Grant Agreement No. 727348

Project Acronym:

SOCRATCES

Project title:

SOlar Calcium-looping integRAtion for Thermo-Chemical Energy Storage.

DELIVERABLE D8.6

System risk analysis

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EXECUTIVE SUMMARY

SOCRATCES project aims to generate new knowledge and demonstrate the feasibility of the concept of thermochemical energy storage through the calcium looping cycle - concentrated solar power, a high-efficiency integration, in the pathway towards industrial exploitation of the technology.

This document sets the definitions, preliminary concepts and references used and extended in deliverables within WP8, as the cases of deliverables D8.7 and D8.14. They are the concepts and definitions for the processes of Risk analysis and KPIs for energy storage performance evaluation.

Within this context, it has been envisaged a project's risk management and technological risk assessment (Task 8.3 "Operating Risk Assessment" and Task 8.4 "Definition of the technological risks and ways of mitigating them by applying Product and Process Failure Mode Effect & Analysis (FMEA)") with two different purposes:

- *Project's risk management*. Since M21, a risk management process is being carried out by Vertech Group with the collaboration of all partners in order to achieve all the project's objectives throughout a Plan-Do-Check-Act process, according to ISO 31.000:2009 (ISO, 2018). This methodology allows detecting and assessing project risks, establishing mitigation and contingency measures, and implementing them to avoid or minimise the risks' consequences affecting the project objectives accomplishment.

- *Technological risk assessment*. The aim of this study is the identification of different types of risks affecting hypothetical industrial-scale plants producing SOCRATCES system to be in place, so the future planning and roll-out of these plants can count on a preliminary risk assessment with a set of mitigation/contingency measures, thus reducing the inherent risks to deploy this innovative energy storage industry. The FMEA methodology will identify the risk (Carbone & Tippett, 2004; Safari, Faraji, & MAjidian, 2016).

Data will be collected throughout the final year of the project's execution and, eventually, processed to release the risk assessment result of the technology developed SOCRATCES within D8.7.

Complementarily, key performance indicators (KPIs) are analysed and compared for existing energy storage technologies. These key performance indicators are used to define the framework of the technology and for the analyses within the next deliverables of WP8 to identify the positioning of the technology and its potential market positioning.

1. TERMS AND DEFINITION

These terms and definitions have been extracted from the International Standard ISO 31.000:2009.

Risk: effect of uncertainty on objectives.

- An *effect* is a deviation from the expected – positive and/or negative.

- *Objectives* can have different aspects (e.g. financial, health and safety, and environmental goals) and can apply at different levels (e.g. strategic, organisation-wide, project, product and process).

- *Risk* is often characterised by reference to potential events and consequences or a combination of these; moreover, it is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.

- *Uncertainty* is the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence, or likelihood.

Risk management: coordinated activities to direct and control an organisation with regard to risk.

Risk management framework: set of components that provide the foundations and organisational arrangements for designing, implementing, monitoring, reviewing and continually improving risk management throughout the organisation.

- The foundations include policy, objectives, mandate and commitment to manage risk.

- The organisational arrangements include plans, relationships, accountabilities, resources, processes and activities.

- The risk management framework is embedded within the organisation's overall strategic and operational policies and practices.

Risk management policy: statement of the overall intentions and direction of an organisation related to risk management.

Risk attitude: organisation's approach to assess and eventually pursue, retain, take or turn away from risk.

Risk management plan: scheme within the risk management framework specifying the approach, the management components and resources to be applied to the management of risk.

- Management components typically include procedures, practices, assignment of responsibilities, sequence and timing of activities.

- The risk management plan can be applied to a particular product, process and project, and part or whole of the organisation.

Risk owner: person or entity with the accountability and authority to manage the risk.

Risk management process: systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analysing, evaluating, treating, monitoring and reviewing risk.

Establishing the context: defining the external and internal parameters to be considered when managing risk and setting the scope and risk criteria for the risk management policy.

External context: the external environment in which the organisation seeks to achieve its objectives. External context can include:

- The cultural, social, political, legal, regulatory, financial, technological, economic, natural and competitive environment, whether international, national, regional or local;

- Key drivers and trends having an impact on the objectives of the organisation; and

- Relationships with, and perceptions and values of external stakeholders.

Internal context: the internal environment in which the organisation seeks to achieve its objectives. Internal context can include:

- Governance, organisational structure, roles and accountabilities;

- Policies, objectives, and the strategies that are in place to achieve them;

- The capabilities, understood in terms of resources and knowledge (e.g. capital, time, people, processes, systems and technologies);

- Information systems, information flows and decision-making processes (both formal and informal);

- Relationships with, and perceptions and values of, internal stakeholders;

- The organisation's culture;

- Standards, guidelines and models adopted by the organisation; and

- Form and extent of contractual relationships.

Communication and consultation: continual and iterative processes that an organisation conducts to provide, share, or obtain information and engage in dialogue with stakeholders regarding risk management.

- The information can relate to the existence, nature, form, likelihood, significance, evaluation, acceptability and treatment of risk management.

- Consultation is a two-way process of informed communication between an organisation and its stakeholders before deciding or determining a direction on that issue. Consultation is a process that impacts a decision through influence rather than power, and it is an input to decision making, not joint decision making.

Stakeholder: person or organisation that can affect, be affected by, or perceive themselves to be affected by a decision or activity. A decision-maker can be a stakeholder.

Risk assessment: the overall process of risk identification, risk analysis and risk evaluation.

Risk identification: the process of finding, recognising and describing risks.

- Risk identification involves the identification of risk sources, events, their causes and their potential consequences.

- Risk identification can involve historical data, theoretical analysis, informed and expert opinions, and stakeholder's needs.

Risk source: an element that, alone or in combination, has the intrinsic potential to give rise to a risk. A risk source can be tangible or intangible.

Event: occurrence or change of a particular set of circumstances.

- An event can be one or more occurrences and can have several causes.

- An event can consist of something not happening.

- An event can sometimes be referred to as an "incident" or "accident".

- An event without consequences can also be referred to as a "near-miss", "incident", "near hit", or "close call".

Consequence: outcome of an event affecting objectives.

- An event can lead to a range of consequences.

- A consequence can be certain or uncertain and can have positive or negative effects on objectives.

- Consequences can be expressed qualitatively or quantitatively.

- Initial consequences can escalate through knock-on effects.

Likelihood: chance of something to happen.

- In risk management terminology, the word "likelihood" is used to refer to the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period).

- The English term "likelihood" does not have a direct equivalent in some languages; instead, the equivalent of the term "probability" is often used. However, in English, "probability" is often narrowly interpreted as a mathematical term. Therefore, in risk management terminology, "likelihood" is used with the intent that it should have the same broad interpretation as the term "probability" has in many languages other than English.

Risk profile: description of any set of risks. The set of risks can contain those related to the whole organisation, part of the organisation, or otherwise defined.

Risk analysis: process to comprehend the nature of risk and to determine the level of risk. Risk analysis provides de basis for risk evaluation and decisions about risk treatment. Risk analysis includes risk estimation.

Risk criteria: terms of reference against which the significance of a risk is evaluated. Risk criteria are based on organisational objectives and external and internal context. Risk criteria can be derived from standards, laws, policies and other requirements.

Level of risk: magnitude of risk or combination of risks, expressed in terms of the combination of consequences and likelihood.

Risk evaluation: the process of comparing the results of risk analysis with risk criteria to determine whether the risk and/or its magnitude is acceptable or tolerable. Risk evaluation assists in the decision about risk treatment.

Risk treatment: process to modify risk. Risk treatment can involve:

- Avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk;

- Taking or increasing risk in order to pursue an opportunity;

- Removing the risk source;

- Changing the likelihood;

- Changing the consequences;

- Sharing the risk with another party or parties (including contracts and risk financing); and

- Retaining the risk by informed decision.

Risk treatments that deal with negative consequences are sometimes referred to as "risk mitigation", "risk elimination", "risk prevention", and "risk reduction". Risk treatment can create new risks or modify existing risks.

Control: a measure that is modifying risk.

- Controls include any process, policy, device, practise or other actions which modify risk.

- Controls may not always exert the intended or assumed modifying effect.

Residual risk: the risk remaining after risk treatment.

- Residual risk can contain unidentified risk.

- Residual risk can also be known as "retained risk".

Monitoring: continual checking, supervising, critically observing or determining the status in order to identify change from the performance level required or expected. Monitoring can be applied to a risk management framework, risk management process, risk or control.

Review: activity undertaken to determine the suitability, adequacy and effectiveness of the subject matter to achieve established objectives. Review can be applied to a risk management framework, risk management process, risk or control.

2. PROJECT RISK MANAGEMENT

2.1 Framework for risk management

The success of risk management (coordinated activities to direct and control an organisation regarding risk) will depend on the foundations and arrangements set out by its framework. The different parts of the risk management framework and its interrelations are shown in Figure 1.
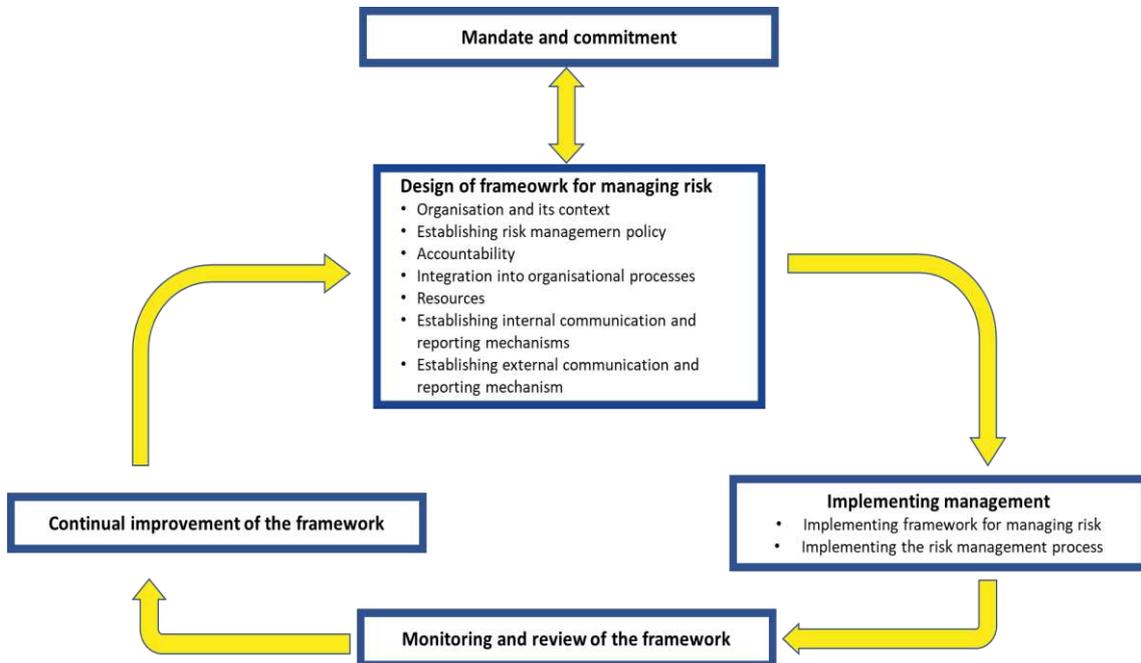

Figure 1. – Relationship between the framework's modules for managing risk (adapted from (ISO, 2018))

2.2 Mandate and commitment

SOCRATCES consortium is aware of the risk management importance in R&D projects. The achievement of the project's objectives depends on how the consortium handles the organisational, financial and scientific/technical risks. As part of this activity, the consortium endorses the risk management policy and the assignment of roles and responsibilities and supports and participates in all the actions carried out within the Project Risk Management.

The project consortium is committed to complying with the Risk management principles:

- Risk management creates and protects value.

- Risk management is an integral part of all organisational processes.

- Risk management is part of decision making.

- Risk management explicitly addresses uncertainty.

- Risk management is systematic, structured and timely.

- Risk management is based on the best available information.

- Risk management is tailored.

- Risk management takes human and cultural factors into account.

- Risk management is transparent and inclusive.

- Risk management is dynamic, iterative and responsive to change.

- Risk management facilitates the continual improvement of the organisation.

2.3 Project and consortium's context

It is important to evaluate and understand both the internal and external context of both project and consortium since they strongly affect the design of the framework.

- *External context*: The SOCRATCES project belongs to the EU Research and Innovation programme Horizon2020. This funding programme is the financial instrument to drive economic growth and create jobs while addressing sustainability criteria, boosting EU competitiveness through innovation. This project falls within the LCE-2016-RES-CCS-RIA, topic LCE-07-2016-2017. The project consortium tailored SOCRATCES activities addressing the scope and specific challenges of this topic, dealing with applying the calcium-looping cycle in a new concept of thermochemical energy storage. For further information, the reader is referred to the Project Grant Agreement № 727348.

- *Internal context*: The SOCRATCES project is supported by 14 partners of which many industrial organisations (CALIX, Virtual Mech, TTZ Bremerhaven, CSIC, iSiTEC, BioAzul, Vertech and SPI) and research institutions (Universidad de Sevilla, Politecnico di Torino, Universidad de Zaragoza, CNR, CERTH and AUTH) are in the consortium. The partners come from 7 different European countries (Spain, UK, France, Greece, Portugal, Germany, and Italy).

The main purpose of the H2020 projects' risk management processes is to ensure the satisfactory achievement of the project's objectives, overcoming the critical risks to its implementation. Consequently, these objectives are extracted and shown below for a better contextualisation of the project risk management process:

Table 1.- Main project's objectives and means of verification.

Technical objectives		
Topic	**Objective**	**Means of verification**
Energy storage	- High-density thermal storage - Reduced heat loss - Affordable and sustainable solution	- Cheap, efficient and no toxic storage - High stability - Validation at the prototype level - Seasonal storage capacity - Integration and uses of by-products
Transfer fluid	- Effective heat transfer - Reduction of receiver's cost	- Calcination temperature reduction - Solar receiver technology - Validation of the prototype level - Integration of receiver and calciner
Power cycle	- Maximum temperatures increase	- High carbonator temperatures - Efficient integration with carbonator - Scale-up for systems integration - Assessment of the effects of regulation and control on the whole system

Table 2. Main project's objectives and means of verification.

Commercial objectives		
Market entry	- Reduction of system costs	- Assessment of CaL TCES costs - CSP plant LCOE lower than other CSP technologies in the market
Social objectives		
Environment	- Reduced environmental impact	- Validation of environmental LCA
Society	- Citizen quality of life	- Reduction of carbon footprint compared to existing alternatives
Economy	- Create added value	- Assessment of the pathway for business creation based on this technology - Creation of pathways to foster the use of solar energy

2.4 Risk management policy

The SOCRATCES project consortium understands the need to carry out the Project Risk Management to increase the success rate in the different objectives addressed in Table 1 and Table 2 by assessing, treating, and monitoring the critical risks related to the project implementation.

Risk management forms part of the strategic and operational management responsibilities, and it is integrated within the coordinating structures of the SOCRATCES project. In other words, the project risk management is embedded in all the project activities, acting as a tool for better use and management of the resources of the different partners, thanks to the commitment of all people involved and ensuring the overall project success.

The consortium ensures that there is accountability, authority and appropriate competence for managing risk, including implementing and maintaining the risk management process and ensuring the adequacy, effectiveness and efficiency of any controls. In this section, it is well described the main responsibilities and mechanisms followed up by the consortium to ensure these actions. In Table 3, it is shown the roles and accountability of each partner of the consortium:

Table 3.- Risk management accountability.

Partner	Role and responsibility
General Assembly	The project GA, led by the project coordinator, is responsible for: • Ensuring that the consortium has and uses its resources properly to eliminate and/or reduce risks. • Reviewing and analysing the project risk management and mitigation plans in each periodic project board meetings (or whenever presented).
University of Seville (USE)/Vertech Group (VTG)	USE is the project risk manager since December 2020 (previously was Vertech Group). The risk manager is responsible for carrying out the coordination of activities related to the process of managing project risks. As the risk manager, USE will: • Prepare and keep updated the risk management set of documents following the ISO standard.

	• Implement the risk management plan described and documented in this deliverable.
	• Organise risk management sessions within the project meetings to review and update the risk assessment and treatment plans.
	• Explain properly to all partners the risk management policy, giving them the needed tools to develop its role.
	• Ensure that critical risks to the project are closely monitored.
Consortium	All the members of the consortium are responsible for assisting the project risk manager in the risk management process. This includes participation in: • Risk assessment (identification, analysis and evaluation of project risks related to the tasks and activities related to each partner). • Risk treatment (implementation of the mitigation measures tailored for significant risks they may be responsible for, monitoring its performance and taking notice of residual risks). • Risk management process monitoring and review, reporting its assessments in periodic project meetings and, when needed, by immediate communication mechanisms.

The performance of the risk management plan will be periodically evaluated and discussed, analysing if risks are being properly managed and their consequences being controlled. In case of a bad performance, the Project GA, together with the Project Risk Manager, will find out the causes and establish measures to mitigate the impact. Each risk assessment owner and its responsibilities will be later described within the risk management process section.

The project consortium is committed to making the necessary resources available to assist those accountable and responsible for managing risks, since the correct performance of the risk management process strongly depends on that (therefore, the project's objectives accomplishment).

Only when the objectives and scope of the Risk Management are defined is it possible to provide estimates of the human, financial and other resources needed. The human and financial resources needed to manage project risks addressed in the project proposal have already been foreseen in the SOCRATES project budget. If new risks or treatment measures arise, the existing resource may or may not manage them, so the Project GA will concern about these possible needs and afford them by reallocating the existing human, financial, and other resources (World Health Organization (WHO), 1998).

Initially, the human resources committed for Risk Management are included in the Staff effort reflected as persons per month in the WP8. Nevertheless, it should be noticed that these resources are also committed to the technical risk assessment within this deliverable too. Each one of the WP8-task leaders will be responsible for assisting the risk manager (USE) during the risk management process, providing the information requested in project meetings or by any other internal communications. The WP8-task leaders in charge will be free to organise and allocate their resources to develop the activities related to the owned risks and support the risk manager. Table 4 addresses the task leaders and the main contact of each organisation: these persons will be responsible for assistance for the Risk Manager in the risk management process.

Table 4.- Work Package leaders and main contact to assist in the risk management process.

WPs	Leader	Main contact
WP1. Project management	USE	Ricardo Chacartegui
WP2. Carbonation	CSIC	Luis Maqueda
WP3. Solar calcination	CALIX	Tom Hills
WP4. Power system	TTZ	Gerhard Schories
WP5. Integration and control	ZAR	Luis Miguel Romeo
WP6. Engineering and construction	CALIX	Simon Thomsen
WP7. Validation and test	VIRTUALMECH	Juan Valverde
WP8. LCA, LCC, risk assessment, technology watch, business development	USE	Ricardo Chacartegui (since Dec 2020, before Hector Leiva VTG)
WP9. Dissemination and exploitation	BIOAZUL	Angela Magno

The project consortium has established the internal communication, reporting and external communication mechanisms regarding the execution of the project within the Grant Agreement Nº 727348. The risk management process, for the sake of simplicity, has adopted the same procedures. The consortium ensures the ISO 31000:2009 requirements: "the key components of the risk management framework and any subsequent modifications are communicated appropriately; there is adequate internal reporting on the framework, its effectiveness and the outcomes; relevant information derived from the application of risk management is available at appropriate levels and times; and there are processes for consultation with internal stakeholders" (ISO, 2018).

2.5 Implementing risk management

Once the framework for risk management has been designed, it must be implemented the framework and put in place related processes. The risk management process heavily relies and develops based on the framework, which provides the system with all the organisational and administrative tools required.
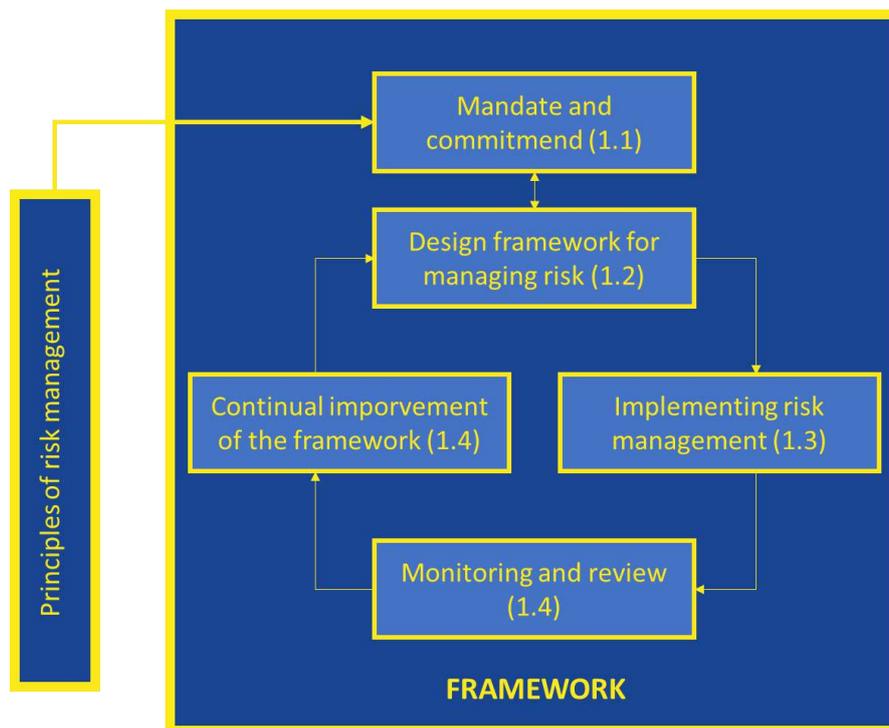
Figure 2. – Relationship of risk management principles, framework and process (adapted from (ISO, 2018))

The timing for implementing this framework is:

- Implementation of the project. Since the proposal stage, the different partners have considered the risks of the project.

- Project meetings. In these six-month based meetings, the consortium will inform about the performance of the framework, pointing out the possible weaknesses and improvement opportunities to have a better organisation and implementation of the framework. During the next meeting, the project risk management framework will be explained to the consortium, emphasising the partner's roles and internal reporting mechanism.

All partners must continuously monitor the framework for managing project risks with any responsibility while the planned activities are being carried out. During these evaluations of the framework, it is addressed the effectiveness of the framework and whether it is still appropriate (policy, context, plans, communication mechanisms, etc.). If any deviation or shortcoming of the risk management plan or framework is detected, the GA and the risk manager will study how it can be improved or corrected.

3. METHODOLOGY OF THE RISK MANAGEMENT PROCESS

3.1 Context

This deliverable follows up the contingency and mitigation actions addressed in the SOCRATCES proposal, continuously updating and monitoring the risks as part of the project Risk Management.

The main objective of Risk Management is to maximise the chances of project success by identifying risks early on and planning how to manage them. Thus, thanks to the project risk management during the three years of execution of the project, the following objectives are achieved:

- To identify, evaluate and treat the risks during project implementation.

- To feed with useful information to project consortium, resulting in improved tasks' performance.

- To tailor appropriate mitigation and contingency measures for non-tolerable risks, so their negative impacts are minimised, therefore maximising the probabilities of achieving each project's objective.

- A continuously updated set of documents dealing with risk assessment and treatment, which permit handling and predicting all the possible risks during the project.
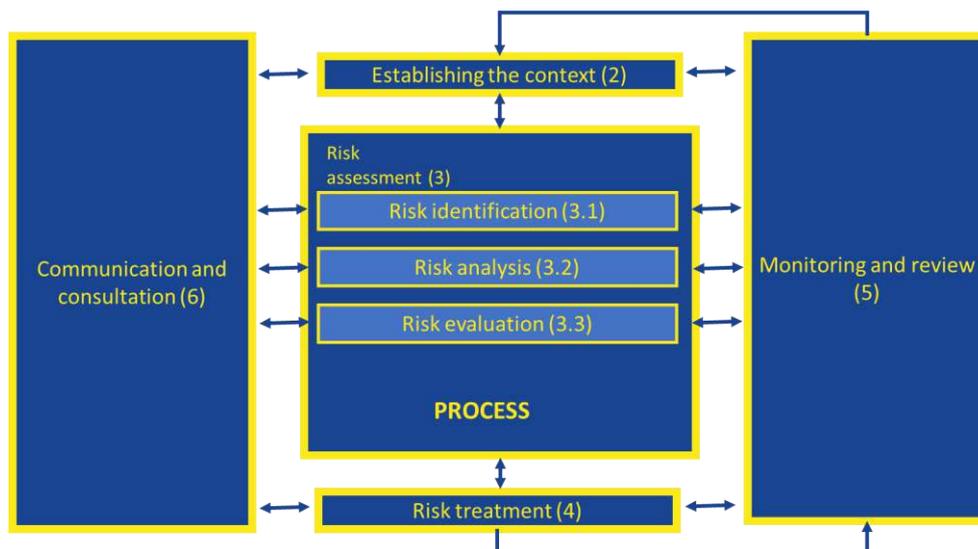
Figure 3. – Risk assessment process (adapted from (ISO, 2018))

The scope is identifying and evaluating administrative, financial, IPR, exploitation and dissemination risks related to SOCRATCES project execution, addressing contingency and mitigation plans for significant risks. The risk management during project execution is focused on overcome potential threats to achieving the objectives.

The risk manager manages the documentation and coordinates the risk management activities, gathering the information and assessing all risk management steps. The Project General Assembly is responsible for carrying out the review and improvements of the risk management process during project meetings as the main decision organism in the project. Meanwhile, the different partners take accountability for the risk assessment and treatment related to their activities, always guided by the risk manager.

3.2 Risk criteria

The consortium must define the criteria to evaluate the significance of risk and where it should be treated. The Horizon2020 guidelines (European Commission, 2017) recommend tailoring mitigation measures to those critical risks whose impact may cause that the stated project's objectives are not achieved. More specifically, they define critical risk as a "plausible event or issue that could have a high adverse impact on the ability of the project to achieve its objectives". The following factors will be considered:

- *Nature and types of risks assessed.* For project implementation, the categories in which the risks are classified are administrative, financial, technological, IPR, exploitation and dissemination.

- *Definition of likelihood.* The likelihood is the estimated probability that the risk will materialise even after taking account of the mitigating measures put in place. The likelihood will be described qualitatively as indicate the Table 5:

Table 5.- Likelihood criteria

Likelihood	Description	Score
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.	A
Unlikely	Not expected, but there's a slight possibility it may occur at some time.	B
Possible	The event might occur at some time. The event has a casual occurrence.	C
Likely	There is a strong possibility the event will occur. The event has a frequent occurrence.	D
Almost certain	The event is expected to occur in most circumstances. The event has a regular occurrence.	E

- *Definition of consequences of the risk.* It is the outcome of an event affecting objectives. It can be going from insignificant to severe. It can have positive or negative effects on objectives. The consequences will be described quantitatively as a function of its impact on the project's objectives as:

Table 6.- Consequences criteria

Consequence	Description	Score
Insignificant	If it occurs, a risk event will have little or no impact on achieving outcome objectives.	1
Minor	If it occurs, a risk event will have a minor impact on achieving desired results, to the extent that one or more stated outcome objectives will fall below goals but well above minimum acceptable levels.	2
Moderate	If it occurs, a risk event will have a major impact on achieving desired results, to the extent that one or more stated outcome objectives would fall below goals but above minimum acceptable levels.	3
Major	If it occurs, a risk event will significantly impact achieving desired results, to the extent that one or more stated outcome objectives would fall below acceptable levels.	4
Severe	If it occurs, a risk event will have a severe impact on achieving desired results, to the extent that one or more of its critical outcome objectives will not be achieved.	5

- *Definition of the risk level.* The magnitude of risk or combination of risks is expressed in terms of the combination of consequences and likelihood. This project is measured following a qualitative method, rating from the low to the extreme levels.

		Consequence				
		Insignificant 1	Minor 2	Moderate 3	Major 4	Severe 5
Likelihood	Rare A	Low	Low	Medium	Medium	High
	Unlikely B	Low	Low	Medium	High	High
	Possible C	Low	Low	Medium	High	Very High
	Likely D	Low	Medium	High	Very High	Extreme
	Almost Certain E	Medium	Medium	Very High	Extreme	Extreme

Figure 4. – Risk matrix defined for SOCRATCES project

- *Risk tolerance and ownership.* Depending on the level of the risk, it is classified as Low, Medium, Moderate, High, Very High o Extreme risk. Low risks are considered negligible, and there is no need to implement any treatment measure. Medium and High risks, which are still acceptable, must be treated, tailoring any effective measures for its mitigation or control. Very High and Extreme risks, which are unacceptable, must be urgently treated before the causes of the events occur.

  Depending on the level of the risk, different staff of the organisation will be involved in its management (always with the support and guidance of the Risk Manager). For Low risks, it is considered that the task leader and its team can manage it, monitoring its progress and, if it is decided, implementing treatment measures. For Medium and High risks, the task leader will be responsible for executing mitigation measures and managing the risk, but the WP leader will also oversee the management process. Regarding Very High and Extreme risks severely affecting the project's objective, the GA and the task leader will be involved in the decision-making related to how the risk will be managed and treated.

Regardless of the result of evaluating each risk, if the consortium detects that a certain set of low risks are affecting the same outcome (objective) of the project, it will be tailored and an integrated package of mitigation measures for treating them.

3.3 Risk assessment methodologies

Every partner will be provided with a Risk register template so they can document the project's risk management process and report it properly to the Risk Manager and the rest of the consortium (see ANNEX).

Given the objectives and scope of this project's risk management plan, it is considered that the wide experience and quality of the teams involved in the different tasks will be enough to identify the project's risks before they occur properly.

Nevertheless, in every project meeting, WP technical meetings, and any other communication mechanism, the experts will discuss the identification of new risks.

Risk treatment can involve:

- To avoid the risk by deciding not to start or continue with the activity that gives rise to the risk.

- To take or increase risk in order to pursue an opportunity.

- To remove the risk source.

- To change the likelihood.

- To change the consequences.

- To share the risk with another party or parties (including contracts and risk financing).

- To retain the risk by informed decision.

The risk owner must select the most suitable treatment, considering costs, efforts, resources committee. The treatment options selected set the treatment plan, which should be implemented in an orderly way paying attention to the performance of the treatment and the level of residual risks.

4. DEFINITION OF INDICATORS

Concerning the definition of indicators, two types of indicators will be defined: key risk indicators (KRI) and key performance indicators (KPIs). KRIs will be used for the previously defined risk assessment methodology. It is closely linked to Task 8.4, related to the definition and analysis of technological risks. KPIs will be used for defining the technological framework used for LCC and market prospective analyses.

4.1 Key Risk Indicators (KRI)

Key Risk Indicators (KRIs) are metrics used to determine the potential for eventual risk and take appropriate actions. KRIs are the alarms that alert when something is not working. There are different kinds of indicators. While KPIs focus on the technical data associated with the technology and historical data, the KRIs are intended to forecast what might happen. It helps to anticipate future problems and opportunities based on observing trends that may affect an organisation.

Although there are many reasons for using indicators, it is important to incorporate them into the management process because they provide useful information about the potential risks that can impact a project's strategic objectives. In this sense, risk indicators provide information that is vital to achieving strategic goals. For that reason, the design of a good risk indicator begins with the organisational objectives. This relationship between objectives and central strategies helps to identify the most relevant information that can be used to recognise emerging risks.

KRIs will be defined according to the objectives to be achieved in the SOCRATCES project. These encompass different categories. They also include administrative, financial, IPR, exploitation and dissemination. They are defined in Table 7. They can be extended in view of the control risk objectives to be accomplished when the risk analysis is performed. The following key performance indicators have been proposed. Firstly, in order to build the list, the full name of

the key indicator is required. Secondly, a short description is following to make clear the function of the specific key indicator. In some cases, this action is not necessary because its name can reveal its function.

Table 7. List of KRIs

KRI name	Description
Identified risks	The identified risks are those you are aware of and which you know will occur during the project. If your risk reduction strategies are en-point, you will notice that the number of these identified risks reduces over time, or they don't turn up during subsequent projects.
Actual risks	Not all of your identified risks become a reality. But some do. If you notice that the number of actual risks is as high as the identified ones, your risk measurement process is probably not right. An effective risk manager will know how to reduce the extent of actual risks too.
Unidentified and unanticipated risks	While it's challenging to anticipate certain risks, effective risk management requires project managers to place measures to solve any problem. Based on experience, identifying perilous situations and establishing solutions that can be used to tackle them if they arise.
Frequency of risks	A risk management practice is appropriate only when it prevents the onset of the risk at later stages of the project. However, if you notice the same uncertainty plaguing you at various stages of the project, it means that you don't have the right risk management techniques in place.
Severity of risks	When we talk about the severity of risks, we refer to how close the seriousness of the predicted threat is to that of the actual risk. If your risk manager evaluated the project risks correctly, he would have set up adequate measures to safeguard your project. However, poor risk management occurs when the project is too little-equipped or over-equipped to deal with the hazard. Both circumstances can result in a loss of time and resources.
Cost incurred due to risks	Ideally, the risk management strategies should not only help you mitigate the risk but should also assist with finding cost-effective solutions. When you compare your current risk status to a past project/timeline, you might notice a drop in the expenses you incurred due to the risk. This would indicate effective risk management
Speed and effectiveness of solutions	Finally, the speed with which you implemented risk mitigation solutions and how effective they were in actually reducing the risk indicates how well-prepared your organisation is. A strong and successful risk management plan is one that actively updates as the project proceeds and which, when implemented, helps the company get back on track without much hassle.

These KRIs are used in deliverable 8.7 to implement the risk assessment methodology described in section 3.

4.2 Key Performances Indicators (KPI)

This report also has the objective to prepare and collect a list of Key Performance Indicators (KPIs), which could be linked with the development of risk assessment or the technical indicators for SOCRATCES technology and prospective evaluation of technology in other deliverables. Both sets of indicators, KPIs and KRIs, consider the different aspects of each field.

The KPIs selected are based on the final targets of the project, which have also been established in the Grant Agreement. The objective of considering these indicators in the Deliverable D8.6 is that this risk analysis system (technological and non-technological) will directly affect achieving these values. These will be the values that, compared to those currently in the market, will demonstrate the competitiveness of SOCRATCES technology.

The selected set of KPIs is defined in Table 8. It specifies the name of the KPI and its units, the type of KPI, and a brief description.

Table 8: List of KPIs

| KPI name	Units	Type	Description	Ref
Charge/discharge power	kW	Technical	The design power of the plant	[1,2]
Expected Lifetime	Years	Technical	The lifetime of any energy storage technology	[1,2]
Energy Storage Capacity	kWh	Technical	Refers to the amount of energy available in the storage device; it is the total energy stored in the energy storage device.	[1,2]
Storage time	h	Technical	Refers to the amount of energy available in the storage device; it is the total energy stored in the energy storage device.	[1,2]
Response Time	ms-h	Technical	It measures the release time of the stored energy to meet the energy demand of the system.	[2]
Efficiency	%	Technical	The roundtrip efficiency is the ratio of the electricity output of the storage device to the electricity input to the device during a charge/discharge cycle. It takes into account the losses that occur as a result of the storage and withdrawal of energy from the energy storage device. Some of the energy losses occur in the auxiliary devices used in the energy storage process.	[2]
TRL/ Technology maturity	-	Socio-economic	The technological maturity of the energy storage system	[1,2]
Charge/Discharge temperature	ºC	Technical	It is applied to thermal energy storage systems. Refers to the temperature that the working fluid reaches.	[1]
Storage system costs	€/kWh	Socio-economic	The unit cost of storage	[1,3]
PCS cost	€/kW	Socio-economic	Power Conversion System costs	[3,4]
BOP cost	€/kW	Socio-economic	Balance of Plant cost	[3]
O&M cost	€/(kW-year)	Socio-economic	The Fixed and variable Operation and Manteinance costs. The operating cost includes the cost of operation, maintenance, disposal and replacement.	[1,3]
LCOE	€/(kWh)	Socio-economic	Levelized Cost of Energy	[3]

These KPIs are used to define the technology framework within the current context, LCC, market analysis and analysis of future development pathways. They are developed in the following tasks and deliverables within WP8.

5. REFERENCE INDICATOR VALUES

In this section, the main indicators for the most relevant energy storage technologies are analysed. They are presented here as a non-exhaustive analysis in order to identify and define the framework for SOCRATCES technology development and the adequate KPIs for SOCRATCES technology reference. They will be extended in the analyses performed in the deliverables for performance evaluation, market and commercialisation and environmental impact.

5.1 Power output and Expected Lifetime

Power capacity and expected lifetime define the capacity of an energy storage technology for different applications. Figure 5 shows the output power range of relevant energy storage technologies, represented on a logarithmic scale.
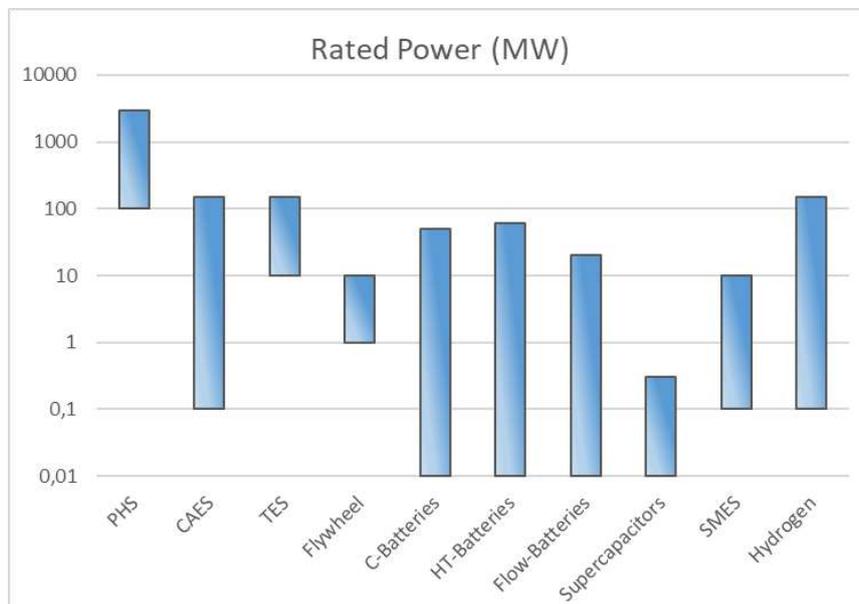
Figure 5: Output rated power range chart by technology (Data extracted from Gallo et al. 2016; Palomba and Frazzica 2019)

For the integration of renewables in the grid, there are only a reduced number of technologies with capacity for their integration at large scale power generation plants. Pumped hydro systems (PHS)cover the highest power range, although their use is limited to locations where there is significant water storage and enough altitude differences among the reservoirs. Compressed Air Energy Storage (CAES) and hydrogen can be applied to variations of existing commercial thermal power plants based on gas turbines technologies, being the rated output linked to the integration can go from 100 MW to 100 kW). The most versatile systems are batteries, with a power output range from 10 kW to MWs. The rated output power range will be used for the subsequent indicator plots, positioning the different technologies.

Lifetime is one of the most relevant indicators for evaluating the economics and sustainability of a technology. Table 9 shows the estimated expected lifetime for these technologies.

Table 9: Expected lifetime and output range by technology (extracted from Gallo et al. 2016; Palomba and Frazzica 2019)

	Power [MW]		Expected Lifetime [years]	
	Min	Max	Min	Max
Pumped Hydro Systems (PHS)	100	3000	30	60
Compressed Air Energy Systems (CAES)	0,1	150	20	40
Thermal Energy Storage (TES)	10	150	22	28
Flywheels	1	10	15	20
C-Batteries	0	50	5	20
HT-Batteries	0	60	10	15
Flow-Batteries	0	20	5	15
Supercapacitors	0	0,3	10	20
SMES	0,1	10	15	20
Hydrogen	0,1	150	20	30

Figure 6 shows a lifetime map over the power range for these storage technologies. Despite their power output versatility, batteries have a reduced expected lifetime. Together with their higher cost, it is difficult for their commercialisation in the range of higher power output required for power plants and the large scale integration in the electrical grid of renewables. TES systems have an extended lifetime range that guarantees their profitability at various scales depending on the application and materials. On the other hand, systems based on specific conditions of the locations, such as PHS and CAES, are designed under long operation conditions, extended over decades.
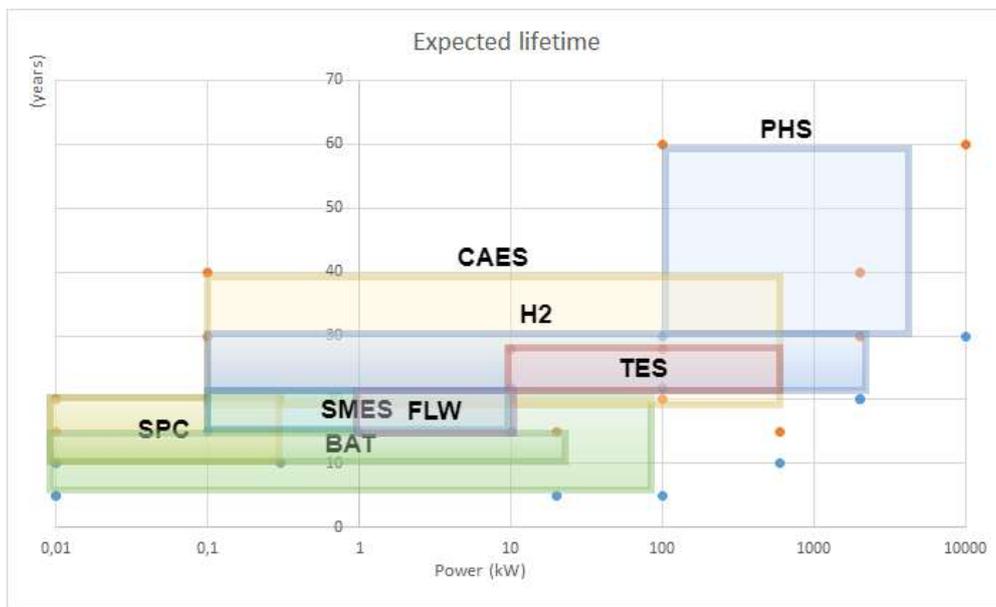

Figure 6: Expected lifetime-Power Output map

5.2 Energy Storage Capacity and Storage Time

Energy Storage Capacity refers to the total amount of energy available in the storage system. It is different from the energy recovered from the storage device, as the discharge is usually incomplete. PHS and CAES have a large storage capacity, and they are therefore suitable for grid-scale energy storage applications, specifically for the requirements for large scale integration of renewables. Technologies under development, and other technologies at the concept stage, may be suitable for grid-scale applications as they are scalable and based on mature mechanical components. The storage time is related to this concept. It expresses a similar concept but considers the discharge power and the number of hours the storage system can be discharging at full power. Table 10 shows the range of variation for both indicators and the selected energy storage technologies for the definition of indicators to be used in the project.

Table 10: Storage capacity range and storage time by technology (extracted from Gallo et al. 2016; Palomba and Frazzica 2019)

	Power [MW]		Storage Capacity [MWh]		Storage Time [hours]	
	Min	Max	Min	Max	Min	Max
PHS	100	3000	1000	10000	0,3	48
CAES	0,1	150	1	10000	1	48
TES	10	150	0,5	2000	1	24
Flywheel	1	10	0,01	5	0,5	5
C-Batteries	0	50	0,1	100	0,01	2
HT-Batteries	0	60	0,12	600	0,01	2
Flow-Batteries	0	20	0,01	20	0,01	10
Supercapacitors	0	0,3	0	0,01	0,01	2
SMES	0,1	10	0	0,1	0,01	0,3
Hydrogen	0,1	150	100	2000	1	48

Figure 6 shows the energy storage capacity range for the different technologies on a logarithmic scale on both axes. Similarly, Figure 7 shows the storage time range on a logarithmic scale in the power axis.
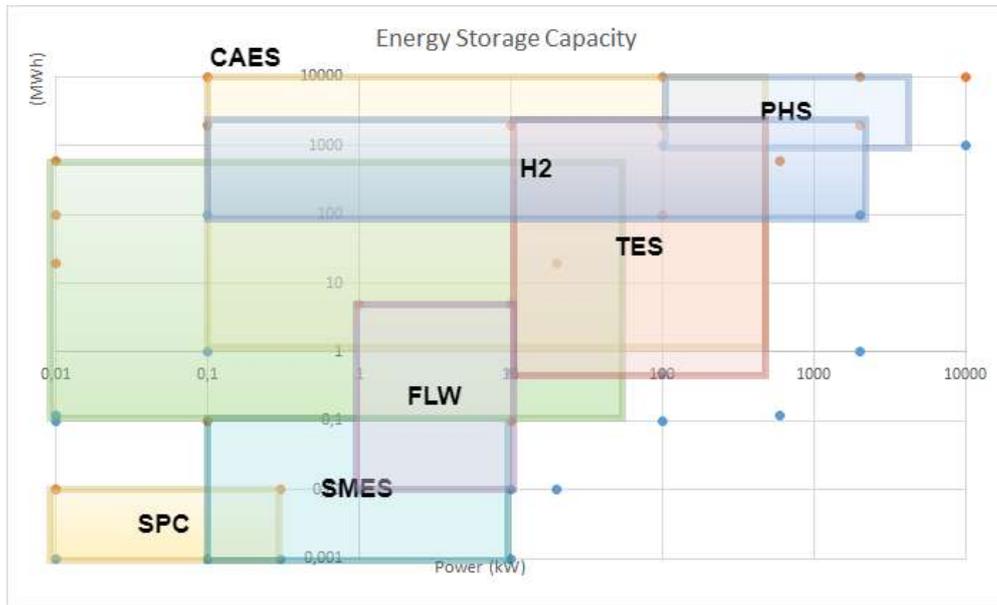
Figure 7: Energy Storage Capacity (MWh) – Power (kW) map

The figure shows how batteries and CAES have wider ranges of application of the technologies. In the range of applications of SOCRATCES project, power generation from sun, at MWs scale, differences can be appreciated among CAES, PHS, H2 and TES systems. It must be taken into account that each one of them includes different specific technologies with their linked constraints.
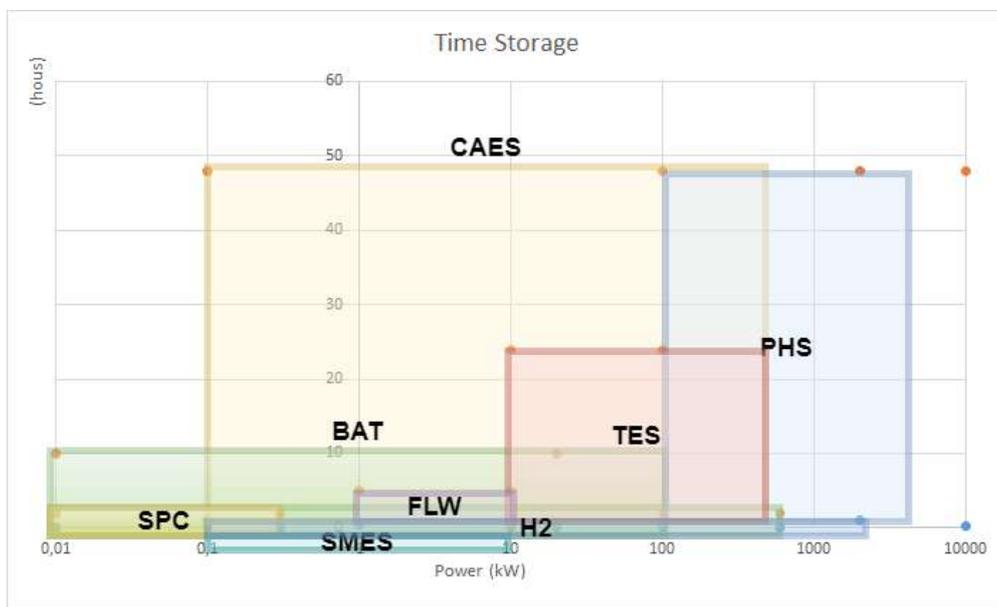
Figure 8: Time storage (h) – Power (kW) map

PHS and CAES cover the widest ranges, up to 50 hours. Except for TES and battery systems, the rest remain at reduced levels, in the range of 1-2 hours or even minutes.
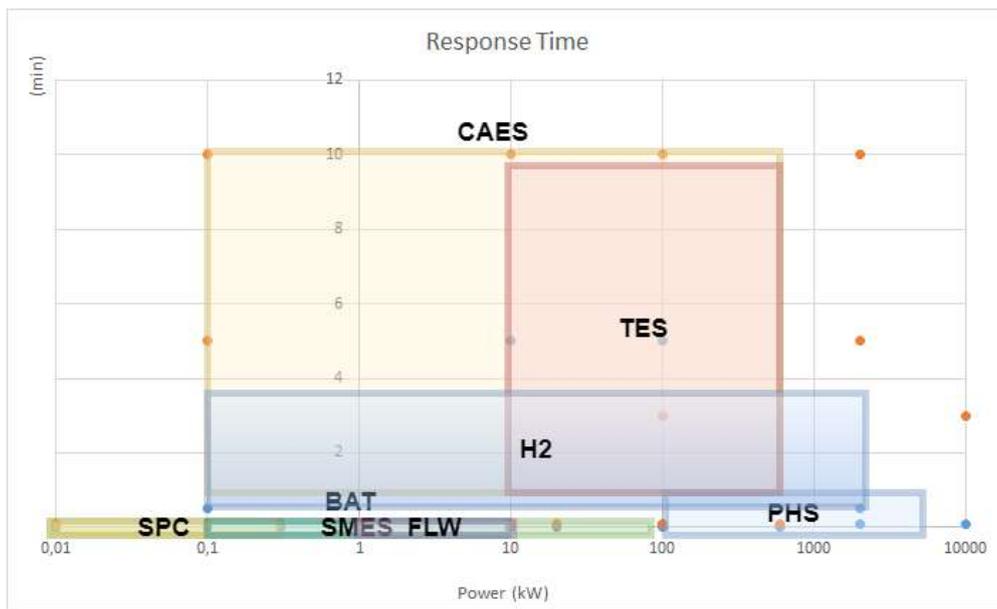
5.3 Response Time

Depending on the power system requirements, a response time to deliver energy is required. Table 11 shows the range of response times for the technologies considered [2].

Table 11: Response time range (extracted from Gallo et al. 2016)

	Power [MW]		Respone Time [hours]	
	Min	Max	Min	Max
PHS	100	3000	0	3
CAES	0,1	150	0	10
TES	10	150	5	10
Flywheel	1	10	ms	<0,1
C-Batteries	0	50	ms	<0,1
HT-Batteries	0	60	ms	<0,1
Flow-Batteries	0	20	ms	<0,1
Supercapacitors	0	0,3	ms	<0,1
SMES	0,1	10	ms	<0,1
Hydrogen	0,1	150	0,5	10

Figure 9 shows the response time -power output range map for the analysed technologies.

Figure 9: Response time (min) – Power (kW) map

Depending on the application scale, there are different requirements and available technologies. In large scale power, CAES, TES and hydrogen systems have response times that can reach orders of hours depending on the power system where they are integrated(i.e. if they are integrated with steam power plants or combined cycles and departing from cold starts).
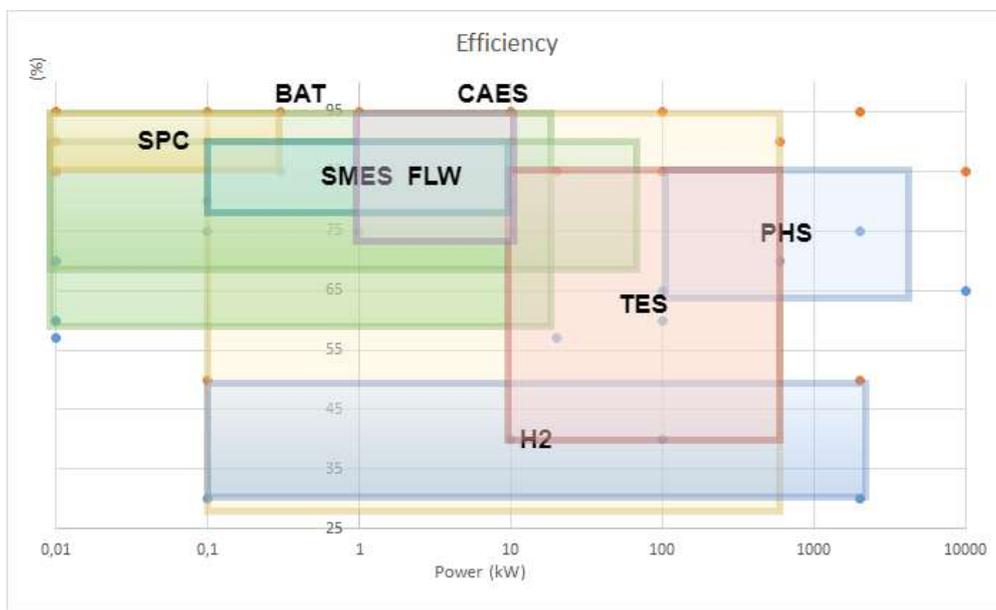
5.4 Roundtrip efficiency

Roundtrip efficiency is the ratio of the electricity output of the storage device to the electricity input to the device during a charge/discharge cycle. It considers losses that occur due to the storage and supply of energy from the energy storage system. Table 12 shows the roundtrip efficiency range for the different energy storage technologies.

Table 12: Roundtrip efficiency range [2]

	Power [MW]		Efficiency [%]	
	Min	Max	Min	Max
PHS	100	3000	65	85
CAES	0,1	150	75	95
TES	10	150	40	85
Flywheel	1	10	75	95
C-Batteries	0	50	60	95
HT-Batteries	0	60	70	90
Flow-Batteries	0	20	57	85
Supercapacitors	0	0,3	85	95
SMES	0,1	10	80	90
Hydrogen	0,1	150	30	50

Figure 10 shows the efficiency-power map developed from the values in the table.

Figure 10: Roundtrip efficiency (%) – power (kW) map

It shows a wide diversity of values depending on the range and the involved technologies in the storage and the power recovery. In those cases linked to thermal power plants, the efficiency of power conversion will reduce the efficiency, constrained by the upper limit of the Carnot's cycle efficiency, compared to electrochemical systems without this constrain for energy conversion

5.5 Technology maturity

Figure 11 shows the map of technology maturity versus power range.
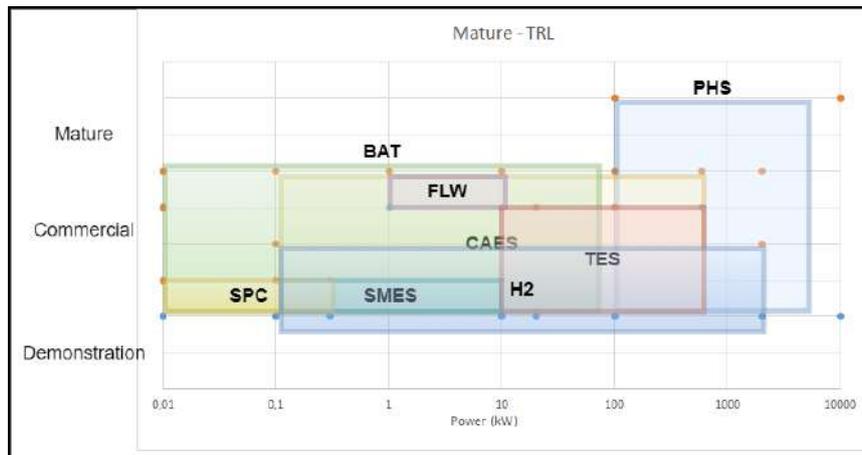
Figure 11: Technological maturity – power (kW) map (data extracted from Gallo et al. 2016; Palomba and Frazzica 2019)

Technological maturity is defined in terms of TRL. The most mature energy storage technologies are PHS and lead-acid batteries. CAES has been developed and commercially demonstrated decades ago, but its roundtrip efficiency still needs to be improved, which is the main focus of much current research on CAES systems. Other technologies, such as flow batteries, flywheels, and supercapacitors, have also been developed and commercially available, mainly in demonstration projects. Their application for large-scale energy storage is scarce.

5.6 Costs

Table 13 shows the estimated costs range for the analysed technologies. They provide cost per kWh, per kW and per kWh per cycle, balance of the plant (BOP) and operation and maintenance costs.

Table 13: Costs range [1,3,4]

	Power [MW]		Storage Section [$/kWh]		PCS [$/kW]		BOP [$/kW]		O&M [$/kW-yr]	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
PHS	100	3000	5	136	403	4644	3	30	2	10
CAES	0,1	150	2	141	432	1674	3	30	2	5
TES	10	150	-	-	560	2000	-	-	-	-
Flywheel	1	10	216	162000	32	756	54	300	5	6
C-Batteries	0	50	132	4104	161	4320	0	140	2	123
HT-Batteries	0	60	194	1210	211	3240	68	130	2	54
Flow-Batteries	0	20	142	1080	163	1620	11	151	3	51
Supercapacitors	0	0,3	108	101520	108	864	11	108	1	6
SMES	0,1	10	-	-	200	300	-	-	-	-
Hydrogen	0,1	150	2	15	540	4809	11	43	17	48

Figure shows the ranges of operation and maintenance costs and the balance of the plant costs as a function of the power output range for the different technologies.
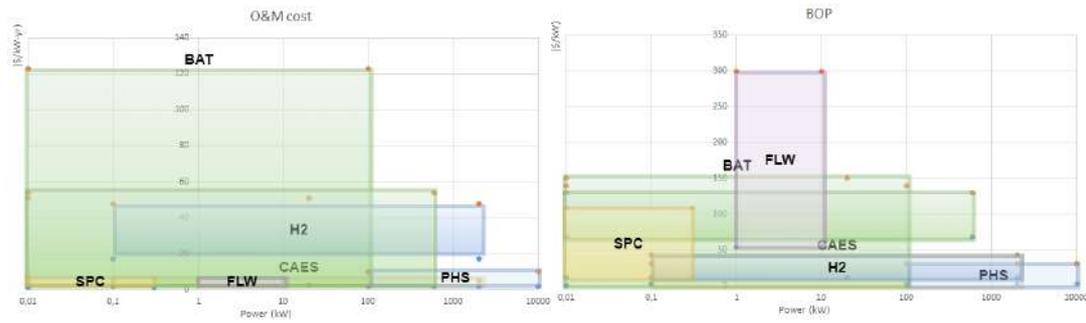
Figure 12: Operation & Maintenance cost & Balance of plant cost – Power maps

Currently, batteries have by far the highest operating and maintenance costs. In the balance of plant cost, flywheels stand out. Figure 13 shows the cost of the power conversion system and the unit cost of storage. PHS, hydrogen and batteries show the highest values. In terms of storage unit cost, represented on a logarithmic scale, flywheels and supercapacitors stand out from the rest.
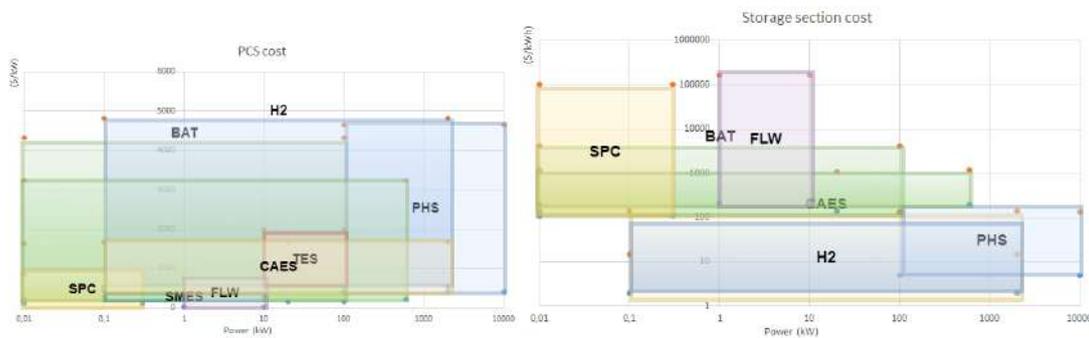
Figure 13: Power conversion system cost & Storage Section cost – Power maps

Table 14 shows investment costs and LCOE, according to the studies of Gallo et al. [2] and Ould Amrouche et al. [4]. This table does not consider TCES systems, discussed in more detail in the next section.

Table 14: Investment cost and LCOE (data extracted from Gallo et al. 2016; Ould Amrouche et al. 2016)

	Investment Cost [$/kW]		LCOE [$/kWh]	
	Min	Max	Min	Max
PHS	600	2000	5	100
CAES	400	800	2	50
Flywheel	250	350	250	350
C-Batteries	100	3000	300	500
HT-Batteries	100	4000	500	2500
Flow-Batteries	100	2500	100	1000
Supercapacitors	100	300	100	300
SMES	200	300	200	300
Hydrogen	1000	-	-	-

6. EXPECTED INDICATORS FOR TES AND TCES IN CSP

The role of thermal energy storage systems in a CSP plant strongly depends on the daily and yearly variation of solar irradiation and the corresponding electricity demand profile. Thermal energy storage may be sized and operated to answer to a specific production scheme. The main options are buffering, delivery period displacement, and delivery period extension. Currently,

commercially available in CSP plants are only storage technologies based on sensible systems: steam accumulators and molten salts. Table 15 shows the energy storage systems used in some of the existing solar power plants [28,29].

Storage steam accumulators are used as intermediate storage in some DSG plants. It benefits from a standardised and straightforward design and provides a fast discharge response, adapted to smooth out variations in the steam flow due to cloud transients. Nevertheless, they experience a significant decrease in pressure and temperature during discharge, which penalises the efficiency of the power block. In addition, the limited size of the storage vessels makes this technology costly and challenging to scale up to large storage capacities.

Systems with two molten salt tanks are the most widespread storage technology, with about 30 GWht of installed capacity. They are operated in direct mode (up to 565°C) when the HTF is molten salt, or in indirect mode (up to 390°C) when the HTF is thermal oil and can enable 24/7 power generation. Such technology benefits from a relatively cheap, safe and efficient storage medium. However, the corrosive behaviour of salts requires special steel grades for the containers. Due to their high freezing point temperature, they require special heat tracing systems, special operating strategies, and adapted components (especially pumps and valves).

Table 15: Solar thermal power plants with storage [28,29]

Plant name	Solar field type	Owner / Developer	Country	Start year	Net rated power (MW$_e$)	Operating temperatures (°C)	TES type	TES medium	TES capacity (h)
PS10	CRS	Abengoa	Spain	2007	11	250	SA	w/s	0,5
PS20	CRS	Abengoa	Spain	2009	20	250	SA	w/s	0,5
Gemasolar	CRS	Torresol	Spain	2010	20	290/565	TTAD	ms	15
Crescent Dunes	CRS	SolarReserve	USA	2013	110	290/565	TTAD	ms	10
SunCan Dunhuang Phase I	CRS	SunCan	China	2016	10	?	TTAD	ms	15
Khi Solar One	CRS	Abengoa	South Africa	2016	50	250	SA	w/s	2
PE2	LFR	Novatec	Spain	2008	30	60/270	SA	w/s	0,5
Andasol 1	PTC	ACS/Cobra	Spain	2008	50	293/393	TTAI	ms	7,5
Andasol 2	PTC	ACS/Cobra	Spain	2008	50	293/393	TTAI	ms	7,5
Andasol 3	PTC	Ferrostaal	Spain	2008	50	293/393	TTAI	ms	7,5
Archimede	PTC	ENEL	Italy	2010	4,7	290/550	TTAD	ms	8
Extresol-1	PTC	ACS/Cobra	Spain	2010	50	293/393	TTAI	ms	7,5
Extresol-2	PTC	ACS/Cobra	Spain	2010	50	293/393	TTAI	ms	7,5
La Florida	PTC	SAMCA	Spain	2010	50	293/393	TTAI	ms	7,5
Arcosol 50 (Valle 1)	PTC	Torresol	Spain	2011	50	293/393	TTAI	ms	7,5
La Dehesa	PTC	SAMCA	Spain	2011	50	293/393	TTAI	ms	7,5
Manchasol-1	PTC	ACS/Cobra	Spain	2011	50	293/393	TTAI	ms	7,5
Manchasol-2	PTC	ACS/Cobra	Spain	2011	50	293/393	TTAI	ms	7,5
Termesol 50	PTC	Torresol	Spain	2011	50	293/393	TTAI	ms	7,5
Extresol-3	PTC	ACS/Cobra	Spain	2012	50	293/393	TTAI	ms	7,5
Astexol II	PTC	Elecnor/Aries	Spain	2012	50	293/393	TTAI	ms	8
La Africana	PTC	Ortiz/TSK /Magtel	Spain	2012	50	293/393	TTAI	ms	7,5
Termosol 1	PTC	NextEra/FPL	Spain	2012	50	293/393	TTAI	ms	9
Termosol 2	PTC	NextEra/FPL	Spain	2012	50	293/393	TTAI	ms	9
Arenales	PTC	OHL	Spain	2013	50	293/393	TTAI	ms	7
Casablanca	PTC	ACS/Cobra	Spain	2013	50	293/393	TTAI	ms	7,5
Solana	PTC	Abengoa	USA	2013	250	293/393	TTAI	ms	6
Noor I	PTC	ACWA	Morocco	2015	146	293/393	TTAI	ms	3
KaXu Solar One	PTC	Abengoa	South Africa	2015	100	293/393	TTAI	ms	2,5
Bokpoort	PTC	ACWA	South Africa	2016	50	293/393	TTAI	ms	9,3

According to the IEA [6], the TES system accounts for 9% of the total investment cost of a 50 MWe PTC plant with indirect 7-hour storage. Salts correspond to about half of the investment cost of the TES system. Total specific costs for active direct two-tank molten salt TES operated at 565°C are estimated between 20 and 33 USD/kWht [NREL 2017].

SOCRATCES: Thermochemical Energy Storage based on Calcium-Looping

Focusing on TCES based on Calcium looping, as mentioned in the work of Ortiz et al. [7], the cost of the CaL process for TCES has already been evaluated, estimating a total system cost of 10.9-21.9 $/kWht, with an LCOE of 56-59 $/MWhe [8,9]. It should also be noted that the SunShot initiative (USA), which envisages a target cost of 15 $/kWht for energy storage in CSP plants, fits within the range of these estimates.

Table 16: Expected values for KPI's in Calcium-Looping

| KPI name	Units	Value	Ref
Charge/discharge power	kW	2000-67000	[10,11]
Expected Lifetime	Years	25 years	[12]
Energy Storage Capacity	kWhe	120000-480000	[7]
Storage time	h	4-24	[7]
Response Time	ms-h	1-20 minutes	
Efficiency	%	35-45%[1]	[7]
TRL/ Technology maturity	-	TRL5 (SOCRATCES)-TRL7 (CLEANKER)	[13–15]
Charge/Discharge temperature	ºC	700-950ºC (charge) 600-1000ºC (discharge)	[7]
Storage system costs	€/kWh	10-20	[16]
PCS cost	€/kW	1000-1500	[17]
BOP cost	€/kW	290	[18]
O&M cost	€/(kWh-year)	0.012	[10]
LCOE	€/(kWh)	0.08-0.2	[10]

- Charge/discharge power: CaL technology for energy storage is scalable from a few MWe to tens of MWe. The limits are imposed by the minimum size of the power cycle to achieve economically profitable values and by the maximum size of the CSP plants associated with energy storage. Tessio et al. [11] proposed a small-size CaL power plant based on a supercritical CO_2 power block. An order of magnitude of few MWe seems possible for CSP-

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[1] Effiency without solar side losses

CaL systems based on small gas turbines, while for tens of MWe, other power cycles could also be considered, such as steam cycles or combined cycles [19]. On the other hand, for CSP plants, the large receiver thermal power is around 660 MWth [20]. Taking into account a solar multiple (SM) of 3, a receiver efficiency of 60% (due to the high temperature), and a solar-to-electric conversion of 40%, would mean a maximum turbine capacity of $\sim$ 53 MWe.

- Expected lifetime: The lifetime of CSP-CaL plants are related to those expected for their main subsystems. CSP plants have an expected lifetime of ~25-30 years [12]. It is worth highlighting the almost insignificant degradation and loss of performance observed in the first eight years of operation of CSP plants in Spain, with almost the same power production in 2013 as in 2020 [21]. Cement plants main components lifetime would be in the same order ($\sim$ 25 years) [22] as well as a typical gas turbine lifetime[2]. Components and industries that are directly linked to SOCRATCES CaL-CSP technology.

- Energy storage capacity and time: The maximum energy storage capacity is limited by the amount of products stored. This is constrained by techno-economic aspects that must be carefully evaluated by each potential CSP plant to be constructed. Considering a standard operation of the CaL process, the total stored products would be $\sim$ 27.69 tonnes/MWh [23]. At large-scale storage, considering 24 hours operation, with 16h provided by the energy storage system at full turbine capacity (i.e. 30 MWe), would require $\sim$ 13500 tonnes of material, which is in the range of previous works [7].
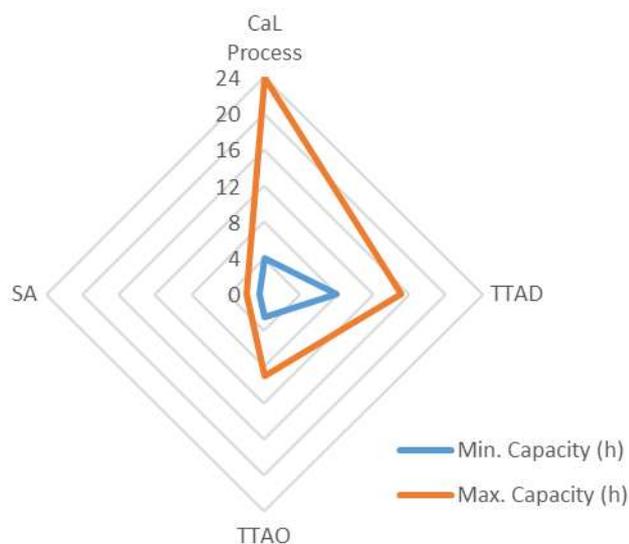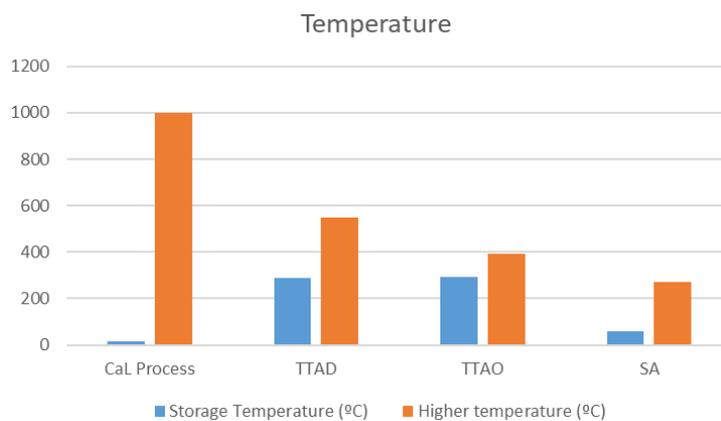

Figure 14: Thermal Energy Storage systems: storage capacity. CaL: Calcium Looping, SA: Steam Accumulator, TTAD: Two-Tank Active Direct, TTAI: Two-Tank Active Indirect [5]

- Response time for the CSP-CaL process is expected in the order of a few minutes. When energy is needed, CaO and CO_2 are transported (for instance, by pneumatic conveying) to the carbonator, where the reaction is estimated from laboratory results to take values below 1-5 minutes [24]. It is expected that the system will take a few more minutes to produce power, considering the heating time of the reagents, the HTF, and the heating of the turbine to start operation.

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[2] https://www.sulzer.com/en/shared/services/lifetime-assessments

- Efficiency: Different works have analysed different configurations for the CSP-CaL system, with efficiencies around 35-45% [7] (without solar side losses). The overall solar-to-electric efficiency would be in the range of 18-25% [23,25], considering receiver and solar field efficiencies around 60% and 80%, respectively.

- Calcination (charging) minimum temperature varies between 700ºC under very low CO_2 partial pressure [26] (by using an atmosphere of He, N2 or H2O and 950ºC under pure CO_2 atmosphere. The higher the temperature, the larger particles sintering and, therefore, the lower multicyclic efficiency [27].

- Costs: The total cost of the CaL system could be as low as 11.25 $/kWh [16]. The Sunshot program (DOE) looks for energy storage systems integration with a cost lower than 15 $/kWh [9]. The power cycle cost depends on the technology selected. For well-known mature steam cycles, the cost would be around 1000$/kWe [17], whilst novel power cycles (i.e. supercritical CO_2) would involve higher costs.

Figure 15: Thermal Energy Storage systems: Temperatures [5]

CONCLUSIONS

Deliverable D8.6 has focused on establishing the basis for the development of the risk analysis by describing the methodology and the definition of indicators for risk, Key risk indicators (KRIs) and key performance indicators (KPIs) for energy storage. It sets the definitions, preliminary concepts and references used and extended in the successive deliverables within WP8, as in deliverables D8.7 and D8.14. They include the concepts and definitions for the processes of Risk analysis and KPIs for energy storage performance evaluation.

The Risk Management Process provides the consortium with a systematic and procedural framework to identify, assess and tackle the risks affecting the accomplishment of projects' objectives. The continuous monitoring and revision ensure the permanent improvement of the framework and tools used.

The risk management process, whose methodology has already been described in this deliverable, together with the FMEA analysis, is fully developed and applied to the project execution in the next version of the risk analysis (deliverable 8.7).

Technical and socio-economic indicators have been identified, covering aspects related to power and energy, time, efficiency, maturity, temperatures and costs of existing energy storage technologies. The status of the different storage technologies in these indicators has been described through the review of the available literature, with an in-depth study of thermal storage systems in solar thermal plants, and the framework for SOCRATCES technology have been defined for these indicators. These global key performance indicators of energy storage

technologies support the definition of the framework of the technology. They are used in WP8 deliverables to analyse the performance of SOCRATCES technology and its market potential.

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ANNEX

The template for the risk register is below:

Risk ID and type	
WP and/or task	
Main ownership	
Other risk owners	
Risk lifetime	

RISK IDENTIFICATION				
Source of risk				
Risk description and consequences				

RISK ANALYSIS	Rate	Date	Rate	Date
Likelihood				
Consequences				

RISK EVALUATION	Rate	Date	Rate	Date

RISK TREATMENT	Description			Date
Measure				
Residual risk				
Measure performance				

		Consequence				
		Insignificant 1	Minor 2	Moderate 3	Major 4	Severe 5
Likelihood	Rare A	Low	Low	Medium	Medium	High
	Unlikely B	Low	Low	Medium	High	High
	Possible C	Low	Low	Medium	High	Very High
	Likely D	Low	Medium	High	Very High	Extreme
	Almost Certain E	Medium	Medium	Very High	Extreme	Extreme