D4.1 SWOT ANALYSIS

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1 INTRODUCTION

This document presents a Strength, Weaknesses, Opportunities and Threats (**SWOT**) analysis for a smooth and successful introduction of hybrid RES-energy storage power systems, namely batteries, pumped hydro, hydrogen and desalination, to the market and increase RES share in such areas.

The S, W, O and Ts were firstly identified by the project partners, then new elements were added and the SWOT was quality assured by means of the workshops to interested parties (e.g., RES technology providers, system operators, users, etc) and bilateral meetings.

After the identification of the S, W, O and Ts in the SWOT exercise, success factors were assigned to each S, W, O and T. These success factors were divided into four categories:

- Technical
- Market
- Social
- Environmental

This study was undertaken aiming to:

- establish a broad understanding of the technical and economical market potential for hybrid RES-energy storage power systems.
- identify and quantify the technological and practical issues relevant for this market.
- identify the legal, regulatory and administrative hurdles for market development and recommend ways in which the authorities might resolve these issues.
- propose a **roadmap** for the introduction of hybrid RES-energy storage power systems.

2 SWOT ANALYSIS PER STORAGE TECHNOLOGY

In order to evaluate the different success factors, different tools and approaches were applied. The assessment of parameters for the SWOT analysis have initially identified within Task 4.1 by SOFTECH. A SWOT analysis was initially carried out among the partners as a first step exercise drawing from their own experiences, knowledge and contacts. This provided preliminary critical success factors and focus for the data collection phase. Then, new elements were added and the SWOT was quality assured by means of the workshops to interested parties (e.g., RES technology providers, system operators, users, etc).

The information flow from these activities was fed into the SWOT analysis. The objectives were to:

- Obtain a reality check on the critical success factors
- Gain additional feedback
- Update and add to the critical success factors

2.1 BATTERY SYSTEMS

2.1.1 Technology

Batteries are at present the most common, practical and widely form of storing electrical energy, and they range in size from the button cells used in watches to megawatt load-leveling applications. The potential for electricity storage in battery systems can increase RES penetration in electricity systems, especially in islands and isolated regions. Batteries have traditionally been used for small-scale applications. Only recently large-scale application of battery storage has got some interest. Utility electricity storage requires a battery system that can be repeatedly charged and discharged, like the lead-acid battery used in a car or a portable computer. Batteries can be classified into *primary* and *secondary* types. A primary battery stores electrical energy in a chemical form which is introduced at the manufacturing stage. When it is discharged and this chemically stored energy is depleted, the battery is no longer serviceable. A secondary or rechargeable battery absorbs electrical energy, stores this in a chemical form and then releases it when required. Once the battery has been discharged and the chemical energy depleted, it can be recharged with a further intake of electrical energy. In recent years much of the focus on the development of electricity storage technology has been on battery storage. There is a wide variety of battery types serving various purposes. Although energy density is paramount, other important attributes are service life, load characteristics, maintenance requirements, self-discharge costs and safety. Nickel-cadmium is the first rechargeable battery in small format and forms a standard against which other chemistries are commonly compared. The trend is towards lithium-based systems [1].

Nickel-Cadmium (NiCd): mature and well understood but relatively low in energy density. Nickel-cadmium is used where long life, high discharge rate and extended temperature range is important. Main applications are two-way radios, biomedical equipment and power tools. Nickel-cadmium contains toxic metals and is not environmentally friendly.
Nickel-Metal-Hydride (NiMH): has a higher energy density compared to nickel-cadmium at the expense of reduced cycle life. There are no toxic metals. Applications include mobile phones and laptop computers. NiMH is viewed as steppingstone to lithium-based systems.
Lead-Acid (Pb-Acid): most economical for larger power applications where weight is of little concern. Lead-acid is the preferred choice for hospital equipment, wheelchairs, emergency lighting and UPS systems. Lead acid is inexpensive and rugged. It serves a unique niche that would be hard to replace with other systems.
Lithium-Ion (Li-ion): fastest growing battery system; offers high-energy density and low weight. Protection circuit are needed to limit voltage and current for safety reasons. Applications include notebook computers and cell phones. High current versions are available for power tools and medical devices.
Lithium-Ion-Polymer (Li-ion polymer): - a potentially lower cost version of the Li-ion. This chemistry is similar to the Li-ion in terms of energy density. It enables very slim geometry and allows simplified packaging. Main applications are mobile phones.
Reusable Alkaline - replaces disposable household batteries; suitable for low-power applications. Its limited cycle life is compensated by low self-discharge, making this battery ideal for portable entertainment devices and flashlights.

Nevertheless there are some technical problems with the use of batteries: the cell will discharge itself so they are only suitable for short-term electricity storage and they have a tendency to age resulting in a decreasing storage capacity.

Table 2.1.1 – Strengths, weaknesses, opportunities and threats & critical success factors for the technology

Technology	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Mature and well established technology Large practical experience	Short-term electricity storage	Suitable for large scale markets	Emergence of large scale markets for competing technologies	Bring out the advantages to the competing technologies
	Potential for high density energy storage	Age resulting in a decreasing storage capacity			Decrease procurement cost
	Guaranteed power from a RES system	Procurement cost			Increase life-time of electricity storage
	Able to handle power fluctuations: ideal for integration with intermittent RES				

2.1.2 Market

Electrical energy storage systems find ready application in a diverse range of markets. They include traction and propulsion, the automotive starting, lighting and ignition sector, standby power, remote area power supplies and in island electrical power systems. This last-named sector is of most interest in this project.

Batteries are manufactured in a wide variety of capacities ranging from less than 100 watts to modular configurations of several megawatts. They currently have the widest range of applications as compared to other energy storage technologies. The type and the number of battery storage applications are constantly expanding mainly in the areas of electric and electric hybrid vehicles, electric utility energy storage, portable electronics, and storage of electric energy produced by renewable resources such as wind and solar generators.

There are a number of battery chemistries that have evolved, from the age-old lead acid to nickel-based chemistries and most recently, lithium chemistries. Lithium batteries have captured the electronics markets to a large extent. Their superior performance and technology specifications imply great value and potential for the automotive sector. A combination of battery chemistries is likely to be of greater use in the market and reduce gas consumption.

Primary batteries are generally in the low-cost domestic environment, in portable equipment such as torches, calculators, radios and hearing aids. In the domestic environment secondary batteries are used in portable hand tools, laptop computers and portable telephones. Higher powered applications in industry include use in road and rail vehicles and in standby power applications. With customized primary non-rechargeable and secondary rechargeable battery power and packs, Electrochemical enables missions in a diverse set of critical markets, such as oil and gas services, pipeline inspection, military, aerospace, medical instrumentation and more [1,2].

Table 2.1.2 – Strengths, weaknesses, opportunities and threats & critical success factors for the market

Market	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Widest range of applications Already existing experience in handling Use in the market and reduce gas consumption Large number of players already in the market Large practical experience	High cost for small scale application Lack of after sales support scheme	Innovation related to the make-up and management of complete battery packs Energy cost in remote autonomous power systems Diversification of companies involved in the energy sector High power application	Short-term application	New job opportunities High power application Decrease cost for small scale application

2.1.3 Social

Nowadays batteries are used in several applications and they have gained popularity, becoming portable and useful for a variety of purposes in modern societies.

As reported above, batteries are widely used in portable equipment such as calculators, radios, portable hand tools, laptop computers, electronic music devices and portable telephones.

Table 2.1.3 – Strengths, weaknesses, opportunities and threats & critical success factors for social issues

Social	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Existing public awareness an acceptance for battery	Eco-innovative credentials	business and economic growth for the community	Novelty of hydrogen technology	New business opportunities
	Codes and standard already existing		attract new investments and funding	Emerging technologies (e.g. H2 and Fuel cells)	New eco-innovative battery systems

2.1.4 Environmental

The widespread use of batteries has created many environmental concerns, such as toxic metal pollution produced by some kind of battery like Nickel-cadmium. Battery manufacture consumes resources and often involves hazardous chemicals. Used batteries may be harmful and also contribute to increase electronic waste. Some areas in many countries have battery recycling services available to recover some of the materials from used batteries. Recycling or proper disposal prevents dangerous elements (such as lead, mercury, and cadmium) found in some types of batteries from entering the environment.

The major potential pollutant in batteries is mercury, which commonly accompanies zinc and which was for many years added to alkaline batteries to aid conductivity and to prevent corrosion. In the mid-1980s, alkaline batteries commonly contained between five and seven percent mercury. Today's alkaline batteries may contain approximately 0.025 percent mercury.

The environmental impact of battery systems can be reduced by matching operating conditions and battery characteristics in a life cycle perspective. To decrease the environmental impact of battery systems, the development of battery technologies should aim at the recycling of materials, increased service lives and higher energy densities. To decrease the environmental impact arising from the use of metals in battery systems, metals with relatively high natural occurrence should be used, and regulations implemented to decrease the need for virgin metals.

In the United States, for example, some cities like California and New York City prohibit the disposal of rechargeable batteries in solid waste. The rechargeable battery industry has nationwide recycling programs in the United States and Canada, with drop-off points at local retailers. The Battery Directive of the European Union has similar requirements, in addition to requiring increased recycling of batteries, and promoting research on improved battery recycling methods [1-3].

Rechargeable batteries produce far less waste than the non-rechargeable variety because they can be reused hundreds of time. In terms of preserving the environment, switching to rechargeables makes common sense.

Table 2.1.4 – Strengths, weaknesses, opportunities and threats & critical success factors for the environment

Environment	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Potential for high density energy storage	Non-rechargeable battery increase electronic waste	New recyclable material	Noise level of the main competing systems (e.g. H2)	Guaranteed power from a RES system
	Able to handle power fluctuations and therefore ideal for integration with intermittent RES	Hazardous materials cause environmental impact	Use of rechargeable battery	Negative environment impact	Lack of recycling and re-use schemes
	Guaranteed power from a RES system	Lack of recycling and re-use schemes			New eco-innovative battery systems

2.2 PUMP HYDRPO

Pump Hydro

Pump hydro energy storage utilizes excess electrical energy to pump water from a lower reservoir to a higher one. The energy will be stored as potential energy. When power is needed, water from the higher reservoir will flow to the lower reservoir through a turbine and thus generate electricity to meet demand.

Typical operating cost for pumped hydro is low, reliable and has a long lifetime. Efficiencies of this system are approximately 75-80%. Pumped Hydro Storage plants usually create large environmental concerns.

Pumped storage hydro-electricity is a remarkably simple principle. To start with, two reservoirs at different altitudes are required. Water stored at height offers valuable potential energy. During periods of high electrical demand, the water is released to the lower reservoir to generate electricity. When the water is released, kinetic energy is created by the discharge through high-pressure shafts which direct the water through turbines connected to generator/motors. The turbines power the generators to create electricity. After the generation process is complete, water is pumped back to the upper reservoir for storage and readiness for the next cycle. The process usually takes place overnight when electricity demand is at its lowest.

While pumped storage facilities are net energy consumers, they are valued by a utility because they can be rapidly brought on-line to operate in a peak power production mode. This process benefits the utility by increasing the load factor and reducing the cycling of its base load units. In most cases, pumped storage plants run a full cycle every 24 hours.

The pump storage type is actually used for enhancing the demand of electricity in pikes. In periods of low electricity demand the water from a lower reservoir is pumped to an upper reservoir. During periods of high electrical demand, the upper reservoir is opened, for example between 6 and 7 o' clock when people come home from work and do most of their household chores. The water is flows back to the lower reservoir, passing a turbine which generates electricity [4].

2.2.1 Technology

Pump-hydro is the most commonly used method of storing energy for the power grid, since it consists of pumping water uphill and then letting the water move downhill to produce electricity when needed. It is a well established technology. There are robust plants. The oldest ones have been in operation for over 80 years. Not a single pumped storage plant has been decommissioned as they are always found to be excellent additions to electrical grids [4].

The round trip energy storage efficiency in modern pumped Hydro Storage plant is over 80% and can be as high as 84%. This represents the percentage of electrical energy regenerated from 100% of the energy used for pumping. Older plants have round trip energy efficiency of about 75%, which was state of the art until 20-30 years ago.

In pumped-storage plants, pump turbines transfer water to a high storage reservoir during off-peak hours, thereby evening out the daily generated load. The stored water can then be used for hydroelectric power generation to cover temporary peaks in demand. The advantage of this technology is that it can come online very quickly, making it a useful tool to balance the varying electricity demand from consumers or unplanned outages of other power plants. The most common type of pure pumped storage is the off-stream configuration. The off-stream configuration consists of a lower reservoir on the water source, and a reservoir located off-stream usually at a higher elevation.

The latest advance in pumped storage technology is the introduction of adjustable speed motor/generators. With this technology pumped storage projects have realized a quantum increase in operational capabilities. Three major benefits that are used to justify the use of Adjustable Speed Hydro units are: (1) frequency regulation in the pump mode (2) part load pumping and (3) increased overall operating efficiency. The list of benefits from an adjustable speed machine in a pumped storage hydro plant includes:

- Part load pumping

- Frequency regulation in pump mode
- Increased overall annual efficiency of 3% or more
- Reduced vibration and reduced mechanical wear
- Increased pump-turbine life
- Fish friendly turbine operation

Table 2.2.1 – Strengths, weaknesses, opportunities and threats & critical success factors for the technology

Technology	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Mature and well established technology Large practical experience Conventional hydro machinery Higher global cycle efficiency compared to other storage solutions Low and predictable Operation and Maintenance cost Able to handle power fluctuations and therefore ideal for integration with intermittent RES	Need of high elevations in island territories	Suitable for large scale markets Long-term electricity storage Potential for Adjustable Speed Hydro units	High civil work costs	Existence of high elevations in island territories Long term electricity storage Large practical experience Very quick electricity on line

2.2.2 Market

Pumped Hydro Storage is the most widely used grid energy storage system. Modern plant has good round trip efficiency of up to 84%. Large storage capacity can be constructed at acceptable cost. Alternative storage systems tend to be either less efficient or more expensive. Components of a pump-hydro system are current in the market: pump turbines, motor-generators, control systems and optimised hydro-mechanical and balance of plant equipment.

Out of isolated context, where it can be a need for self-sufficiency, Hydro Storage is economic and flexible means of storing large amounts of excess energy. In fact, managing the balance between energy production and consumption levels has become an issue of growing importance for the stability of electrical networks. The large storage capacity of a pumped-storage plant allows power plant owners to efficiently manage this balancing act. Some energy storage technologies for the power grid are expensive but can be deployed anywhere, while Pumped Hydro is cheap but can only be built in certain locations, such as hilly terrain [5].

The main advantages from the Market point of view of Pumped Hydro Storage are:

- Increase profitability for plant owners in volatile electricity spot markets
- Allow optimisation of power plant fleets and electrical network infrastructures
- Nighttime cost to pump water is less then sales price of daytime electricity.

Table 2.2.2 – Strengths, weaknesses, opportunities and threats & critical success factors for the market

Market	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	No need for fuel transport infrastructure	Missing of codes and standards	Increase profitability for plant owners in volatile electricity spot markets	Size threshold to justify construction costs	Diversification of companies involved in the energy sector
	High practical experience and players in the market	Must be large to justify cost of construction	Energy cost in remote autonomous power systems	Low interest of utilities and major stakeholders	Alternative solutions tend to be more expensive
	Self-sufficient energy supply		Diversification of companies involved in the energy sector	Competing technologies prove to be well adequate	
	Alternative solutions tend to be either less efficient or more expensive				

2.2.3 Social

Pumped Hydro projects are a means of storing energy. Excess off-peak energy is used to pump water to an upper reservoir where it is stored as potential energy. The water is then released to produce peak-load power when necessary. In addition, many storage plants also function as conventional hydropower plants or as pumps to raise water for irrigation or public use.

Pumped Hydro schemes generally involve an important civil engineering effort, which requires a sizeable investment. The payback on this investment can be a lengthy process. There will be local economic benefits during construction due to the amount of people who will have to live and work in the area. The loch created by the reservoir will have recreational possibilities that can also add to the tourism in the area and therefore the economic prosperity.

Pumped Hydro schemes are preferably built in remote areas away from centres of population. They can be a source of employment to that area during construction and operation. They will however, cause an increase in traffic to the area during construction, which will be a long and noisy process. This will affect what might be an otherwise peaceful area.

Table 2.2.3 – Strengths, weaknesses, opportunities and threats & critical success factors for social issues

Social	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Existing public awareness and acceptance for pumped hydro	Eco-innovative credentials	Business and economic growth for the community	Emerging competing technologies after having done important investments	Eco-innovative credentials
	Expertise in cutting-edge technologies		Attract new investments and funding		Emerging competing technologies

2.2.4 Environmental

Like other energy storage systems, Pumped-Hydro Storage can make the power network less volatile and help utilities avoid using expensive backup power plants. Rather than firing up last-resort plants when demand spikes, they can dispatch stored energy. But beyond the obvious fact that pumped hydro can only be implemented in hilly areas, the technology has another very serious hurdle: it spends years in regulatory and environmental review procedures.

Suitable sites have to be available to build hydro storage plants at reasonable cost. Very large water storage volumes are needed. Construction costs are an important consideration. The power station, to be environmentally friendly, can be typically located in an underground cavern. A tunnel excavated through rock carries the water from the upper water basin, and passes through the power house. The power station must also have a wide access tunnel to permit transport of the pump turbines and other bulky equipment such as transformers. All of the associated excavation work can be very expensive. It can also be risky, which could considerably increase the civil works costs.

There are many environmental effects that a pumped hydro scheme will cause. Before a reservoir can be built the ecosystem surrounding the dam is flooded to aid construction by keeping the actual site dry, but this can be accounted for and careful planning can reduce these effects. After flooding, replanting can be done where necessary and the area can become an attractive place for walking and tourism.

Table 2.2.4 – Strengths, weaknesses, opportunities and threats & critical success factors for the environment

Environment	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Reduced environmental impact compared to conventional energy sources	Require a large area with suitable topography	Careful planning to reduce environmental effects	Noise levels	Noise level of the main competing systems

		Large water storage volumes needed Years to be spent in regulatory and environmental review procedures	Replanting and reshaping the ecosystem	Negative environment impact	Availability of large water storage volumes

2.3 HYDROGEN

The potential for energy storage in the form of hydrogen in order to facilitate RES penetration in islands was investigated through an assessment of:

- the technical potential for hydrogen storage as an energy supply buffer (evaluation of hydrogen technology components, case modelling of hydrogen in existing conventional power systems, assessment of existing RES-H2 demonstration plants)
- the market analysis (demand side, supply side)
- the evaluation of external factors (social)
- the evaluation of environmental factors

The main results of these activities are explained in the following sub-sections. The complete SWOT analysis including critical Success Factors for Technology, Market, Social and Environment is shown in Tables 2.1– 2.4, respectively.

2.3.1 Technology

The hydrogen components were classified by production, storage and utilisation.

For *hydrogen production* from intermittent RES, splitting of water through the process of electrolysis is a commercially available option. The types of electrolysers considered were the so-called polymer electrolyte membrane (PEM) and alkaline. Alkaline electrolysis is a mature technology allowing unmanned remote operation with significant operating experience in industrial applications. The PEM electrolysers currently available are not as mature as alkaline electrolysers with relatively high cost, low capacity, poor efficiency and short lifetime. However, PEM electrolysers are a promising technology potentially benefiting from development synergies with PEM fuel cells. This technology has been introduced to the market recently, but mainly for small capacities. The development of PEM electrolysers is interesting as they provide compact systems having a potential for high-pressure output and flexibility to accommodate power fluctuations. Solid Oxide electrolysers could be considered in the future due to their suitability for solar thermal and solar electric applications.

In general, there are two commercially available *hydrogen storage* options; (1) compressed gas and (2) liquefied gas. These storage techniques are well established and mature. In addition, metal hydride storage tanks are available on a precommercial basis – with several companies on the verge of commercialisation and may, as such, be considered an alternative storage option.

Although FCs represent a technique for *re-electrification of hydrogen* with high energy efficiencies, they are currently available only on a pre-commercial basis having too short lifetime warranty and far too high prices. There are FCs of different types. Alkaline FCs represent a promising and potentially far less expensive option compared to PEM FCs. Hydrogen Internal Combustion Engines (ICEs) are technologically more mature and have a significantly lower cost, having, however, lower energy efficiencies than FCs, which limits the potential in energy systems where long-term storage of energy as hydrogen is needed. The costs of ICEs are also still high, but the potential for cost reduction, given a market, is significant. ICEs are applied in a number of demonstration plants and may be a bridging technology until FCs will be available at acceptable costs and lifetime expectancy [6].

The technical potential for hydrogen storage and re-electrification was investigated on the basis of the evaluation of hydrogen technology components and the simulation results of the hybrid RES-energy storage power systems (Milos and Corvo case studies). A techno-economic modelling of two hybrid RES hydrogen systems (Milos & Corvo case studies) has been conducted in WP2. For both islands, HOMER was used to simulate and optimize the proposed power systems. For each case study a financial and economic analysis was carried out followed by a sensitivity analysis. The economic assumptions were an important input to the modelling activity. These were identified from a search through available literature and direct contact with hydrogen and renewable energy technology manufacturers. The simulation results for the optimized RES & hydrogen power system in both cases showed that the power generation cost on the islands decreases and at the same time there is a huge increase on RES penetration. A further reduction on the cost of hydrogen energy equipment and the introduction of external costs in the analysis will make the hydrogen-based system economically competitive to the existing one. More specifically, according to the results of the simulation of the proposed hydrogen-based power systems of Milos & Corvo and the comparison to the existing power systems of the these islands, the introduction of hydrogen as an energy storage method results in a decrease in the power generation cost of Milos (ca. 1%) and a considerable decrease in the power generation cost of Corvo (ca. 43%), a huge increase on RE penetration on both islands (from 13.4% to 86% in Milos and from 0% to 80% in Corvo) and a considerable reduction in diesel and heavy oil fuel consumption in both islands [7].

Table 2.3.1 – Strengths, weaknesses, opportunities and threats & critical success factors for the technology

Technology	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Already existing experience in handling of compressed gases Noise level of the main competing	Technology immaturity of FCs and PEM electrolysers Low availability and high cost of	Emergence of large scale markets for H2	Limited practical experience Competing technologies	Self-sufficient energy supply Bring out the advantages to the

	systems (e.g. DEGS)	small electrolysers		prove to be perfectly adequate	competing technologies
	Potential for high density energy storage	Procurement cost			Emergence of large scale markets for H2
	Seasonal energy storage without energy loss over time	Lack of component and system life-time experience			Increase practical experience
	Able to handle power fluctuations and therefore ideal for integration with intermittent RES	Low component efficiency			
	Guaranteed power from a RES system				
	Potential for low and predictable O&M cost				
	Self-sufficient energy supply				

2.3.2 Market

The assessment of the market was divided into demand side, supply side and external factors affecting both the demand and supply.

The market demand for hydrogen technology as a storage option of the excess RES electricity will depend on the external conditions of the market, the characteristics of the demand side use of the target market and the degree of diffusion and acceptance of the technology. The installation of hybrid RES – hydrogen storage power systems would have a major impact on the end-user, hence social attitudes and issues constitute the most important area. However, the managerial and technical aspects must also be taken into consideration, to convince them that this technology should be seen as the definitive solution. Physical integration should also be considered. Minimising the visual and physical impact of the new technology in the environment is vital to overcome social barriers.

The supply side of the market can be divided into (1) operational market players and (2) visionary market drivers. The development of a hydrogen related market for which the technology is not expected to become mature and cost-efficient in the next 5–10 years cannot rely on cost-benefit incentives or profit driven business decisions from the average commercial player. This will particularly be the case for smaller technology developers that cover the various bits and pieces of more complex energy systems involving hydrogen. Without clear short-term commercial incentives, these market players will not produce quick returns. The long-term hydrogen related market developments must rely on the major, long-term and visionary market drivers. These are the large energy companies. It is, however, not so clear when and how fast this market will develop. Fortunately, there will be some niche markets along the way, which will give sufficient possibilities for profit, hence giving the technology and infrastructure developers the necessary incentives to put their best efforts into their specific role in the market development. Hybrid RES – hydrogen storage power systems will probably be one such niche market. The long-term perspective implies that national governments and international public institutions must play a key role. However, the policies and limited public funds must support the strategies of the visionary market drivers [8].

The external factors, other than the more technology related factors, which are seen to affect the size of the hybrid RES – hydrogen storage market are [9]:

- General political climate – for RES
- Energy mix – for RES (security of supply, diversification, environment)
- Subsidies and Fiscal measures – for RES (tax incentives, certificate trading, etc.)
- Implementation of the RES electricity directive
- Security and quality of supply (blackouts, natural disasters, terrorist attacks)
- Population and public perception
- Formal procedures in local planning (environmental regulations, local planning)
- Grid system and cost issues

Table 2.3.2 – Strengths, weaknesses, opportunities and threats & critical success factors for the market

Market	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	No need for fuel transport infrastructure	Missing of codes and standards	Current EU and national funding schemes	Potential end-users have no experience	New job opportunities
	Already existing experience in handling of compressed gases	Low availability and high cost of small electrolysers	New job opportunities	Inadequate commercialization plan	Increase practical experience
	Self-sufficient energy supply	Lack of after sales support	Energy cost in remote autonomous power systems	Limited practical experience	Increase awareness of H2 capabilities and potential benefits
		Week supply network	Diversification of companies involved in the energy sector	Lack of awareness of H2 capabilities and potential benefits	Create adequate legislative network
		Lack of awareness of H2 capabilities and potential benefits		Low interest of utilities and major stakeholders	
		No public available market study		Competing technologies prove to be well adequate	
				Not enough players enter the market	

2.3.3 Social

Innovation and growth benefits – Expertise in cutting-edge technologies like hydrogen might improve the competitiveness of local firms, or generate new high value organisations. Aside from business and economic growth the community as a whole would benefit via learning processes and strengthened cooperation between different actors in the field of high-technology (universities, research institutes, public actors etc.). The community would acquire eco-innovative credentials which later on could attract new investments and funding [10].

New business opportunities – hydrogen can be the technological platform for developing totally new industry. Services are also likely to be needed to facilitate the introduction of the hydrogen technology. These include specialised financial services, insurance, logistics, shipping, truck transportation, retail, surveillance and overhaul and maintenance.

Publicity & prestige – The novelty of hydrogen technology, combined with its potential to change the way we generate and use energy, means that early demonstration projects, are likely to receive significant levels of publicity. Moreover, with a growing international awareness of climate change, regions are eager to improve their profile by establishing their green credentials.

Table 2.3.3 – Strengths, weaknesses, opportunities and threats & critical success factors for social issues

Social	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Expertise in cutting-edge technologies	Missing of codes and standards	business and economic growth for the community	Lack of public awareness for H2 capabilities and potential benefits	New business opportunities
	eco-innovative credentials		attract new investments and funding	Inadequate legislative network	Cooperation between different actors (universities, research institutes, public actors etc.)
	novelty of hydrogen technology		Publicity & prestige		

2.3.4 Environmental

One of the expectations of hydrogen and fuel cells is the significant reductions in CO2 that could arise from their use. On a local scale, the environmental impact of high RES penetration in remote areas is of course greater. In particular, the proposed configuration of the optimized RES & hydrogen power system of Milos & Corvo and hydrogen as an energy storage medium results in a significant decrease on emission production (especially CO2) on the islands (more than 60% for both cases). Moreover, the proposed high RES penetration results in the production of significant amounts of excess energy in both cases, thus the option of

transforming excess energy to hydrogen in order to be used locally in the transport sector seems challenging and beneficial for the quality of the environment of the islands.
Noise pollution, which is often overlooked, is another important issue for rural applications that are important for user categories like tourism and rural residences [7].

Table 2.3.4 – Strengths, weaknesses, opportunities and threats & critical success factors for the environment

Environment	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Reduced environmental impact compared to conventional energy sources Noise level of the main competing systems (e.g. DEGS) Potential for high density energy storage Able to handle power fluctuations and therefore ideal for integration with intermittent RES Guaranteed power from a RES system	Lack of recycling and re-use schemes Missing of codes and standards	Reduction of environmental impact	Negative common perception of the large scale of H2 on climate change	Create a positive common perception of the large scale of H2 on climate change Guaranteed power from a RES system Create recycling and re-use schemes

2.4 DESALINATION

Desalination is a natural procedure during which sea or brackish water is cleared from the minerals that cause salinity in order to provide water within acceptable standards for drinking or using it in the industry. The desalination plants use sea-water or water with high level of minerals as stock. Many large industries use desalination for diminishing the water pollution. During the last half century of the previous millennium, the desalination started to be used in a large industrial scale due to the lack of clear water in many areas of the planet.

Generally, desalination processes can be categorized into two major types: (i) phase-change/thermal; and (ii) membrane process separation. Some of the phase change processes include multi-stage flash, multiple effect boiling, vapour compression, freezing, humidification/dehumidification and solar stills. Membrane-based processes include reverse osmosis (RO) and electrodialysis. All processes are available in the market. Preferred options depend upon the need for, and availability and case of, energy sources, as well as local climatic conditions [11].

The Desalination method that will be examined for the purposes of the STORIES project is the Reverse Osmosis (RO) desalination method. RO is well developed and has been in commercial use for three decades for desalting low salinity brackish water. Moreover, this methods provides significant flexibility in adding capacity and can be provided in various sizes of view kW consumption and a few liters of potable water per hour up to some decades of cubic meters and capacity of some hundreds of kWs. The modular nature of this technology and its flexibility makes this technology an ideal candidate for studying in more detail the combination of RES and desalination systems [12]. Finally, on the island power systems to be studied, desalination plants using this technology have been or are being constructed now.

2.4.1 Technology

Formally, reverse osmosis is the process of forcing a solvent from a region of high solute concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. The membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where most separation occurs. In most cases the membrane is designed to allow only water to pass through this dense layer while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–70 bar (600–1000 psi) for seawater, which has around 24 bar (350 psi) natural osmotic pressure which must be overcome, making the technology very energy intensive [13]. The process is best known for its use in desalination (removing the salt from sea water to get fresh water), but it has also been used to purify fresh water for medical, industrial and domestic applications since the early 1970s.

Desalination plants require major initial capital outlays that need to be depreciated over plant service life which could be 30 years. Hence, the cost of capital has a significant impact on water production cost since capital contribution is usually 30% to 50% of water production cost.

Over the last two decades, numerous desalination systems utilizing renewable energy have been constructed. Almost all of these systems have been built as research or demonstration projects and were consequently of a small capacity. Still there are many problems to overcome to bring to a successful coupling renewable energies and desalination systems. A major problem regards the variation of the produced renewable power as wind speed or level of solar irradiance varies and since most renewable energy systems lack an inherent energy storage mechanism, the produced power has to be consumed directly or else it will be lost. Another problem is that, desalination systems (including the Reverse-Osmosis) have traditionally been designed to operate with a constant power input to ensure continuous operation without interruptions. Unpredictable and non-steady power inputs, such as the renewables, force the desalination system to operate in non optimal conditions (variable and intermittent) and cause operational problems. The addition of an energy storage sub-system results to both cost increase and also system complexity. The above reasons explain why the great majority of RES powered desalination systems developed or installed today are combinations of "conventional" RE systems with "conventional" desalination systems. Only few research trials are found in literature where the whole system (renewable technologies and desalination technologies together) is designed as a "complete" system, while only one is found regarding the effects of variable and intermittent operation on reverse osmosis membranes [11, 13].

Table 2.4.1 – Strengths, weaknesses, opportunities and threats & critical success factors for the technology

Technology	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Very low running and maintenance costs	High capital cost	Increased acceptance of hybrid RES/RO as an appropriate technology	Unpredictable and non-steady power inputs	Design & operate "complete" RES-RO systems
	Mature stand alone technology. Has been in commercial use for three decades	Desalination is very energy-intensive	Accelerate the development of novel water production systems from renewables.	Increased cost and also system complexity	
	High flexibility due to its modular nature	RES-RO as a "complete" system is very immature	RO is an ideal candidate for combining with RES		
		RO systems have traditionally been designed to operate with a constant power input	RO desalination systems under construction/already finalized in the island power systems in analysis		

2.4.2 Market

Since desalination facilities exist in over 100 countries around the world, specifying exact costs for desalting is not appropriate. In any country or region, the economics of using desalination is not just the number of euro per cubic meter, but the cost of desalted water versus the other alternatives. In many water-short areas, the cost of alternative sources of water is already very high and often above the cost of desalting. Any economic evaluation of the total cost of water delivered to a customer must include all the costs involved, such as, the cost of renewable energy input to the plant, capacity and type of plants, plant location, feed water, labour, energy, financing, concentrate disposal, and plant reliability, the costs for environmental protection (such as brine or concentrate disposal), distribution and losses in the storage and distribution system, etc [14].

Furthermore, there is a need to accelerate the development of novel water production systems from renewables. For example the Islands and Mediterranean areas are arid lands but with abundant geothermal energy and this needs to be exploited for large-scale production of freshwater from the oceans. In addition, the results from the simulations in deliverable D2.2 show that RES can mitigate the demand in increase of the islands due to the desalination plants and thus the emissions and fuel cost for the power system. This mitigation can be even higher if the schedule of the desalination plant is based on RES estimations or RES curtailment estimations, with significant benefits for both the power system and the owners of the RES installations on the islands. Thus desalination cannot only provide a method for meeting the water demand of population with limited access to potable water but also for islands with RES curtailment can help with appropriate management to reduce the amount of RES energy curtailed. The investors on wind parks would prefer the scenarios with least wind power curtailment to reduce the income loss [7]. Both the local Energy Authorities and the municipalities would have benefits, since water is produced by lower impact on the operation of the local units reducing both operational costs and emissions.

Of course, there is a need for a much stronger effort in R&D currently inadequate in Europe, which should include closer collaboration between the industry and research institutions as well as co-operation between Europe and the countries of the Mediterranean area and the Middle East

Table 2.4.2 – Strengths, weaknesses, opportunities and threats & critical success factors for the market

Market	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Desalination facilities exist in over 100 countries around the world	It is not possible to exactly determine costs for desalination	Closer collaboration between the industry and research institutions	The impossibility to exactly determine the costs of desalination could hinder a boost of the technology market	Accurate determination of desalination cost
	In many water-short areas, the cost of alternative sources of water is already very high and often above the cost of desalting.		Closer co-operation between Europe and the countries of the Mediterranean area and the Middle East. The investors on		R&D for novel water production systems from renewables

			wind parks would prefer the scenarios with least wind power curtailment to reduce the income loss Benefits for both Electricity Authorities and Municipalities		

2.4.3 Social

In some cases, social acceptance of desalination undertakings is difficult to reach. Mainly when such activities are connected to physical/environmental constraints or conflicts with (limited) land acreage, islands communities are particularly reluctant to welcome them.

Table 2.4.3 – Strengths, weaknesses, opportunities and threats & critical success factors for social issues

Social	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Even people from arid lands may have good quality fresh waters	Lack of awareness raising	Water shortage in coastal regions & islands Closer co-operation between Europe and the countries of the Mediterranean area and the Middle East. Creation of new employments	Difficult social acceptance	Social acceptance & awareness

2.4.4 Environmental

97.5% of the total global stock of water is saline and only 2.5% is fresh water. Approximately 70% of this global freshwater stock is locked up in polar icecaps and a major part of the remaining 30% lies in remote underground aquifers. Less than 1% of total freshwater or 0.007% of the total global water stock available in rivers, lakes and reservoirs are accessible for direct human use. Therefore oceans can constitute an alternative resource of water. However, extraction of fresh water from oceans requires significant development of desalination infrastructure. Desalination is very energy-intensive (e.g. for producing $1m^3$ of desalinated water, RO requires approximately 2.8-4.5 kWh of electric energy when energy recovery devices connected to the brine stream are used) and sustainable energy systems urgently need to be developed. Desalination technology is providing safe drinking water even to some 'water-rich' nations where pollution reduced the quality of natural waters. Moreover and as already stated above, desalination is used in large scale industrial plants to decrease water pollution.

In the other hand, considering the environmental problems related to the use of fossil fuels, if oil was much more widely available, it is questionable if we could afford to burn it on the scale needed to provide everyone with fresh water. Given current understanding of the greenhouse effect and the importance of CO2 levels, this use of oil is debatable. Thus, apart from satisfying the additional energy demand, environmental pollution would be a major concern. If desalination is accomplished by conventional technology, then it will require burning of substantial quantities of fossil fuels and given that conventional sources of energy are polluting, sources of energy that are not polluting will have to be deployed. Fortunately, there are many parts of the world that are short of water but have exploitable renewable sources of energy that could be used to drive desalination processes. Although renewable energy powered desalination systems cannot compete with conventional systems in terms of the cost of water produced, they are applicable in certain areas and are likely to become more widely feasible solutions in the near future. As a matter of fact, recent works have shown that hybrid power systems can provide power and water supply in a better performance with economically and environmentally viable compared to stand alone diesel system [15].

Table 2.4.4 – Strengths, weaknesses, opportunities and threats & critical success factors for the environment

Environment	*Strengths*	*Weaknesses*	*Opportunities*	*Threats*	*Critical success factors*
	Wide availability of the resource Desalination can provide fresh water to those rich countries with highly polluted fresh waters	Lack of required infrastructures to extract fresh water from oceans Desalination is very energy-intensive	Increased environmental awareness Desalination can provide fresh water to those rich countries with highly polluted fresh waters Desalination can be used in large scale industrial plants to decrease water pollution Renewable	Sustainable energy systems for desalination still need further development	Further development of sustainable energy systems for desalination

			energy powered desalination systems are applicable in certain areas and are likely to become more widely feasible solutions in the near future		

3 CRITICAL SUCCESS FACTORS

Here we focus on the presumed main success factors that affect the hybrid RES-energy storage power systems applications all the way through the data collection, the analyses and the recommendations at the end. This will also serve as a structure and methodology for future studies where new success factors could be introduced as they were identified.

The critical success factors identified through the SWOT analysis have been categorized according to their relevance to the FOUR main areas (Technical, Market, Social & Environment) and are shown in Table 3.1.

Table 3.1 - The critical success factors identified through the SWOT analysis for all energy storage options

Category	Critical Success Factors
Technology	1. Bring out the advantages to the competing technologies such as: Long term electricity storage, Quick electricity on line and Self-sufficient energy supply 2. Emergence of large scale markets for storage technologies 3. Acquire practical experience. Design & operate “complete” hybrid RES-energy storage power systems 4. R&D for novel hybrid RES-energy storage power systems
Market	1. New job opportunities 2. Decrease cost for small scale applications 3. Diversification of companies involved in the energy sector 4. Acquire practical experience 5. Increase awareness of energy storage capabilities and potential benefits 6. Create a sufficient legislative network 7. More R&D for novel hybrid RES-energy storage power systems
Social	1. New business opportunities

	2. Eco-innovative credentials 3. Emerging competing technologies 4. Cooperation between different actors (universities, research institutes, public actors etc.) 5. Social acceptance & awareness
Environment	1. Guaranteed power from a RES system 2. Create recycling and re-use schemes 3. Noise level of the main competing systems 4. Create a positive common perception of the large scale systems on climate change 5. Further development of sustainable energy systems

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