridBooster, with a capacity of 250MW/250MWh, is expected to come online by 2025, subject to regulatory approvals. The other two GridBoosters have a capacity of 100MW/100MWh each and were awarded in June 2023.

In November 2023, Kyon Energy received approval for a 137.5MW/275MWh BESS project in Germany's Lower Saxony region. While Kyon claimed it to be the largest BESS in Germany to date, it may not be the largest in Europe.

Additionally, Eco Stor is planning two projects of 300MW/600MWh each in the country. According to a recent expert report commissioned by Eco Stor, the addition of a forecasted 50 GW of storage on the grid by 2037 could significantly increase wholesale market revenues earned by wind and solar assets in the country. This increase could save taxpayers €3 billion in green energy subsidies.

The *MW Storage-Reichmuth JV* project in Arzberg is scheduled to come online in early 2025.

As of mid-2022, the largest BESS project in Germany is the *Lausitz Battery Energy Storage System* which has a capacity of 60MW/52MWh. The project is located at a coal plant operated by the generator LEAG[21].

Figure 27: Germany's largest BESS project to begin construction soon
Source: probidenergy.com

[21] LEAG is a German company operating in the field of energy supply in the country.

FRANCE

By the end of 2023, nearly 900 MW of publicly announced battery storage projects will be operational in continental France. While the country is currently behind its nearest northern neighbor in this regard, the business case for battery storage is steadily gaining momentum.

The UK currently has approximately 1.5 GW of large-scale battery storage, and its market has grown rapidly. Prior to a 200 MW tender for grid services held by the TSO National Grid in 2016, the UK had almost no large-scale battery storage.

The ability to stack revenues from multiple streams, including ancillary services, arbitrage, and the Balancing Mechanism and Capacity Market structures, has propelled the UK into a leading position among regional markets.

A similar revolution in the energy storage market appears to be imminent in France.

It is important to distinguish between continental France and its various island territories. These islands have a significant amount of dispatchable renewable energy tenders.

Within mainland European French borders, there were only a few megawatts of commercial installations as recently as 2019. It is important to note that this represents a small but significant recurring market. That amount increased to approximately 300 MW in 2022.

Clean Horizon has identified that the market will reach almost 900 MW by the end of 2023 by tallying figures from publicly announced projects, including those already operational, under construction, or planned.

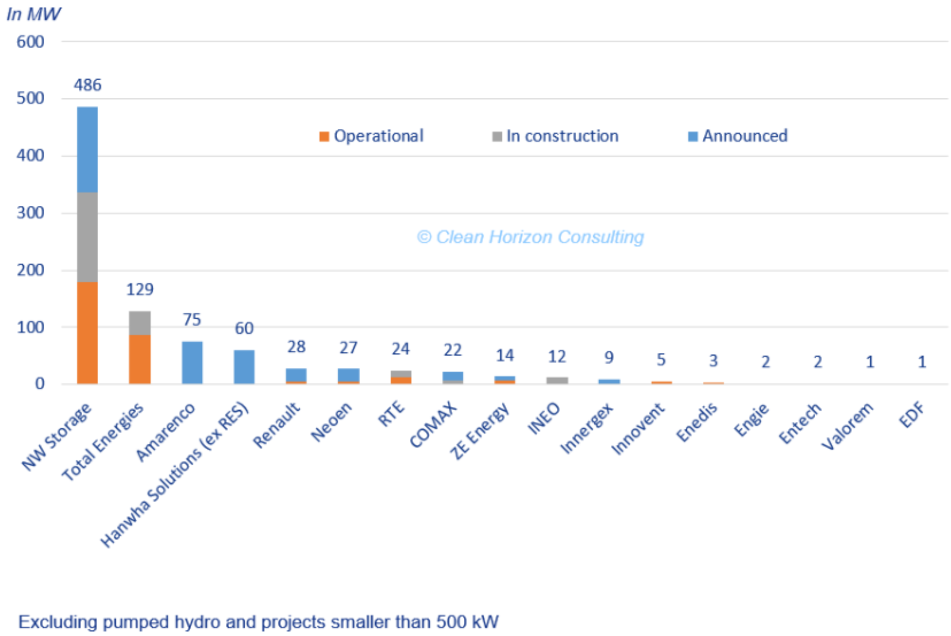


Figure 28: Storage projects in continental France
Source: Clean Horizon Consulting

This is encouraging because, unlike the UK, there are only two revenue streams available for battery storage assets in France today.

One is long-term contracted revenues from the capacity market. France held a dedicated low-carbon capacity market auction in 2019, awarding seven-year contracts to winning bidders for 235 MW of storage, which was announced the following year.

The frequency control reserve (FCR), also known as primary control reserve (PCR), is the first level of ancillary services. Assets in FCR respond to short-term frequency imbalances on the grid within 30 seconds of receiving a grid signal and can cover up to 15 minutes per incident.

Another revenue stream, the aFRR, also known as secondary reserve, is expected to open in the near future. The auction for the power plant, which was scheduled to open in November 2022 and had already begun, was halted due to the European electricity crisis.

Previously, the regulated secondary reserve market required large generators to provide grid services at a price set by the regulator, approximately €19/MW/hr. However, RTE[22] was paying €155 x 24 hours x 750MW = €2.79 million every day, which is about 10 times more than the regulated price.

[22] RTE is France's Transmission System Operator.

In addition to reducing taxes on electricity and fixing prices for end customers, a temporary halt was called for the aFRR auctions.

Nevertheless, many battery developers are interested in the potential revenues.

Battery storage has the potential to capture approximately one-third of the opportunity for aFRR across the interconnected European market by 2025.

Q Energy, a European renewables developer, has commenced construction on *'Merbette'*, a 35MW/44MWh BESS in northeastern France.

The BESS is being built at the Emile Huchet power plant in the town of Saint-Avold and is described as one of the largest storage facilities in the country. This project is part of GazelEnergie's efforts to transform the coal-fired plant into a green facility.

'Merbette' will house 24 battery containers and store enough electricity to meet the daily power consumption of approximately 10,000 people. This is the first of several energy storage projects that Q Energy is developing.

Figure 29: Render of the project 'Merbette' in France
Source: qenergy.eu

5 CASE STUDY

The discussion concerns the design of a BESS system, which involves analyzing and determining a suitable area for construction.

The area must comply with Enel's guidelines, including proximity to the substation and sufficient size to accommodate all containers and auxiliaries. The roads connecting the airport to the site, the access to the area and the internal viability must be suitable for the transit of the vehicles necessary for transporting goods, as well as firefighting vehicles.

Additionally, the maximum slope of the site must be assessed, and it must be lower or equal to 5%. If the slope is between 5% and 15%, the suitability of the area must be evaluated, while slopes of more than 15% are not acceptable.

To assess urban and territorial compliance, an analysis of landscape, archaeological and hydrogeological constraints is necessary from a national, regional, provincial and municipal perspective.

Moreover, the request for grid connection is evaluated to understand the network structure and its implementation timing.

To ensure a complete analysis, a detailed description of the BESS system is also provided. This includes a general explanation of the system architecture and the specific components/equipment chosen during the design phase to maximize the useful area identified.

In conclusion, all the necessary works related to the construction and operation of the plant are described, including civil and electrical works, plant auxiliaries, as well as fire prevention and disposal management.

PREMISE

This case study relates to an application for authorization of a stand-alone electrochemical storage system, called "BESS" (Battery Energy Storage System), with the following characteristics.

Input power: 190 MW

Nominal power: 200.6 MW

Storage capacity: 1604.8 MWh

The plant is located in the Province of Viterbo (VT).

The proposed system will be used for energy trading on the electricity markets and for providing grid services to Terna in order to contribute to the safe management of the national electricity grid.

The Minimum Technical Solution foresees the connection of the above mentioned BESS plant by means of a 150 kV antenna to a new SE RTN 380/150 kV to be inserted with an “in-out” configuration in the 380 kV line of the RTN *"Roma Nord - Pian della Speranza"*.

5.1 Localization of the intervention

5.1.1 TERRITORIAL FRAMEWORK

The following satellite image shows the installation location of the storage system.

Figure 30: BESS plant area by satellite

The storage plant will be built on agricultural land.

5.1.2 GROUND TOPOGRAPHY CONSIDERATIONS

The ground characteristics has been analyzed with the software PVcase, in order to evaluate the suitability of the topography for the BESS installation.
The output of PVcase slope analysis is an image showing the BESS layout inside a mesh where the various colors indicate the percentage (%) of the slope.

The BESS plant area topography is not characterized by significant slopes, considering both east-west and north-south directions.

The results of the slopes analysis conducted with PVcase highlight that the slopes within the entire cadastral area are less than 10%, with around 92% of the area included in the slope range of 0% and 5% in the N-S direction, and 95% in the E-W direction.

Such slopes are negligible and will not have an impact on the installation of the BESS.

Terrain leveling/moving work could be required to install the containers. Ground work will entail extra costs that cannot be quantified at this stage and will need to be estimated during the design phase.

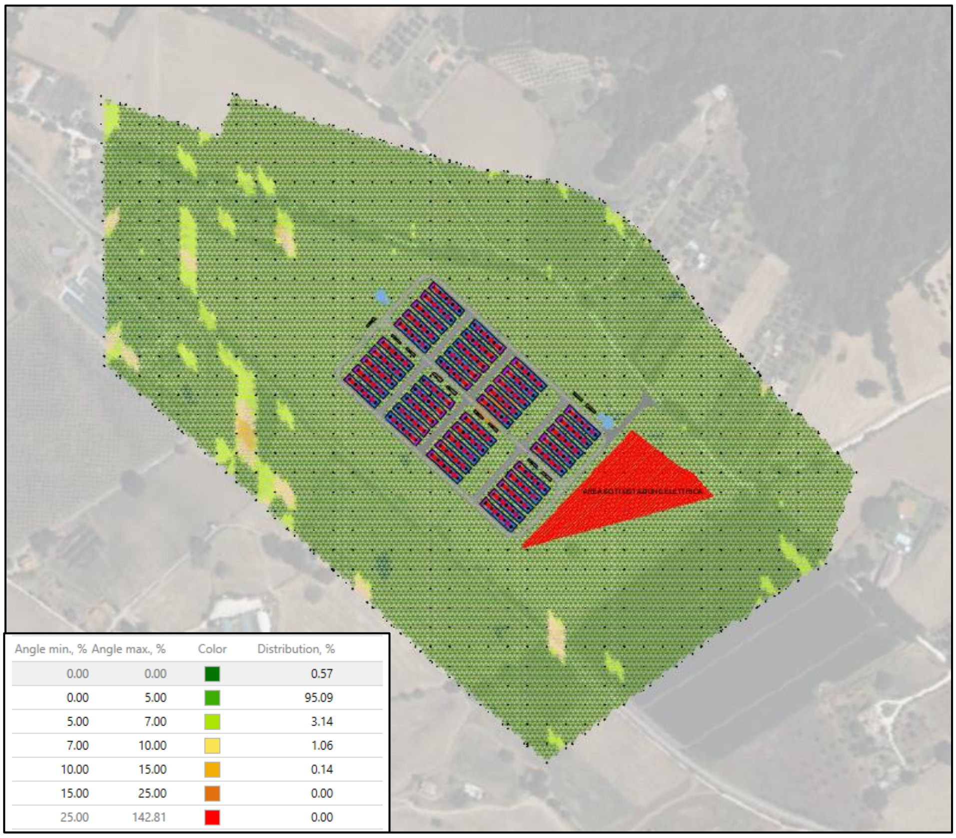


Figure 31: BESS plant slopes (E-W direction)

Figure 32: BESS plant slopes (N-S direction)

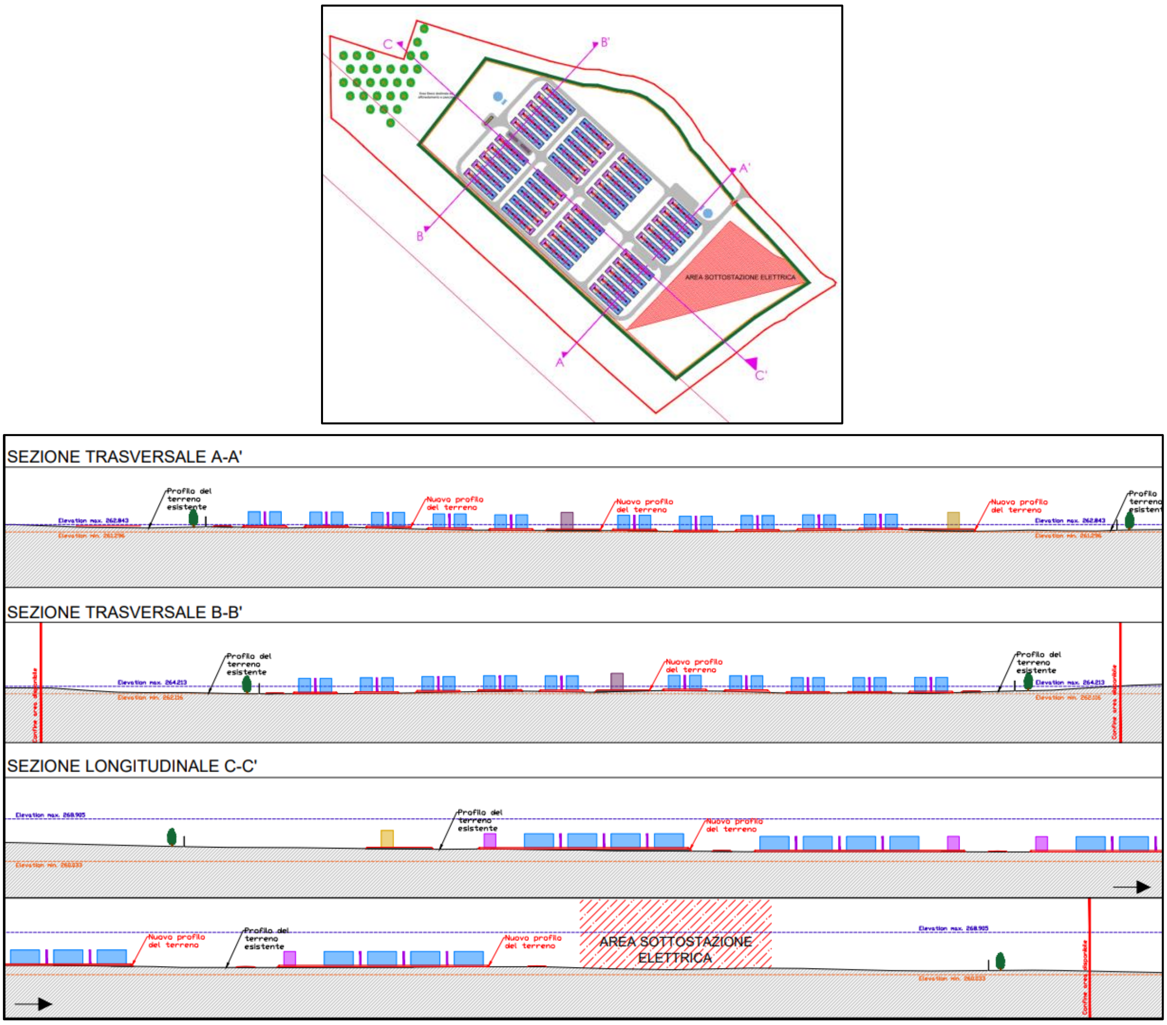


Figure 33: Extract of table "Layout plant: general planimetry_terrain sections"

5.1.3 CADASTRAL CLASSIFICATION

The planned storage system will be developed on a cadastral area located in the Province of Viterbo (VT), Lazio Region.

The area covers approximately 12.20 hectares, as registered on the land cadastre.

A preliminary sale agreement has been signed with the landowners to ensure the availability of the area.

The access to the plant area will be directly from a public municipal road, therefore, it will not be necessary to sign private agreements with the owners of the areas. Instead, it will only be necessary to request authorization for access from the municipal road.

5.1.4 URBAN FRAMEWORK

Based on the analysis of the PRG—*"Piano Regolatore Generale"* (General Regulatory Plan) of the interested municipality, the BESS project area falls:

- partly in agricultural zone E, subarea E4 'Normal agriculture';
- partly in the railway buffer zone;

as confirmed by the CDU – *"Certificato di Destinazione Urbanistica"* (Urban Destination Certificate).

The layout draft will respect the following buffer zones, in accordance with the Technical Standards:

- 20 m from cadastral borders;
- 20 m from municipal roads of type D in accordance with Ministerial Decree 1404/68 and Presidential Decree;
- 10 m from buildings in accordance with Ministerial Decree 1404/68.

Regarding the railway section, it is important to note that a 50 m buffer has been taken into account.

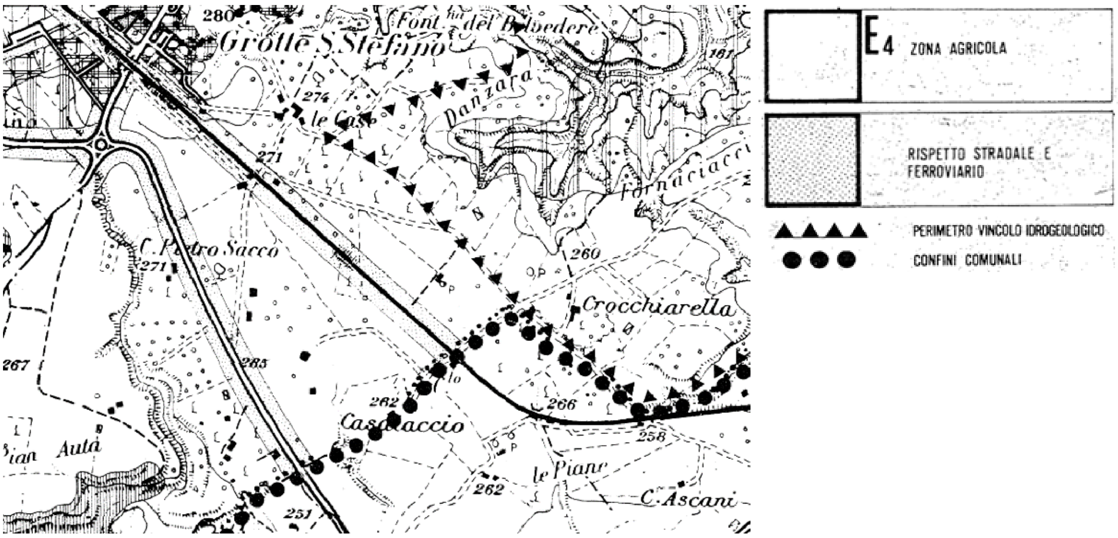


Figure 34: Extract from the webgis showing the PRG

5.1.5 CONSTRAINT FRAMEWORK

<u>Analysis of Natura 2000 protected natural areas, IBA areas and protected natural areas</u>

According to the National Geoportal and the institutional web tool Natura 2000, the BESS plant area is not included in the following categories of protected natural areas: SIC/ZCS, ZPS, IBA areas, Ramsar wetlands, national and regional protected areas.

It should be noted that the area is located about 1.6 km from the EUAP[23] 471 area *"Riserva naturale provinciale di Monte Casoli di Bomarzo"* and about 2.8 km from the EUAP 1215 area "*Monumento Naturale Corviano*".

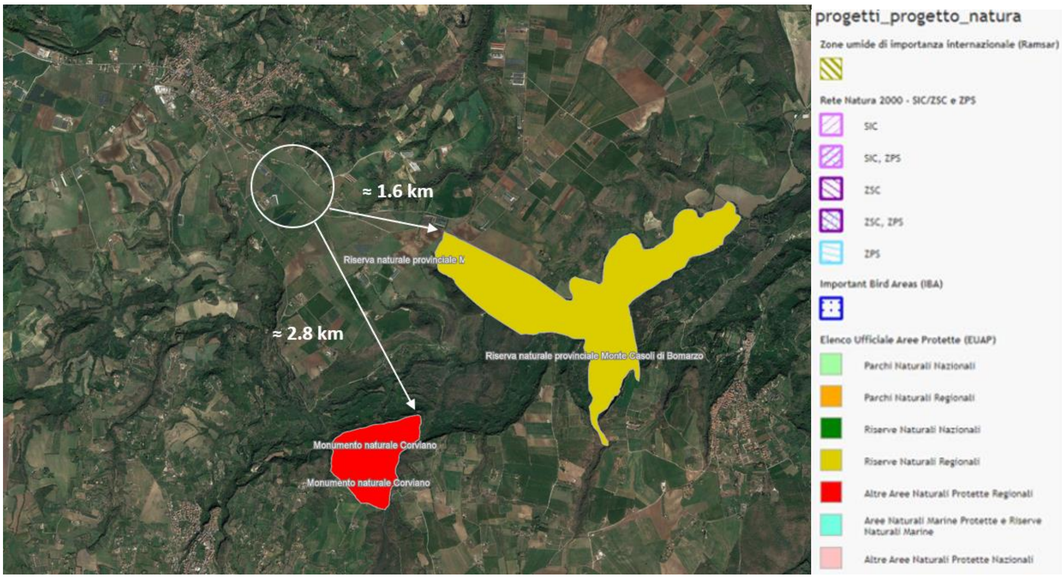


Figure 35: Extract from the Natura 2000 institutional web tool

[23] *"Elenco ufficiale delle aree naturali protette"*, Official List of Protected Natural Areas.

Cultural and Landscape Heritage pursuant to Legislative Decree no. 42/2004

According to the *"Sitap – Portale nazionale dei beni culturali"*, as confirmed by table B of the Regional Territorial Landscape Plan (PPTR), the area of the BESS plant is not included in the sites listed under Decree 42/2004.

***Figure 36*: Extract from the SITAP institutional web tool with the BESS plant area**

Hydrogeological constraint pursuant to R.D. 3267/1923

The analysis of historical cartography shows that the area in question is subject to hydrogeological constraints according to R.D. 3267/1923. However, the cartography of the PRG indicates that the area is outside the restricted perimeter. Therefore, there are no critical issues regarding hydrogeological constraints.

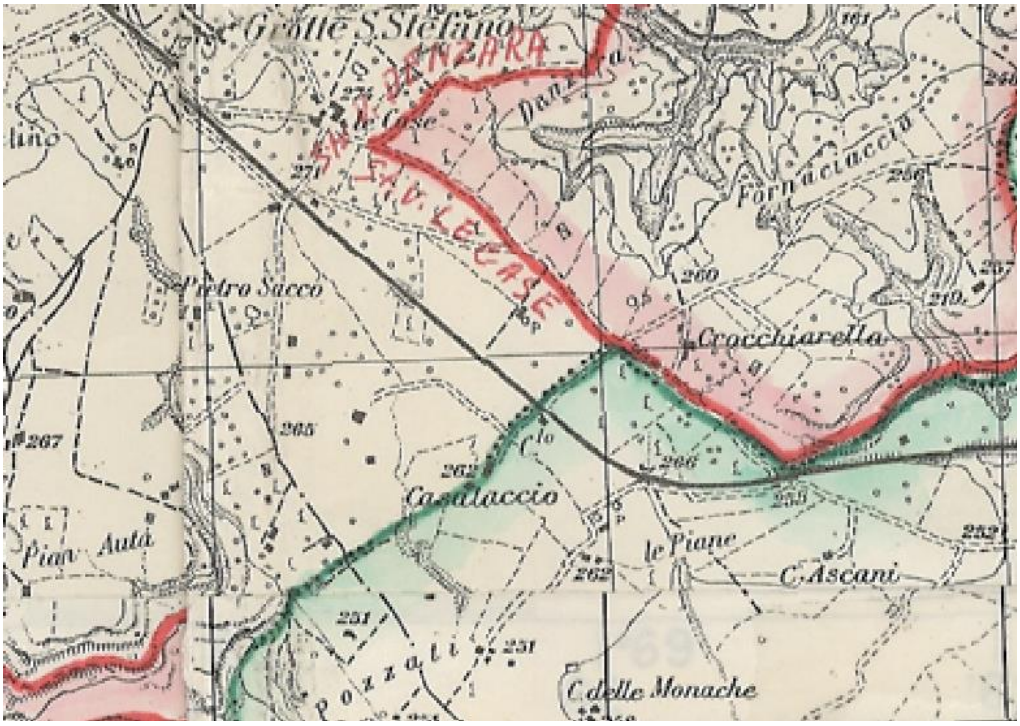


Figure 37: Extract from the historical cartography with hydrogeological constraint pursuant to R.D. 3267/1923

PAI – *"Piano per l'Assetto Idrogeologico"* and PGRA – *"Piano di Gestione Rischio Alluvione"*

From the analysis of the Hydrogeological Structure Plan (PAI) and the Flood Risk Management Plan (PGRA) of the Central Apennines Basin Authority (Tevere Basin), it has been determined that the BESS area is not subject to hydrological or geomorphological hazards or risks.

Based on the analysis of the PGRA update for the second cycle (December 2021) of the Central Apennines Basin Authority (Tevere Basin), it has been determined that the BESS area is not located within flood hazard or risk areas.

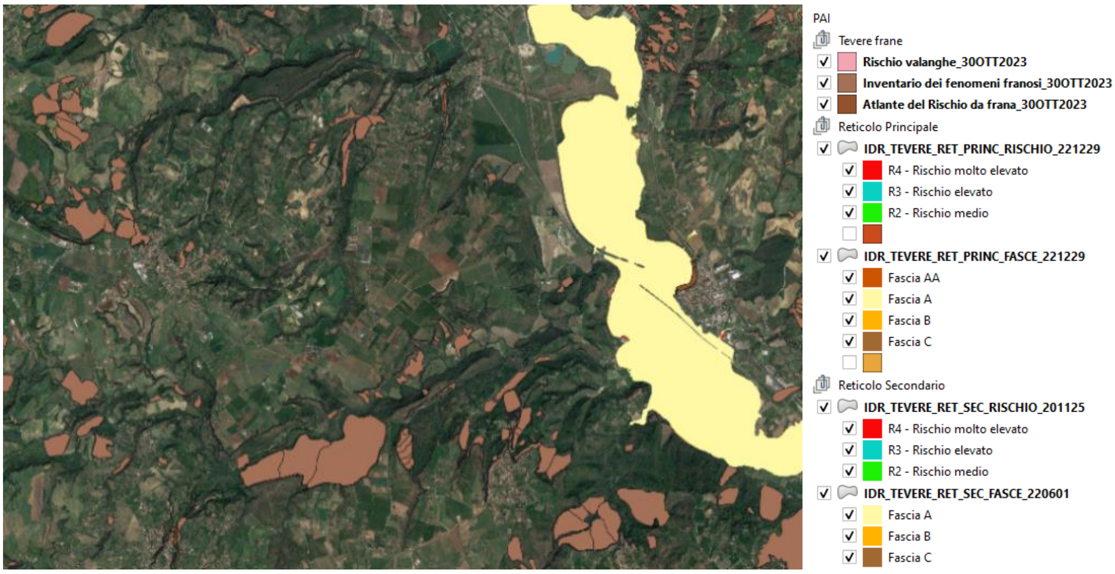


Figure 38: Extract from the overlay with PAI maps

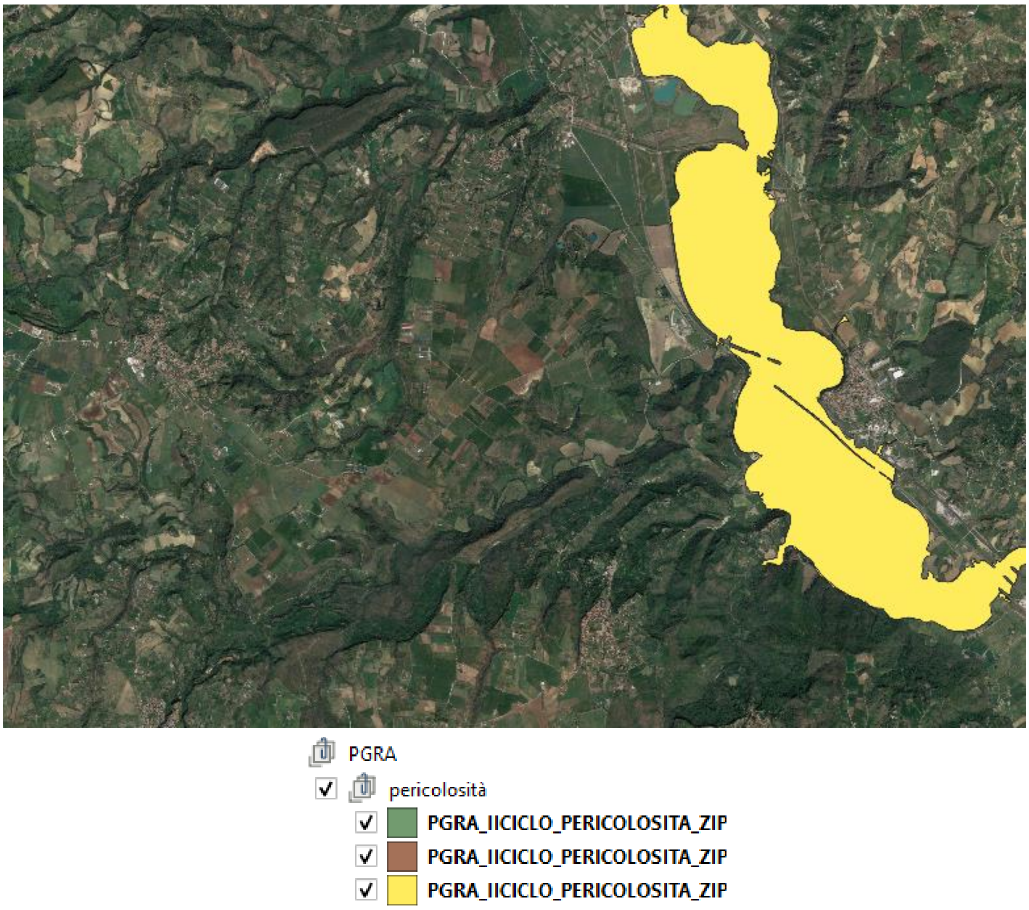


Figure 39: Extract from the overlay with PGRA maps

PPTR – *"Piano Paesaggistico Territoriale Regionale"*

The analysis of Table A of the Regional Territorial Landscape Plan (PPTR) shows that the area in question falls under the category of 'Agricultural Landscape of Value'. According to art. 26 of the Technical Standards, and in particular point 6.1, the technological use (infrastructures and systems) is allowed, respecting the morphology of the sites, the networks must be underground, if necessary; the landscape report must provide for the landscaping of the sites after construction, and the implementation of the interventions is subject to the contextual landscape arrangement envisaged. From a technical point of view, there are no critical issues in this regard.

An analysis of Table C of the PPTR shows that the area in question is bounded by the railway line. According to art. 33 of the Technical Standards, and in particular point 6.1, it is shown that the technological use (infrastructures and installations) is allowed, the network infrastructures must be underground, if possible; the projects must provide for the landscaping of the post-construction sites, with possible mitigation measures of the unavoidable effects on the surrounding context, and the implementation of the interventions is subject to the contextual landscape arrangement envisaged.

Table C of the PPTR also shows that the area in question is bordered by a scenic route. Art. 50 of the Technical Standards provides for a buffer of 50 meters only for the scenic roads shown in Table A. In this regard, it should be noted that Table A does not contain any such features in the vicinity of the area in question and that the scenic route shown in Table C corresponds to the railway line and not to a road.

In any case, a buffer of 50 meters has also been left by the panoramic route, since it corresponds to the buffer zone of the railway imposed by the PRG.

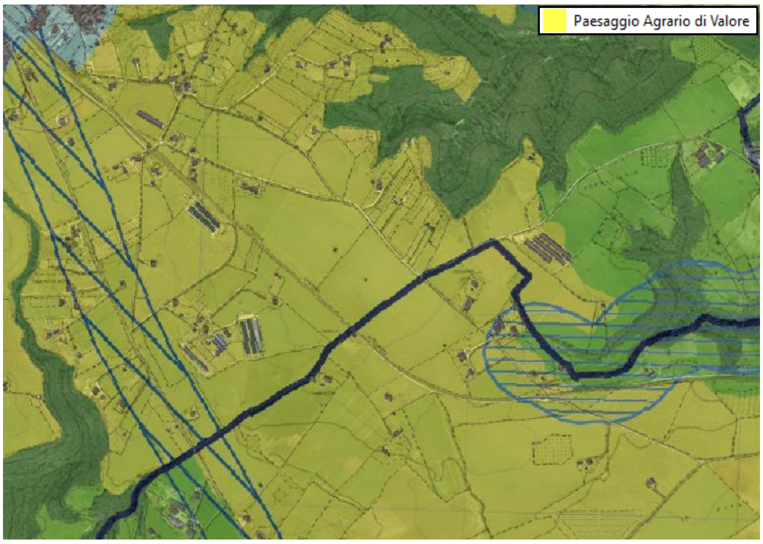


Figure 40a: Extract from table A of PPTR

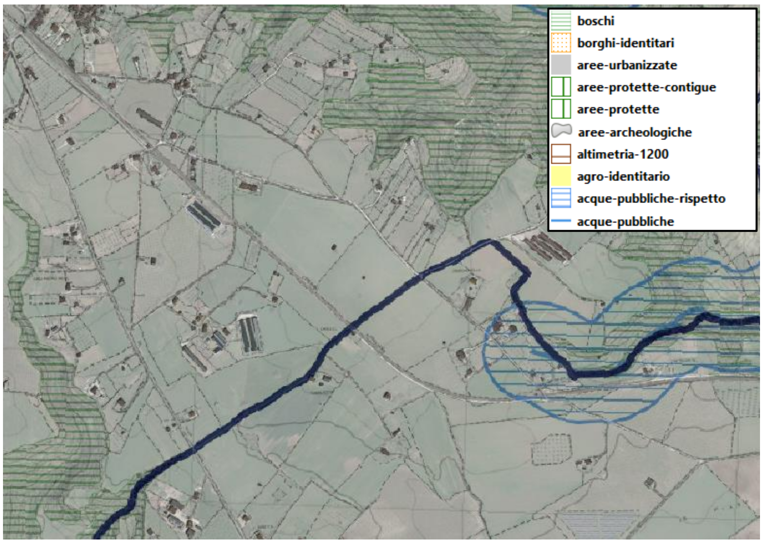


Figure 40b: Extract from table B of PPTR

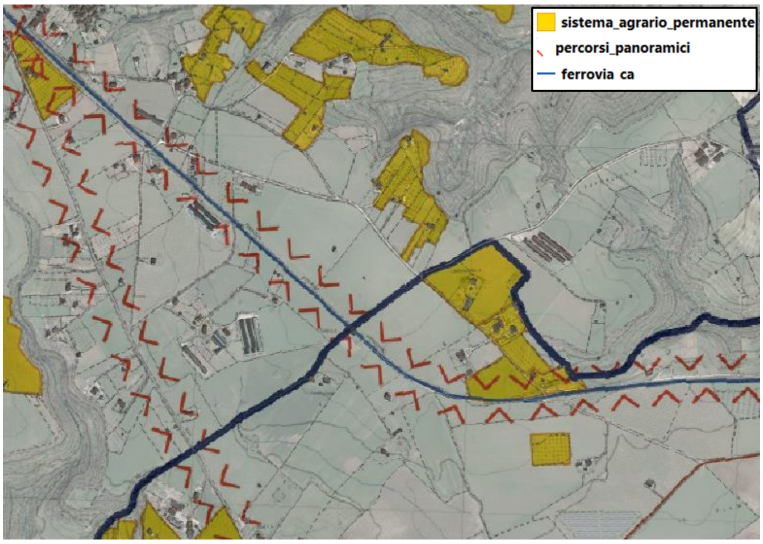


Figure 40c: Extract from table C of PPTR

Civic Uses

From the analysis of the PPTR (and as confirmed by the CDU, attached to the contract for the availability of the areas), the area does not fall within areas affected by civic uses.

Fire areas L. 535/2000

There are currently no online maps or data available regarding the areas covered by the fire according to Law 353/2000.

PTPG - *"Piano Territoriale Provinciale Generale"*

From the analysis of the Viterbo PTPG (General Provincial Territorial Plan), the analysis carried out at the national and regional levels is confirmed. Additionally, it should be noted that the BESS area is not subject to archaeological constraints or within perimeters linked to areas of archaeological interest.

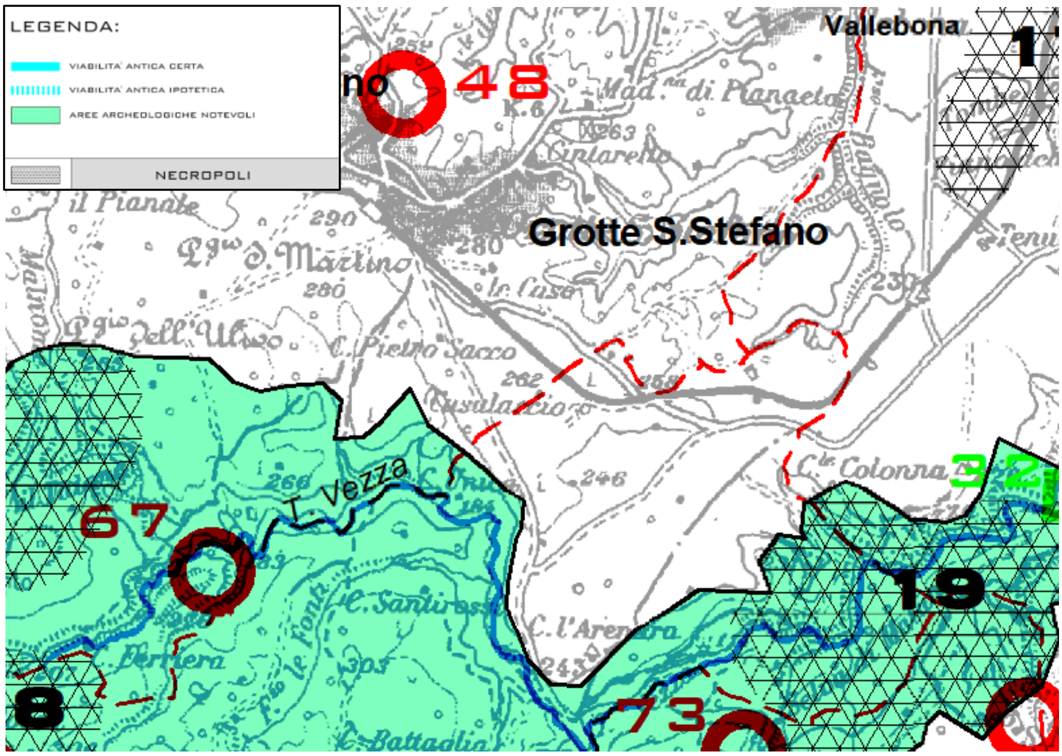


Figure 41: Extract from the cartography "Tav. 2.1.1 - Preesistenze storico archeologiche" of PTPG

5.2 Description of the system

All systems, equipment and components of the BESS will be designed, manufactured and tested in accordance with national and/or international regulations and under strict quality control.

The BESS will be operated mainly remotely, in the absence of local operators, from a central control room that will collect all signals and system diagnostics, allowing it to operate in complete safety.

Local operations will be carried out only during normal and extraordinary maintenance periods of the plant and according to the safety procedures that will be formulated during the start-up phase of the plant. All the control systems are also supplied by UPS[24] systems.

This will ensure a high availability of the control system. All information, messages, alarms will be provided to the remote control room as well as being available locally. There will also be a video surveillance system.

The BESS plant, in accordance with Terna's STMG[25], will be connected to an HV/MV step-up transformer installed in the area adjacent to the plant, through a line with MV underground cable, and then connected by antenna to a new RTN 380/150 kV SE to be inserted with an “in-out” configuration in the 380 kV *"Roma Nord - Pian della Speranza"* line.

The configuration of the BESS depends on the design choices, the available technology and the scalability of the solution. The modularity or scalability of the system is achieved by taking into account the main components of the BESS, such as LV/MV transformers, customized Power Converter System (PCS) cabinets and battery containers.

For the purpose of the design, a typical configuration unit of about 5 MW of deliverable/absorbable power for a duration of 8h has been defined, which is replicated to obtain the nominal power/energy of the plant.

[24] An Uninterruptible Power Supply is defined as a piece of electrical equipment which can be used as an immediate power source to the connected load when there is a failure in the main input power source.

[25] STMG = *“Soluzione Tecnica Minima Generale”*, General Minimum Technical Solution.

The proposed configuration consists of **40** typical units composed as follows:

- No.1 Sungrow MVS 5000-LV Power Conversion Unit consisting of:
  - AC cable entry section;
  - Voltage transformer section (5140 kVA 0.69/36 kV cast iron transformer);
  - MV protection and disconnection panels.

Product Name	MVS5000-LV
MV transformer	
Rated Power	5140 kVA
MV / LV Voltage	11 kV - 33 kV / 0.69 kV
Transformer Vector	Dy11 (standard)
Insulation Level	A
Rated Frequency	50 Hz / 60 Hz
Short-circuit Impedance	8 % (tolerance ± 10 %)
Material of Winding (MV / LV)	Aluminum / Aluminum
Cooling Method	ONAN
Degree of Protection	Transformer body: IP68 , Other parts: IP55
RMU	
Rated Voltage	24 kV / 36 kV / 40.5 kV
Rated Current	630 A (50 Hz) / 600 A (60 Hz)
Units	DCV / CCV / CV / DV
Relay Protection	ANSI 50 , 50N , 51,51N
Rated Short-time Withstand Current	20 kA / 3 s or 25 kA / 1 s
Smart Control Cabinet	
Protection	AC Breaker
Surge Protection	Type I+II
Meter for Main Circuit	Optional
AC Insulation Detection	Support
Cooling Method	Air cooling and HVAC
Degree of Protection	IP55
UPS	2 h
General Data	
Dimensions (W × H × D)	6058 mm * 2896 mm * 2438 mm
Weight	18000 (± 500) kg
Degree of Protection	IP55
Corrosion Prevention	C4 (standard)
Operating Ambient Temperature Range	-40 °C - 60 °C > 40 °C derating (standard) ; > 45 °C derating (optional)
Allowable Relative Humidity Range	0 % - 100 % (non-condensing)
Max. Operating Altitude	4500 m
Compliance	IEC 62271-202, IEC 61439
Communication	Ethernet, Optical fiber, RS485

Figure 42: Datasheet of Sungrow MVS 5000-LV Power Conversion Unit

- No. 8 Sungrow ST5015 battery containers, each with a storage capacity of 5015 kWh, consisting of:
  - 12 racks with 146 modules connected in series for a total storage capacity of 5.015 MWh;
  - N. 1 BMS system;
  - N.1 liquid cooling system;
  - N.3 static DC/AC conversion units of 210 kVA each.

Optimal Cost

- Intelligent liquid-cooled temperature control system to optimize the auxiliary power consumption
- Pre-assembled, no battery module handling on site,transportation of complete system

Efficient and Flexible

- High-efficiency heat dissipation, increase battery life and system discharge capacity
- Front single-door-open design, supporting back to back & side by side layout drawing
- System commissioning in advance, reduce commissioning work on site, accelerate COD process

Safety and Reliable

- AI monitoring for cell health, with early warning
- Electrical safety management, overcurrent fast breaking and arc extinguishing protection
- The electrical cabinet and battery cabinet are separated to prevent thermal runaway

Convenient O&M

- One-click system upgrade
- Intelligent automatic rehydration reduces manual rehydration
- Online intelligent monitoring to reduce manual inspections frequency

SUNGROW
Clean power for all

Technical Data	ST5015kWh-2500kW-2h
DC side	
Cell Type	LFP 3.2 V / 314 Ah
Battery Configuration	416S12P
Nominal Capacity	5015 kWh
Nominal Voltage Range	1123.2 V - 1497.6 V
AC side	
Nominal AC power	210 kVA * 12
AC Current Distortion Rate	< 3 % (Nominal Power)
DC Component	< 0.5 %
Nominal AC voltage	690 V
AC Voltage Range	621 V - 759 V
Power Factor	> 0.99 (Nominal Power)
Adjustable Range of Reactive Power	- 100 % - 100 %
Nominal Frequency	50 Hz / 60 Hz
Topology	Transformerless
Termination (LV)	352 A * 3 Phase * 6
System Parameter	
Container Size (W * H * D)	6058 mm * 2896 mm * 2438 mm
Container Weight	42500 kg
Degree of Protection	IP55
Operation Temperature Range	- 30 ℃ - 50 ℃ (> 45 ℃ De-rating)
Operation Humdity Range	0 % - 100 % (Non-condensing)
Highest Altitude	4000 m
Temperature Control Method	Intelligent Liquid Cooling
Fire Suppression System	FACP、FK5112、Flammable gas detector、Smoke detector、Heat detector 、Sounder beacon、Alarm bell、Warning sign、Extinguishant abort button、Ventilation system、Pressure relief port、Manual automatic switching and emergency starting device (Default) Sprinkler、Vent panel 、Aerosol (Optional)
Communication Interface	Ethernet
Communication protocol	Modbus TCP
Standard	IEC61000, IEC62619, IEC62933,AS3000,UKCA,G99,UN38.3/UN3536,CE,IEC62477

Figure 43: Datasheet of Sungrow ST5015kWh Battery Unit

This solution may be subject to non-essential adaptations due to the subsequent executive design and construction phase, also depending on the technological solutions adopted by suppliers and/or contractors.

The BESS plant will consist of 40 units as described above, with a total capacity of 200.6 MW and a maximum capacity of 1604.8 MWh. The batteries and PCS will be connected to the 30 kV LV/MV transformers present in the BESS area, one per base unit, which will be interconnected in an "in-out" configuration and will have the task of distributing the power supplied/absorbed by the batteries to the 30 kV MV main switchboards allocated in the BESS area. The 30 kV protection and disconnection panels will be connected to the new 30/150 kV substation and then to the 150/380 kV substation through underground MV 30 kV cables.

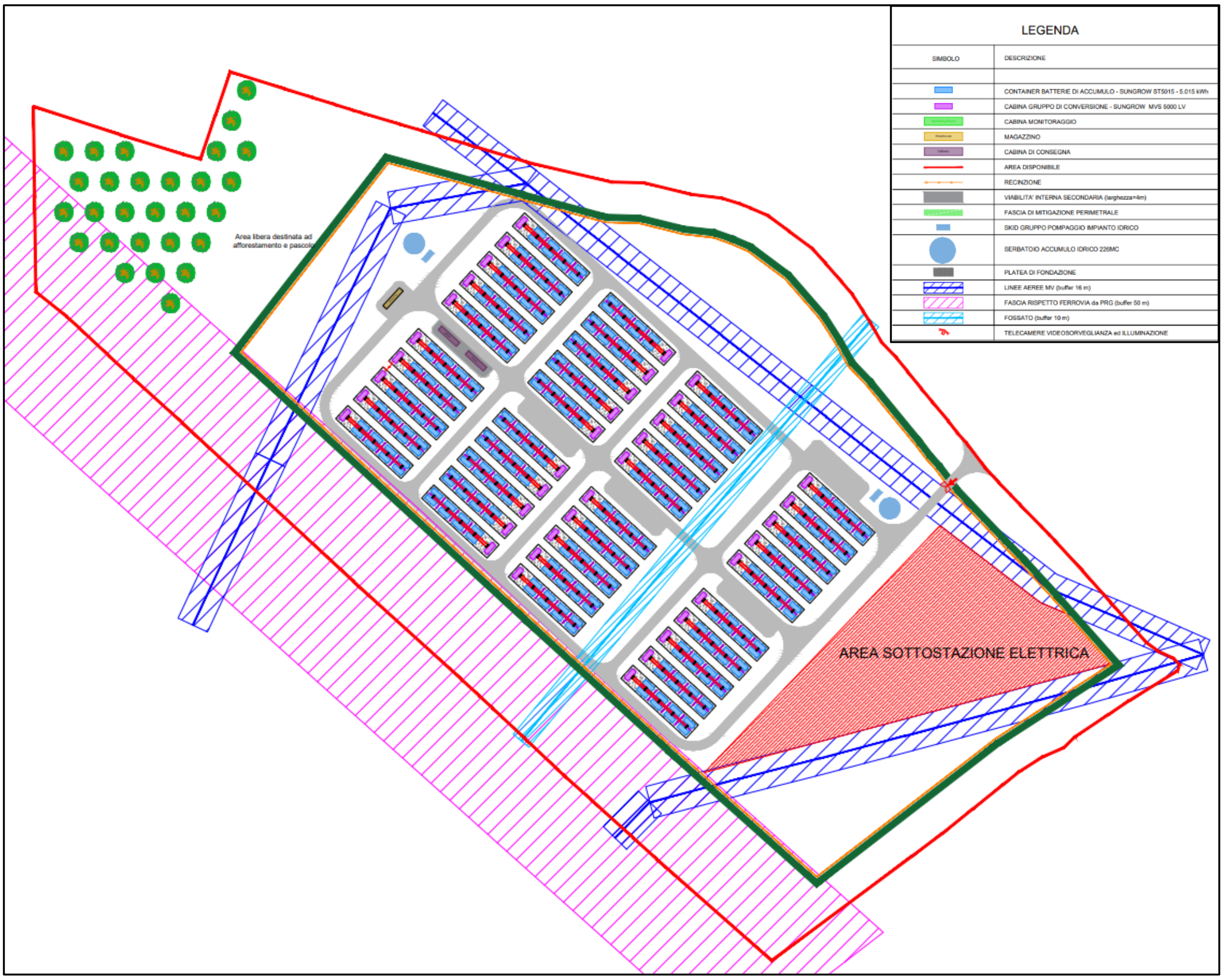


Figure 44: Extract of the table "Plant layout: general planimetry"

5.3 BESS plant description

The BESS is an electrochemical energy storage system that includes batteries, a power conversion system, and a LV/MV control and transformation system.

The design of the BESS is based on subsystems with a clear hierarchy, as shown in the figure below, following the guidelines of the IEC 62933 series.

The system consists of three subsystems:

- the primary subsystem, which includes the storage and power conversion subsystems;
- the auxiliary subsystem;
- the control subsystem, which includes the communication, management, and protection subsystems.

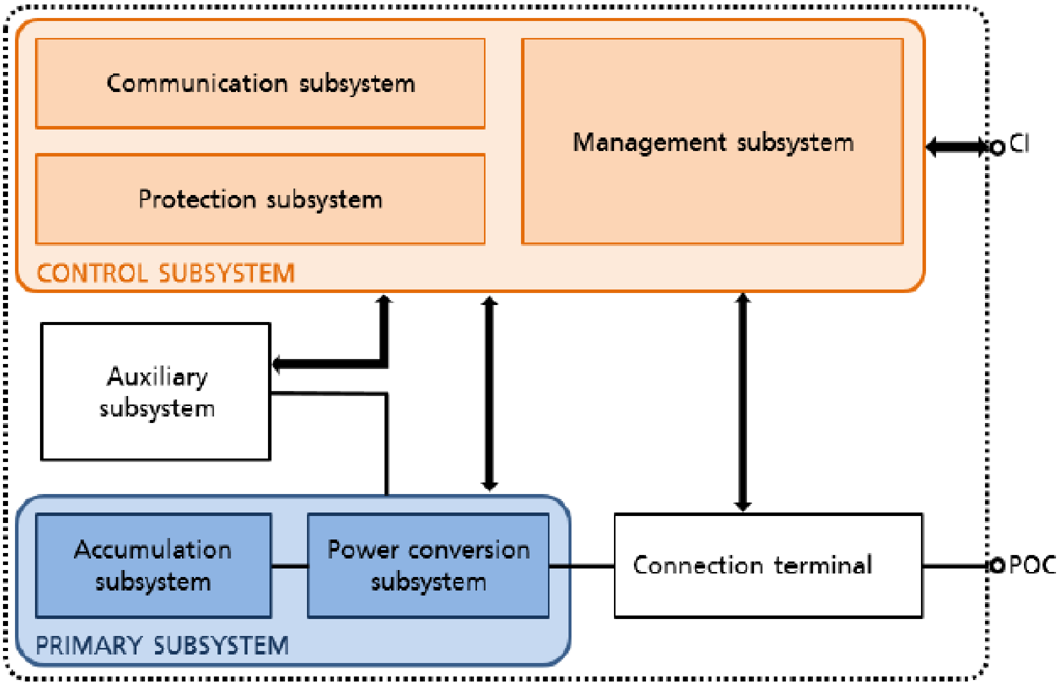


Figure 45: Subsystems comprising BESS

Source: MASE

The BESS will be designed based on the architecture depicted in the figure below:

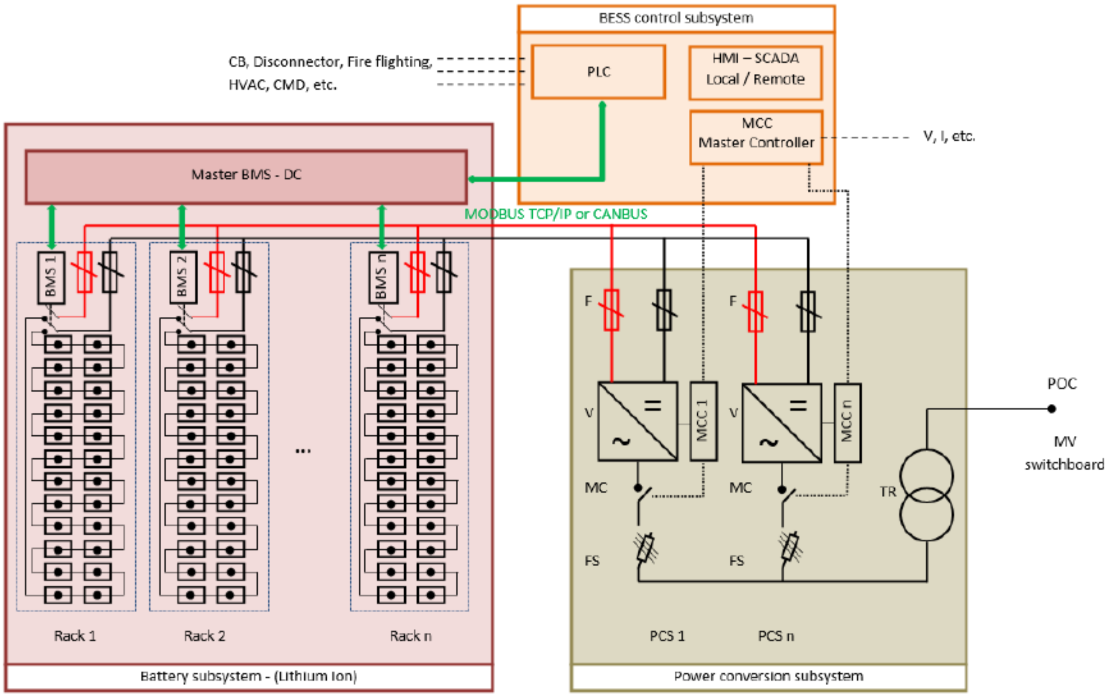


***Figure 46**: Detailed description of the architecture of the subsystems comprising BESS*

***Source**: MASE*

Typically, BESS components are assembled and shipped in one or more containers for installation in the field. The BESS is equipped with all necessary LV, MV, signaling, and control cables, as well as FO (Fiber-optic) cables, to connect subsystems and the BESS to the POC (Point Of Contact).

The BESS includes typical components, such as but not limited to:

The **Battery subsystem** will consist of lithium-ion batteries with a life expectancy equivalent to that of the plant under normal outdoor operating conditions. The batteries will be composed of electrochemical cells that are electrically connected to each other in series and parallel to form battery modules.

The battery modules are connected to each other and assembled in special cabinets or racks to achieve the required power, voltage, and current values. Each rack has its own Battery Management System to manage the State of Charge (SoC), State of Health (SoH), voltage, current, and temperature of each level of the battery modules in the rack, as well as control and protection.

The batteries and their battery management system will be integrated into standard 40-foot ISO containers or custom cabinets designed for outdoor placement. These containers will be equipped with an air conditioning system, fire suppression system, and smoke detection for safety purposes.

The **Power Conversion subsystem** comprises one or more 4-quadrant bi-directional power converters, which are integrated into customized cabinets for outdoor installation or standard ISO containers of 20/40 feet. The subsystem is equipped with an air conditioning system, fire extinguishing system, and smoke detection. It also includes converter controllers, LV/MV transformers, sinusoidal and RFI (Radio Frequency Interference) filters, AC switches and protections, DC switches and protections, and other necessary components.

The **Control Subsystem** comprises several systems, including the plant's Integrated Control System (SCI) that ensures the proper functioning of each PCS-driven battery assembly, and the Integrated Central Control System (SCCI) that reports alarms and warning signals from the BESS plant to the main control room of the plant. The subsystem is divided into the following subgroups:

- The **Battery Management System** (BMS) is responsible for managing and controlling the battery module and its components. It controls protection and safety devices, as well as control, monitoring, and diagnostic devices, and ancillary services;
- The **Energy Management System** (EMS) is composed of industrial PCs that are connected to the system via redundant architecture. The EMS oversees the storage system, manages energy usage, optimizes grid performance, and communicates with higher-level operators;
- **Protection and auxiliaries**. Equipment that performs specific functions in addition to storing or extracting electrical energy. Examples of such equipment include protection and control systems, auxiliary services (such as air conditioning, ventilation, interfaces, and UPS), and energy distribution circuits;
- The **Balance of Plant** includes all components of the power plant that are designed and installed with consideration of the environmental conditions of the installation site, as well as power and voltage characteristics. This includes LV and MV electrical panels, auxiliary transformers, isolation transformers, and MV/HV step-up transformers.

Figure 47a*: *Module

Figure 47b*: *Rack

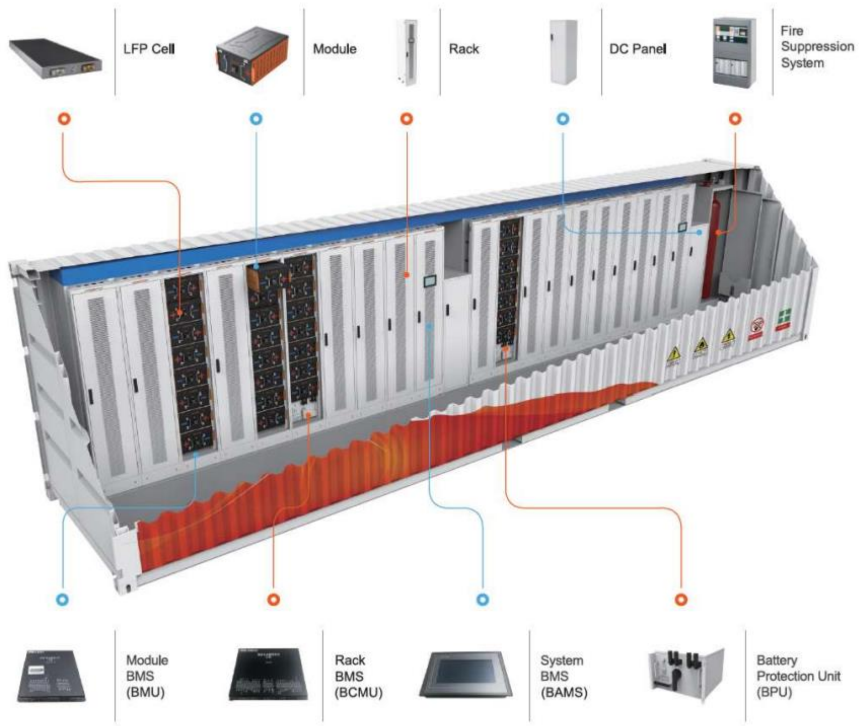


Figure 47c*: *Illustration of Battery Unit components in a containerized solution

Source*: *Narada

5.4 Grid connection review

The General Minimum Technical Solution for the project requires connecting the central to a 150 kV antenna on a new electrical substation (SE) for transformation to 380/150 kV of the RTN. This will be inserted with an “in-out” configuration in the 380 kV line of the RTN *"Roma Nord - Pian della Speranza"*.

According to Article 21 of Annex A to Resolution Arg/elt/99/08 and subsequent amendments of the Regulation for Energy, Networks, and Environment, the new 150 kV power line for the antenna connection of the system to the RTN Electrical Substation is a user system for the connection, while the stall that produces 150 kV in the aforementioned station is used for the network system connection.

Please note that in order to optimize the use of network facilities, it will be necessary to share the stall at the station with other production facilities. Alternatively, further expansion works need to be planned.

According to 1A.5.2.1 of the Network Code, the connection fee is 950 k€ (net of land cost and site development) and complies with the 'Conventional Technical Solutions for the Connection to the RTN' report on average network installation costs.

The fee is calculated by multiplying the above-mentioned costs by the coefficient specified in the Network Code, which in this case is equal to 0.5846.

The RTN works required for the connection will take 20 months to construct the new 380/150 kV SE and 8 months plus 1 month for the construction of 380 kV connections.

The implementation times mentioned above start from the date of the connection contract stipulated in Annex A.57 of the Network Code. This contract can only be stipulated after obtaining all necessary authorizations, as well as title deeds or equivalents for the land intended for transmission installations.

To obtain authorization as part of the single procedure outlined in Article 12 of Legislative Decree no. 387/03, it is essential for the proponent to submit the complete design documentation of the RTN works approved by Terna to the competent administrations.

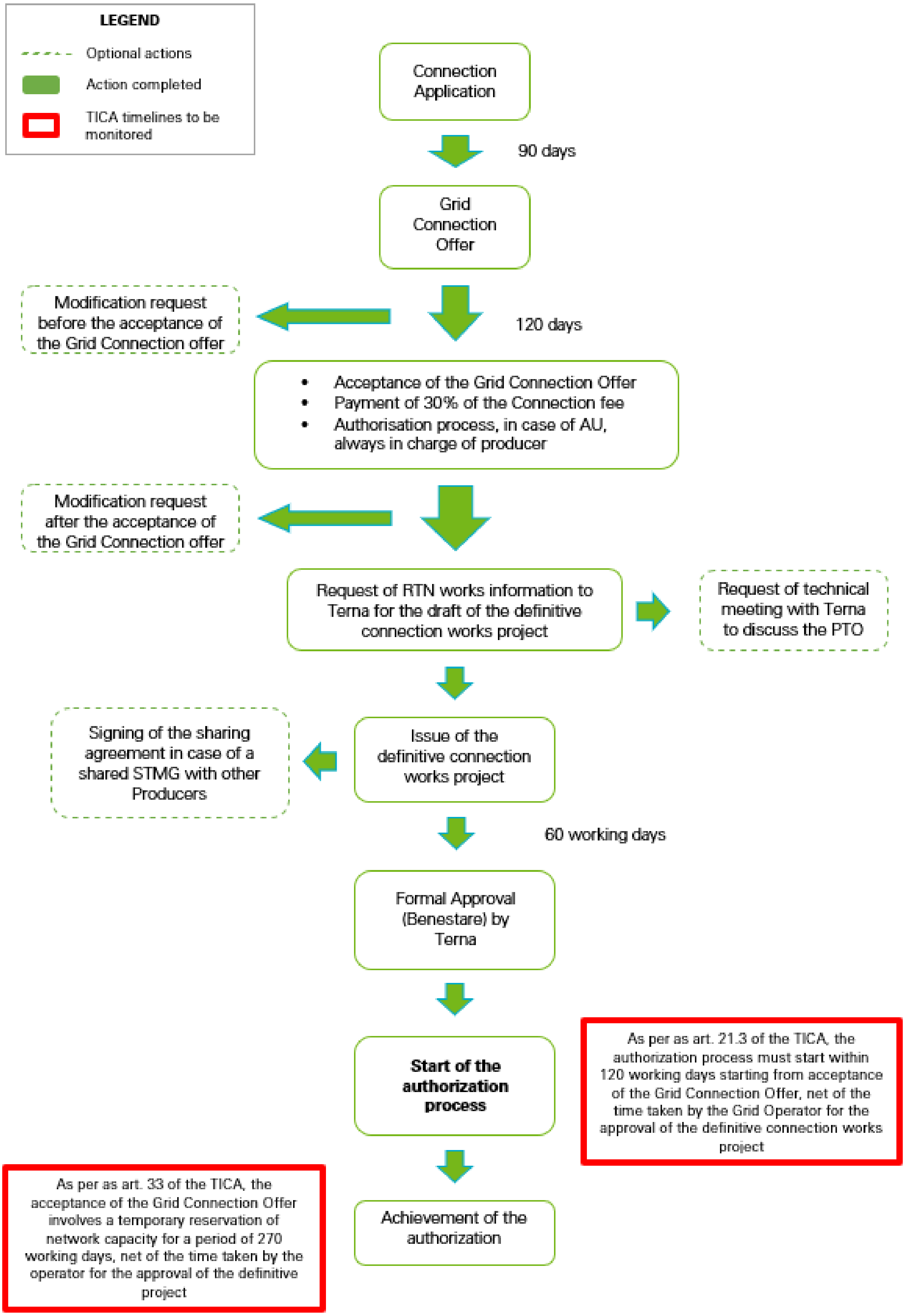
Therefore, the design of the RTN works must comply with Terna's technical requirements and be subject to their verification. Terna will issue a technical opinion within the framework of the Steering Committee, as required by Legislative Decree 387/03.

It is important to note that as the generation scenario in the region progresses, adequate network reinforcements will be necessary. Some of these reinforcements are already included in the RTN Development Plan. It may be necessary to reinforce and upgrade the RTN, as well as adapt existing installations to the new short-circuit currents. These works should be planned according to the actual production scenario that will gradually materialize.

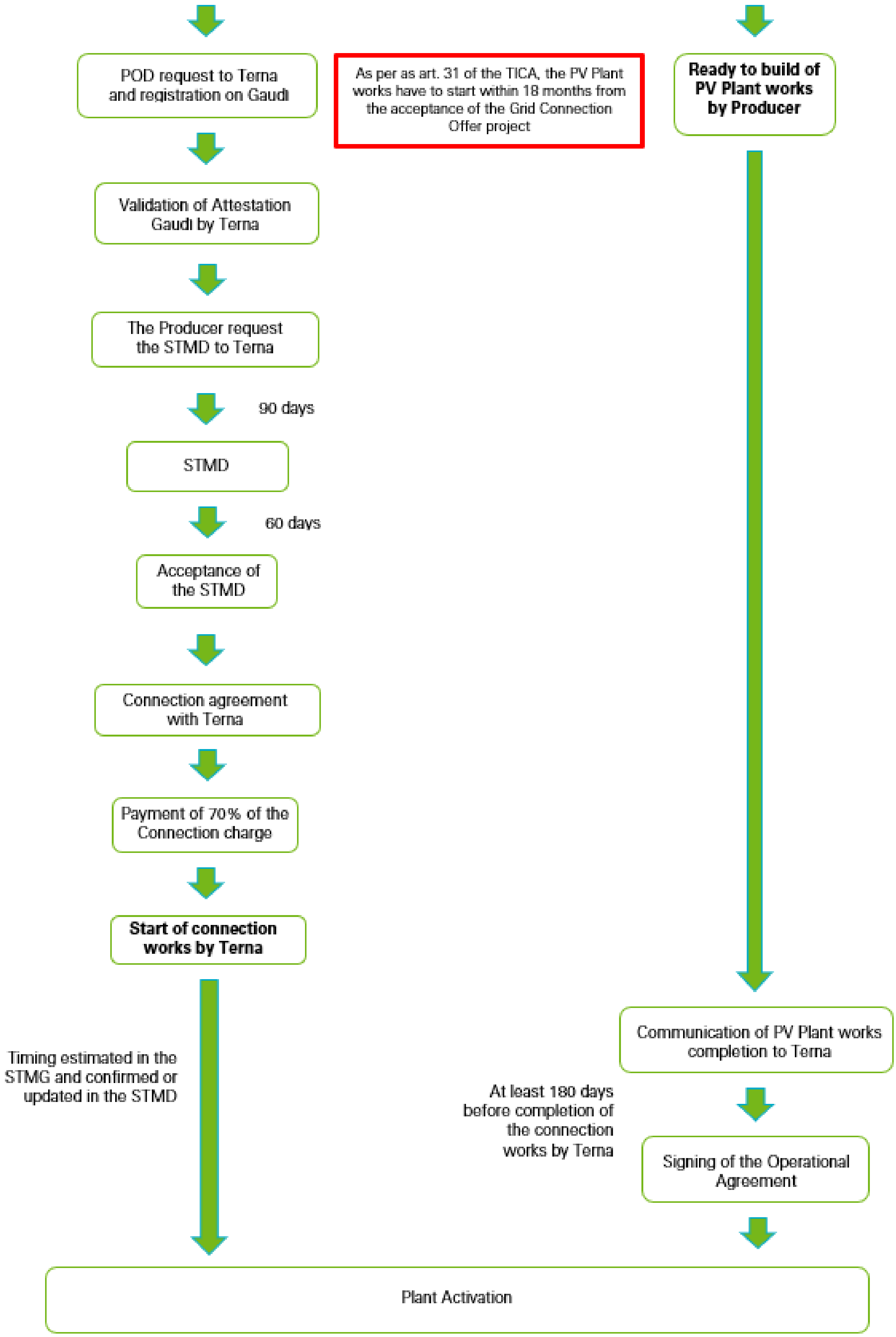
This limitation does not apply to plants powered by renewable sources, which will always have priority. Therefore, while waiting for the completion of the aforementioned interventions, it may be necessary to limit the power generated by new production plants under certain operating conditions to ensure the safety, continuity, and efficiency of the transmission and dispatching service.

The following is a diagram of the connection procedure, a non-exhaustive list of the steps which the Sponsor expects to be carried out for the BESS plant connection.

Given the presence of a high number of existing lines in the area, the possibility of requesting a temporary connection for achieving the COD (Commercial Operation Date) before the completion of the future RTN Electrical Station (SE) will be evaluated. The request can be, in any case, submitted after the signing of the connection contract *"Contratto di Connessione"*.



LEGEND
Optional actions
Action completed
TICA timelines to be monitored
Connection Application
90 days
Grid Connection Offer
Modification request before the acceptance of the Grid Connection offer
120 days
Acceptance of the Grid Connection Offer
Payment of 30% of the Connection fee
Authorisation process, in case of AU, always in charge of producer
Modification request after the acceptance of the Grid Connection offer
Request of RTN works information to Terna for the draft of the definitive connection works project
Request of technical meeting with Terna to discuss the PTO
Signing of the sharing agreement in case of a shared STMG with other Producers
Issue of the definitive connection works project
60 working days
Formal Approval (Benestare) by Terna
Start of the authorization process
As per as art. 21.3 of the TICA, the authorization process must start within 120 working days starting from acceptance of the Grid Connection Offer, net of the time taken by the Grid Operator for the approval of the definitive connection works project
As per as art. 33 of the TICA, the acceptance of the Grid Connection Offer involves a temporary reservation of network capacity for a period of 270 working days, net of the time taken by the operator for the approval of the definitive project
Achievement of the authorization


POD request to Terna and registration on Gaudì
As per as art. 31 of the TICA, the PV Plant works have to start within 18 months from the acceptance of the Grid Connection Offer project
Ready to build of PV Plant works by Producer
Validation of Attestation Gaudì by Terna
The Producer request the STMD to Terna
90 days
STMD
60 days
Acceptance of the STMD
Connection agreement with Terna
Payment of 70% of the Connection charge
Start of connection works by Terna
Timing estimated in the STMG and confirmed or updated in the STMD
Communication of PV Plant works completion to Terna
At least 180 days before completion of the connection works by Terna
Signing of the Operational Agreement
Plant Activation

5.5 Related works

5.5.1 CIVIL WORKS

Container foundations

The containers will be supported by reinforced concrete foundations sized according to the technical indications provided by the suppliers and in accordance with the geotechnical parameters of the area.

Roads

Driveways will be constructed to facilitate routine maintenance operations for all Power Conversion Units and Battery Units.

Fence and gate

A fence made of wooden posts and metal wire with large mesh will enclose the entire perimeter of the BESS area, which will be accessible through a metal gate.

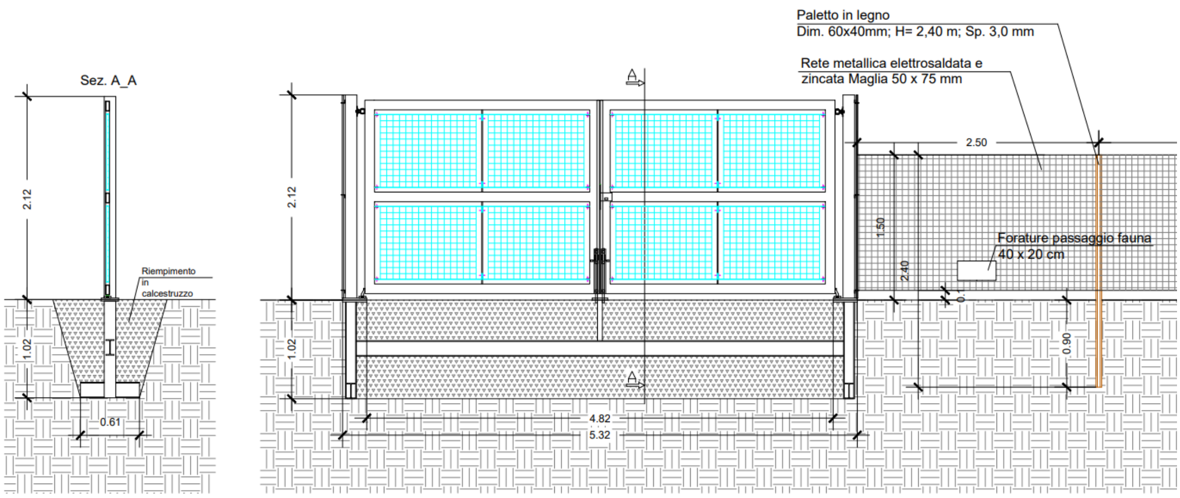


***Figure 48*: Extract of table "Detail of gate, fence and internal roads"**

Cabinets and technical volumes

The Power Conversion Units and Battery Units containers will have a self-supporting metal structure, designed for outdoor installation, built with insulated profiles and panels. The technical volumes will not require disassembly of individual parts. The structure will allow for easy transportation and installation as a single block on supports, with all equipment pre-installed. The battery modules will be the only exception, as they will be dismantled and transported separately if necessary.

A separation wall with a minimum fire resistance degree of REI[26] 60 must be provided between the containers. Alternatively, a minimum distance of not less than 6 m between containers must be guaranteed.

Additionally, containers should be equipped with sensors for environmental measurements, such as temperature and humidity sensors. At least three temperature measurements should be distributed within the custom containers or cabinets.

If necessary, an air conditioning and ventilation system will be provided to maintain optimal internal environmental conditions for the operation of the various components.

Thermocouples are used to monitor the internal temperature of the container, specifically to control post-fire smoldering fires. These measurements will be reported in the BESS auxiliary containers.

The containers will have a minimum degree of protection of IP54 and will be equipped with an anti-burglary system that provides relevant signals. The structure will be anti-seismic and comply with technical standards for construction as outlined in Ministerial Decree 14/01/2008.

Customized containers and cabinets will be designed and equipped with a secondary grounding system, specifically grounding busbars, to connect to the plant's primary grounding system. All racks and conductive metal parts within each enclosure will be connected to the secondary grounding system.

The container will be equipped with an LV auxiliary distribution board to distribute auxiliary power to all equipment inside.

[26] REI certifications refer to the fire resistance classes of individual construction elements.

The power distribution system should have a sufficient number of low voltage outlets to power mobile electrical devices during typical operation and maintenance activities. All sockets and auxiliary circuits must be protected by a residual current circuit breaker that is installed in the LV distribution board. The container will be delivered pre-assembled with all necessary components, including cable trays, fastening and support tools, and cable labels.

The surface treatment will comply with the environmental class of the installation site.

Rainwater regimentation works

Rainwater management works must be planned.

5.5.2 ELECTRICAL WORKS

Electrical protections

The electrical system will be installed with appropriate disconnecting and protection devices to ensure operator safety and automatic intervention in case of electrical system failures.

The protection, regulation, and control systems of the BESS plant will be implemented in accordance with the Terna Grid Code and Terna's Annex A79.

Tunnels and cable routes

The power and control cables will be laid in underground PVC pipes.

Any excavated material will be managed in accordance with current legislation on excavated earth and rocks, specifically Legislative Decree 152/2006 and Presidential Decree 120/2017.

Grounding system

The construction of a single grounding system is planned. All metal columns, containers, electrical equipment and fencing, if metal, shall be connected to the grounding system. Grounding of electronic instrumentation and electronic data processing circuits shall be in accordance with the requirements prescribed by the manufacturers of such equipment.

Prior to energizing the system, appropriate field measurements shall be made to verify the effectiveness of the grounding system.

The ground conductors shall be dimensioned on the basis of the expected short-circuit currents for the different voltage levels in accordance with the requirements of standards CEI EN 61936-1, CEI EN 50522 and CEI 99-5 and the specific documents for the system in question.

5.5.3 GROUND MOVEMENTS AND ESTIMATION OF EXCAVATION VOLUMES

Schematically, the BESS system will be characterized by the following elements:

- No. 320 Sungrow ST5015kWh battery containers, each with a storage capacity of 5015 kWh and dimensions of 6.06m x 2.44 x 2.90m;
- No. 40 Sungrow MVS5000-LV Power Conversion Units measuring 6.06m x 2.44 x 2.90m;
- No. 8 Delivery stations measuring 12.00m x 2.50m x 3.50m;
- No. 1 monitoring cabin measuring 12.00m x 2.50m x 3.50m;
- No. 2 O&M storage rooms measuring 12.00m x 2.50m x 3.50m;
- No. 2 fire water storage tanks of 226 cubic meters with dimensions of (diameter) 10.70m x (height) 3.03m.

This section provides an estimate of the excavation volumes for the project. For an estimate of the excavation and backfill volumes of the related works, please refer to the final design of the power plant.

- Excavation volume of cable ducts from the batteries to the Power Conversion Unit:
  3.197 mc
- Excavation volume of the Power Conversion Unit cables at the Delivery station:
  683 mc
- Excavation volume of CCTV (closed circuit television) cable duct:
  203 mc
- Excavation volume of cable ducts from the Delivery station to the HV substation:
  560 mc
- Excavation volume for internal roads, yards and perimeter fencing:
  3.227 mc
- Excavation volume for fire water storage tanks:
  127 mc

The total excavation volume is 17.600 cubic meters.

Each block of 16 batteries and 1 Power Conversion Unit will be placed on an embankment that is 0.30 meters above ground level.

It is important to note that all cabins are located above the embankment, so the calculation of excavations related to foundation work has not been counted separately but has already been deducted from the total excavation volume related to the embankments.

The table below summarizes the excavation volumes for the trenches of the planned cable ducts. Note that only the excavation below ground level was considered in calculating the excavations for the DC LV cables from the Battery Unit to the Power Station.

Table 7: Excavation volume of cable ducts

EXCAVATION VOLUME CABLE DUCTS			
EXCAVATIONS AC LV (From Battery Unit to Power Station)			
L	**W**	**H**	**VOLUME**
m	**m**	**m**	**mc**
2960,00	0,80	1,35	**3.196,80**
EXCAVATIONS CCTV			
L	**W**	**H**	**VOLUME**
m	**m**	**m**	**mc**
1127,80	0,30	0,60	**203,00**
EXCAVATIONS MV 30 kV TYPOLOGICAL max 1 CIRCUIT (From Power station to Delivery Station)			
L	**W**	**H**	**VOLUME**
m	**m**	**m**	**mc**
1138,56	0,50	1,20	**683,14**
EXCAVATIONS MV 30 kV TYPOLOGICAL max 4 CIRCUITS (From Delivery Station to Substation HV)			
L	**W**	**H**	**VOLUME**
m	**m**	**m**	**mc**
424,51	1,10	1,20	**560,35**
TOTAL EXCAVATION VOLUMES CABLE DUCTS			
			mc
			4.643

The excavation sections are categorized as shown next.

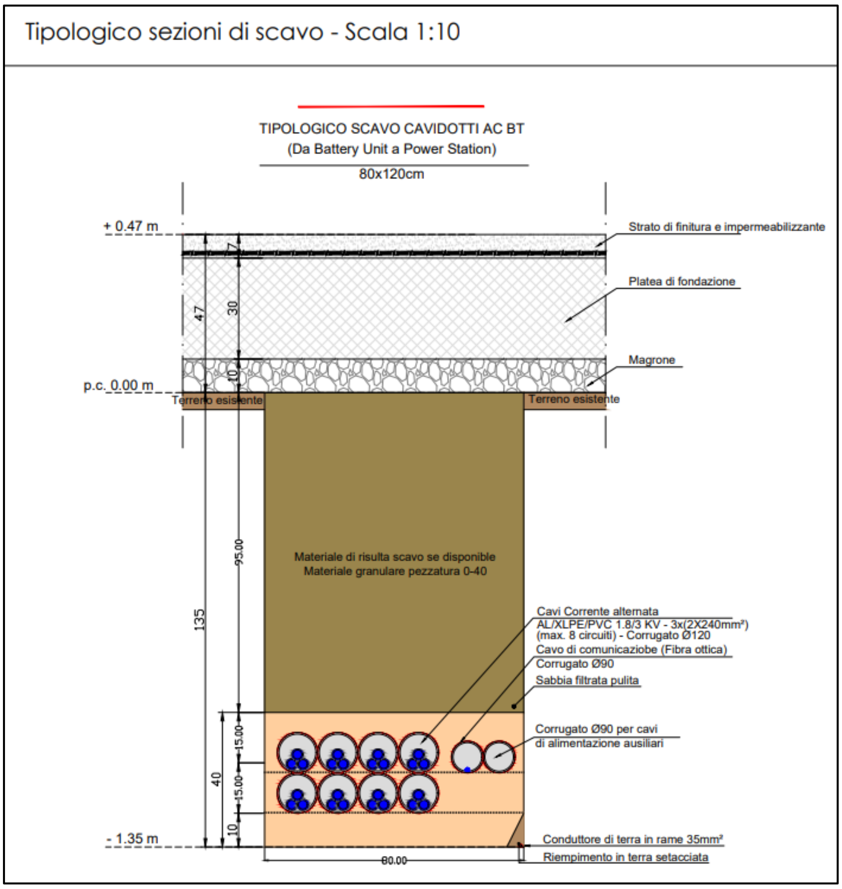


***Figure 49a*: Extract of table "Layout plant: excavations planimetry"**

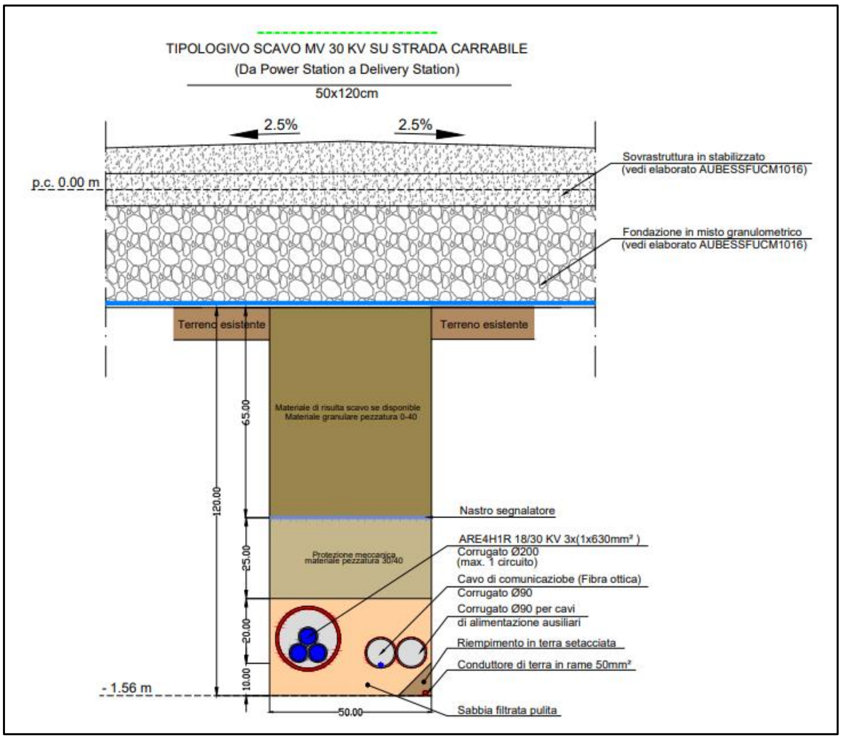


***Figure 49b*: Extract of table "Layout plant: excavations planimetry"**

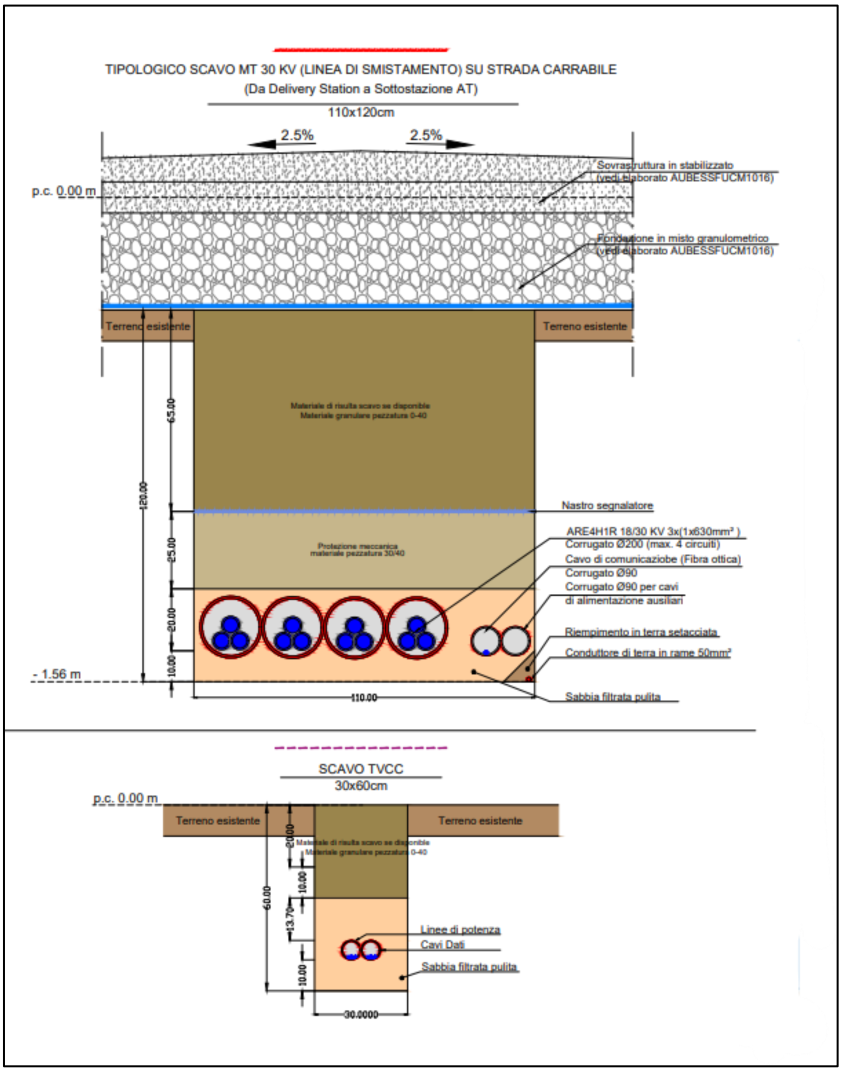


Figure 49c: Extract of table "Layout plant: excavations planimetry"

The table below summarizes the volumes related to the installation of the water storage tank.

Table 8: Excavation volume of water storage tanks

EXCAVATION VOLUME				
WATER STORAGE TANK				
SURFACE	H	VOLUME	N.	TOTAL VOLUME
mq	m	mc		mc
126,68	0,50	63,34	2	126,68
		TOTAL	2	127

The volumes required to build common roads and internal roads/yards are listed in the following table.

Table 9: Excavation volume of roads and fence

EXCAVATION VOLUME (INTERNAL ROADS AND YARDS TO BE BUILT)				
				VOLUME
				mc
SURFACE (mq)				7.728,00
SCOTIC DEPTH (m)				0,30
			TOTAL	2.318
EXCAVATION VOLUME (PERIMETER FENCING)				
	L	W	H	VOLUME
	m	m	m	mc
BESS Area	1135,50	0,80	1,00	908
			TOTAL	908
			TOTAL: ROADS + FENCE	3.227

The table below summarizes the volumes required for building the necessary cabins and extracts of their details are also provided.

Table 10: Excavation volume of cabins

DELIVERY STATION						
L	W	SURFACE	H	VOLUME	N.	TOTAL VOLUME
m	m	mq	m	mc		mc
13,00	3,50	45,50	0,60	27,30	8	218,40
				TOTAL	8	218,40
MONITORING CABIN						
L	W	SURFACE	H	VOLUME	N.	TOTAL VOLUME
m	m	mq	m	mc		mc
13,00	3,50	45,50	0,60	27,30	1	27,30
				TOTAL	1	27,30
POWER CONVERSION UNIT + STORAGE ROOM						
L	W	SURFACE	H	VOLUME	N.	TOTAL VOLUME
m	m	mq	m	mc		mc
43,67	8,88	387,61	0,60	232,57	40	9302,76
				TOTAL	40	9302,76
WAREHOUSE						
L	W	SURFACE	H	VOLUME	N.	TOTAL VOLUME
m	m	mq	m	mc		mc
13,00	3,50	45,50	0,60	27,30	2	54,60
				TOTAL	2	54,60
TOTAL VOLUMES						
						mc
						9603,06
						9.603

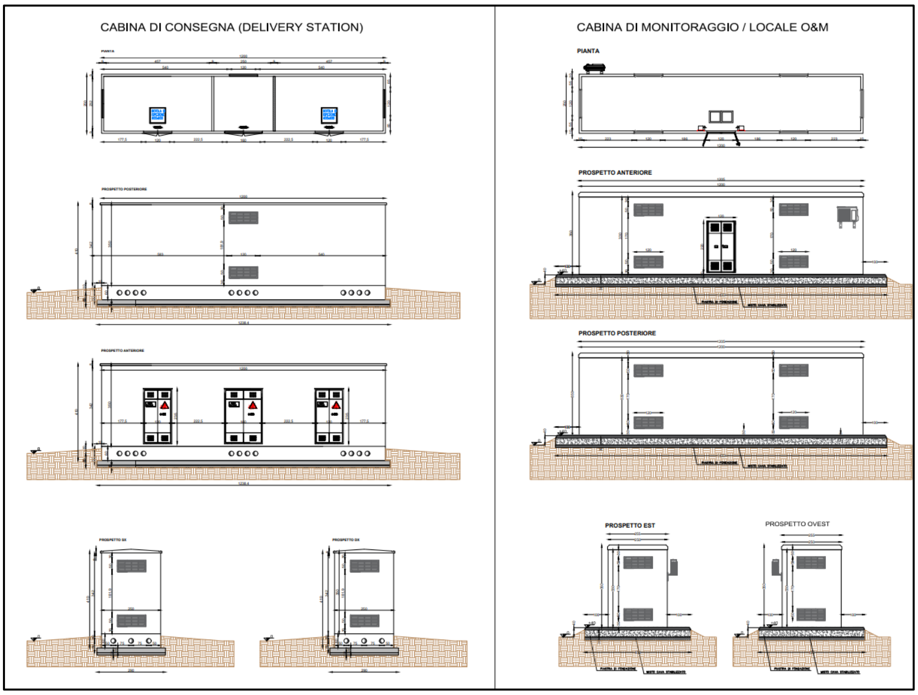


Figure 50: Extract of table "Detail of the delivery station, monitoring room and O&M room (plans and elevations)"

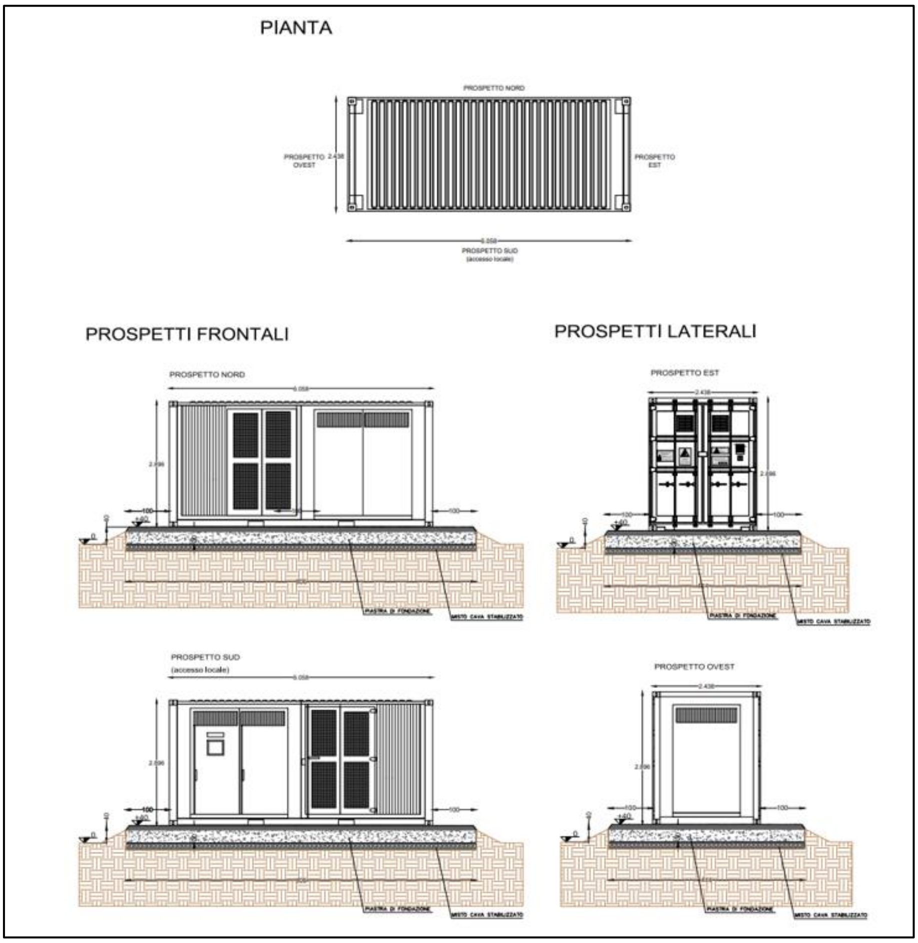


Figure 51: Extract of table "Detail of the power station (plans and elevations)"

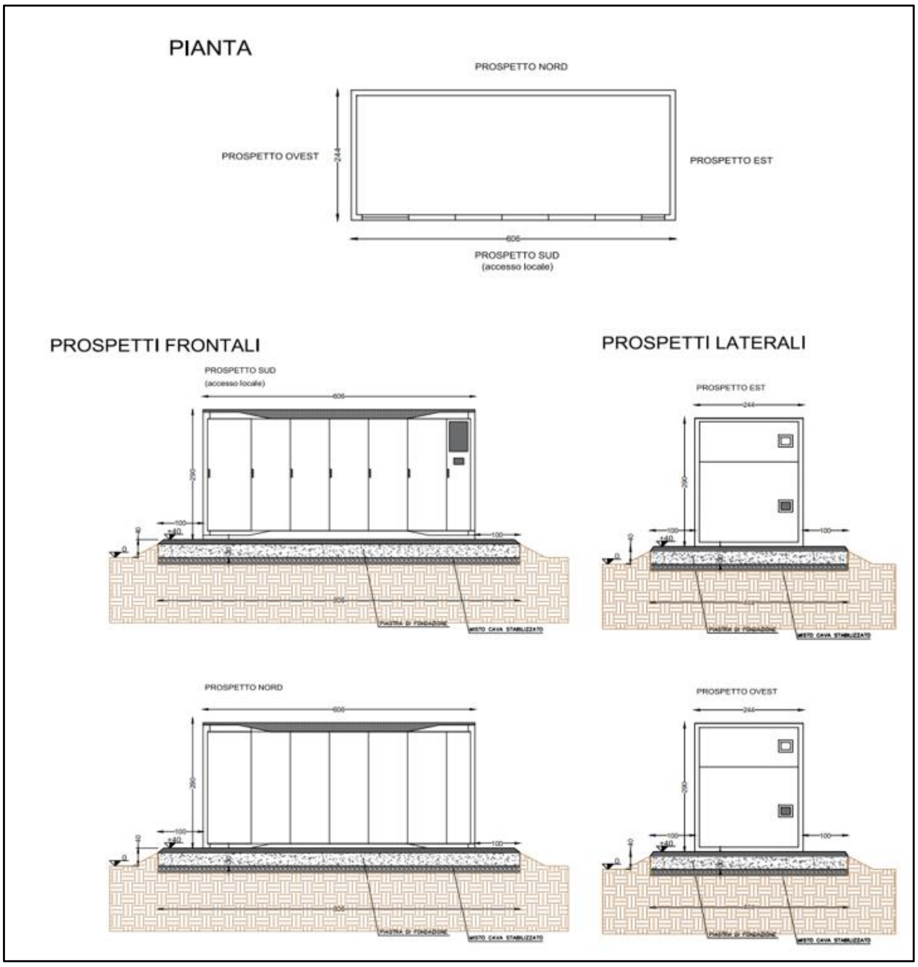


Figure 52: Extract of table "Detail of the storage room (plans and elevations)"

5.5.4 PLANT AUXILIARIES

The BESS will be equipped with a 400V three-phase, four-wire low-voltage distribution system to supply power to auxiliary equipment. Generally, the loads will be classified as: non-essential services, essential loads, and vital loads.

The low-voltage distribution system will consist of one or more main low-voltage switchboards and an adequate number of secondary low-voltage switchboards, which will optimize the grouping of utilities with respect to their function, different working conditions and different maintenance needs.

In the event of a total power failure, the vital loads of the BESS shall be automatically switched to an emergency power supply network, which shall allow the safe shutdown of the BESS.

Auxiliary services will consist of:

- Normal and emergency lighting;
- External lighting of the BESS area;
- Service motive power;
- Air conditioning system;
- Ventilation system;
- Local control system power supply (under UPS).

<u>General and security lighting</u>

A lighting system will be installed around the perimeter and near the power conversion units using LED projectors. Inside all cabins, there will also be light points for normal lighting and light points with buffer battery to ensure illumination in emergency conditions.

<u>Video surveillance and security system</u>

The BESS system shall be equipped with an infrared video surveillance and perimeter security system with motion detection technology implemented with a microphone cable or infrared barrier intrusion detection system. The system shall provide redundancy in case of failure of the communication system or power supply.

5.5.5 FIRE PREVENT SAFETY

<u>Fire suppression system</u>

The storage batteries and the auxiliary power conversion and control systems will be installed outdoors in a protected and video-monitored area so as not to be exposed to shocks or tampering.

It is also planned to implement a fire-fighting network with the construction of 200-litre water storage tanks and pressurization stations to ensure coverage of the hydrant and splinker network to the entire area where the Battery Units will be installed.

The system is designed in such a way that any fire in one part of the equipment will not spread to other parts and/or other buildings in the vicinity, taking into account the safety distances.

For the technological and service systems of the activity, adequate preventive, protective and managerial fire-fighting measures are provided, compatible with the needs of the activity. All control systems are also powered by UPS systems.

The BESS areas will be equipped with vehicular and pedestrian accesses, and the accesses will have the minimum requirements necessary to allow the entry of firefighting vehicles. The internal viability of the BESS shall be designed in such a way as to ensure the possibility of access for fire brigade emergency vehicles. Minimum access dimensions are also maintained for internal routes and maneuvering areas.

The internal viability of the battery park shall be designed in order to ensure the possibility of fire brigade rescue vehicles approaching each battery group.

Fire detection system

All battery boxes, converters, electrical panels will be equipped with fire detectors. The battery containers will also be furnished with an extinguishing system specific to the equipment inside. Portable and wheeled fire extinguishers will be placed near the battery modules, frequency converters and electrical panels.

Signals from the fire alarm systems will be integrated into the plant's existing fire alarm system. The customized containers and/or cabinets housing the battery subsystem will be equipped with a fire detection and extinguishing system designed, tested and certified in accordance with applicable national and international regulations.

The system will be complete with fire detectors, gas detectors, thermal runaway detectors, smoke detectors, horn (internal and external), strobe (external), piping and extinguishing fluid and/or agent devices approved and recommended by the manufacturers according to the chemistry of the battery subsystem.

The system shall monitor the environmental conditions inside the container and, upon detection of smoke, abnormal temperature or other anomalies, shall:

- Alert people inside and outside the container by all visual and audible means;
- Turn on all hazard lights;
- Coordinate with the HVAC system;
- Activate all protective and/or extinguishing devices.

The extinguishing fluid used to extinguish the fire must have limited toxicity to humans, maximum environmental compatibility, and meet the battery manufacturer's specifications for the selected chemistry.

The fire detection and suppression system shall have a communication interface to communicate its status and availability, as well as any messages or alarms, to the SCI. Containers and/or cabinets used to house subsystems other than the battery subsystem shall be equipped with CO_2 fire extinguishers installed near access doors with appropriate signage.

5.5.6 LIGHTNING PROTECTION SYSTEM

The BESS system will be protected from both direct and indirect lightning strikes.

Currently, there is no new LPS (Lightning Protection System) for direct discharges to protect the new BESS system, as it is located near the central chimney, which has a lightning collection system at the top and ropes for its discharge to the ground.

A study of the existing LPS at the plant will be conducted to verify its coverage of the new BESS area; therefore, the current lightning protection system will only be extended to cover the entire new BESS area if necessary.

On the other hand, adequate surge arresters will be installed in the existing main electrical panels to comply with the regulations.

5.5.7 DISPOSAL OF END-OF-LIFE BATTERIES

The process of decommissioning, recycling and disposal of the materials constituting the BESS system will be carried out in compliance with the national, European and international legislation in force (including the European Directive on Batteries and Accumulators 2006/66/EC), ensuring compliance even in the event of modifications and/or additions to the latter from the moment the system is put into service.

The BESS supplier shall provide appropriate documentation describing the management and technical methods of the recycling and disposal process, as well as the related timing and safety aspects.

As of January 1st 2009, Legislative Decree No. 188 of 20/11/2008, extends the collection obligation in Italy to batteries and accumulators not based on the use of lead, but on the use of other metals or compounds. This decree implements and enforces the European Directive 2006/66/EC.

At the end of its life, the storage system will be dismantled and transported to an authorized collection and recycling center in accordance with current legislation.

5.5.8 TIME SCHEDULE

The design, supply of components, civil works construction, system installation, and functional testing are estimated to take approximately 48 months.

5.5.9 CONSTRUCTION SITE MANAGEMENT

Before starting the works, all dimensions and measurements indicated on the drawings will be verified on site.

The works for the installation of the BESS system will be carried out in accordance with Title IV - Temporary or mobile worksites - Legislative Decree 81/08 and subsequent amendments and additions.

The number of workers on site is estimated at an average of fifteen people, with a maximum peak of approximately thirty people.

Access to the area

Construction site vehicles can easily access the intervention area via the existing municipal road, which is wide enough for normal road vehicles. The composition of the vehicular traffic generated by the planned activities will be divided into a proportion of light vehicles for the transportation of people and heavy traffic related to the procurement of large components and the delivery of installation materials.

The vehicles for the execution of the works can be positioned in the immediate vicinity of the intervention area.

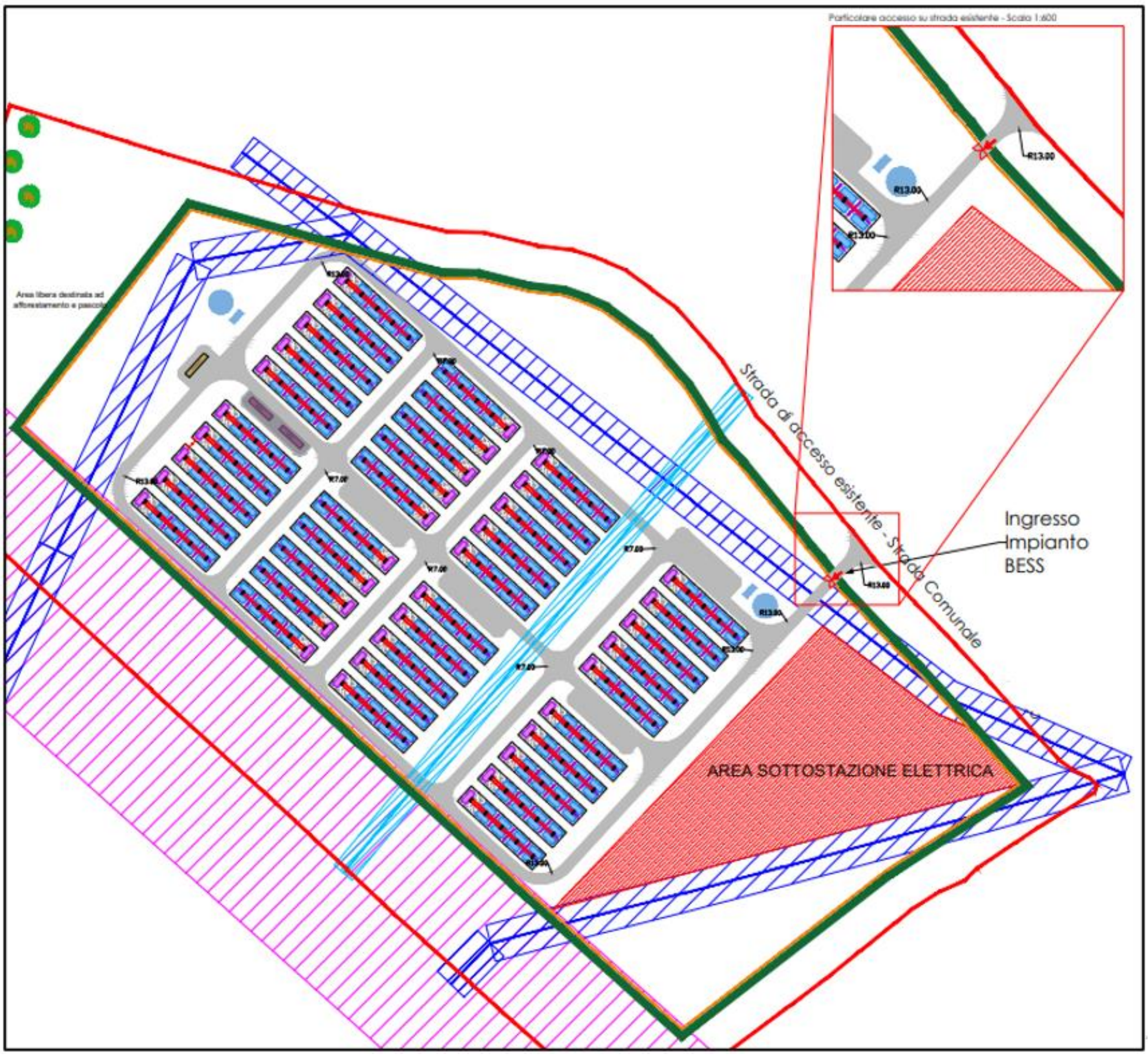


Figure 53: Extract of table "Planimetry of accesses and viability"

Construction sites

The logistic area of the site will be limited to the essential services of the company. The company will be able to set up the construction site area in a free space adjacent to the northern part of the intervention area, easily accessible by the existing road system.

The area can be organized with

- Prefabricated single blocks for offices, changing rooms, toilets and tool storage;
- Containers for the deposit of waste and processing waste;
- Area for the storage of various materials, carpentry, formwork, iron, etc.

The site will be equipped with appropriate safety and signaling signs, fire-fighting and first-aid equipment, in accordance with current legislation on safety on construction sites.

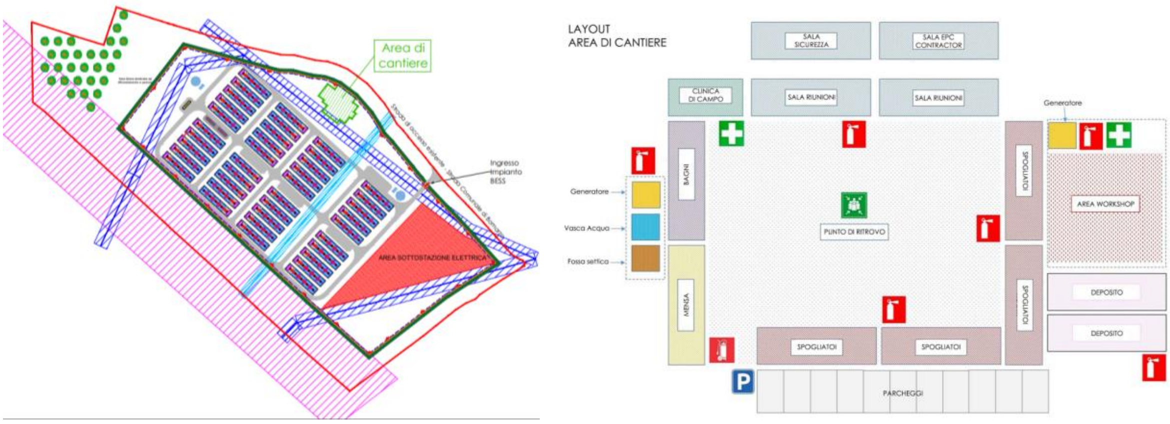


Figure 54: Extract of table "Planimetry of construction site area"

Macro phases of the intervention

Below is a schematic list of the interventions planned in the project:

- Site preparation and storage of materials;
- Removal of vegetation and surface scarification;
- Regularization of the area with granular material;
- Building the foundations of the prefabricated boxes;
- Construction of the cable routes and the rainwater drainage network;
- Installation of prefabricated boxes;
- Execution of the electromechanical works of the BESS and connection to the RTN;
- Completion and finishing works;
- Removal of the site.

Safety

The works must be carried out in compliance with the general safety measures laid down by the legislation in force, in particular Title IV of Legislative Decree 81/08 on temporary and mobile work sites.

Therefore, the critical phases of the works related to the complexity of the construction process must be considered in order to prevent or reduce risks to the safety and health of workers.

The sizing of site areas and related equipment has been done on a parametric basis, depending on the assumed average presence of workers on site.

It will be the responsibility of the Contractor to define the maximum number of presences on site and to articulate the site equipment on the basis of the variation in the presence of personnel during the work phases.

Depending on the technical and logistical choices made by the contractors, the risks must also be identified, analyzed and evaluated in terms of:

- The site areas;
- The organization of activities;
- Interfering operations;
  Risks other than those specific to the activities of individual contractors or self-employed workers.

Conclusions

In the current landscape, characterized by the urgency of reducing greenhouse gas emissions and mitigating climate change, Battery Energy Storage Systems (BESS) are emerging as pivotal elements in the transition to a sustainable energy system. Integrating renewables, reducing emissions, providing operational flexibility, stabilizing the grid, and promoting electrification are just some of the reasons why BESS are deemed essential. As we confront the challenges posed by climate change, BESS offer a versatile solution that addresses multiple aspects of the energy evolution.

Throughout this thesis, a recurring theme has been the significance of integrating renewable energy sources and energy storage solutions in the collective endeavor to mitigate the impacts of climate change and shift towards a sustainable energy future. By delving into the authorization frameworks, technological advancements, and revenue dynamics shaping the deployment of BESS, this study sheds light on critical aspects of this transformative adjustment.

However, despite the progress made in understanding and deploying BESS, we are still in the early stages of research and implementation. These stages are marked by limited data availability and a lack of field experience, which contribute to significant uncertainty and variability. Bridging these gaps requires further progress, clearer policies, and increased investments, which are crucial to refine BESS technologies and optimize their integration into existing energy infrastructures.

In fact, the potential of BESS is vast and spans across various sectors, from large-scale industrial and commercial applications to residential contexts, where they can facilitate the daily lives of ordinary citizens. Recognizing this potential underscores the critical importance of investing in the development and deployment of such systems to ensure a secure, clean, and efficient energy future.

Understanding market attractiveness hinges on factors such as risk appetite, investment size, preferred set-up, market design, and future energy market developments. Despite expectations of exponential growth in the grid-scale energy storage market, navigating battery markets presents challenges for developers and investors. Therefore, strategic decision-making and risk management strategies are essential to capitalize on the opportunities presented by the evolving energy storage landscape.

Additionally, it is important to consider that the maturity of this technology and the level of interest in it do not necessarily imply the same level of effectiveness and efficiency when it comes to the authorization and construction of these plants. The bureaucratic process in our country, but supposedly in general, can be lengthy and may dampen enthusiasm.

The BESS system may be difficult to understand, particularly since it is a relatively new concept. It is important to reflect on this issue and ensure that clear and concise information is provided to those who actually have the authority to approve the plants.

Consequently, the question arises: **is society prepared to embrace growth and innovation or will it succumb to inertia despite daily warnings from our planet?**

The table is set, and the seeds have been planted. We find ourselves as key players tasked with making a difference in shaping our future. With collective action and proactive measures, we can leverage the transformative potential of BESS to construct a sustainable and resilient energy infrastructure for generations to come.

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