NEUE ENERGIEN 2020

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Projekttitel: STOR-E - Advanced Electrical Storage Facilities to become Economically and Environmentally sound

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1 Inhaltsverzeichnis

2 Einleitung

Initial Situation - The objective of STOR-E is to develop and design a cost- and energy- efficient mid- to long term storage of electrical energy based on compressed air for small scale applications.Currently compressed air energy storage (CAES) is the most probable solution that is able to match the characteristics of low investment costs with fewer restrictions (no degradation like batteries or no topographical needs like storage hydro power stations).

Particular Objectives - The objectives of STOR-E are to develop and design a technology enabling cost-effective and efficient storage of electrical energy through the medium of compressed air. Three prototypes are envisaged to be developed and designed for the identified integration scenarios within the municipality Hartberg. Specific targets for this new technology are: ● Electrical storage facilities with efficiency degrees of more than 60%. ● Back-up start-up times of less than 3 min and power ramps in operation > 50%/min based on electrical demand of three representative sites within the municipality of Hartberg. ● The provision of ancillary services as a small-scaled decentralized application that serves as emergency power system respectively auxiliary generator. ● No CO2 emissions and low acoustic emissions to allow implementing STOR-E facilities at urban areas at a later stage.

Evidence - Energy is a major determinant of economic growth. Austria's energy supply is characterised by structural weaknesses and shortcomings, particularly regarding security of supply and climate change. Energy supply security, mitigating climate change and economic competitiveness are therefore the main drivers for energy research, within the context of sustainable development. Due to the advantageous situation of Austria, with vast biomass and water resources, the electricity demand of the country is covered by app. 50% of locally available renewable energy sources. Nevertheless the coverage of peak load, grid related problems arising from increasing share of renewables and future demand changing (e-mobility, changing consumer behavior etc.) become major issues.

Methods - Local analysis and discussion were already performed with all relevant parties to get a clear vision of the project and expected specific outcomes. Especially the municipal utility of Hartberg appreciates the project very much as it will provide an additional possibility to promote renewable energy sources in their local territory and to work together with a highly professional technology provider consortium. In order to achieve the envisaged objectives described above in the most efficient way, the chosen approach relies on three pillars: A good and efficient project management, a sound methodology based on the following basic principles and jointly agreed quality assurance measures: ● Ensuring the successful achievement of project goals and timely provision of deliverables in the most cost-effective manner. ● Identifying demands from different types of end-user scenarios (industrial/commercial, wind park, PV integrated in branch lines). ● Establishing a reliable technical and information base in relation to electricity storages to guarantee optimised procedures for detailed planning and technical design. ● Addressing all technical aspects regarding the engineering of the three planned STOR-E devices with all components.

Work plan - For achieving the envisaged objectives described above in the most efficient way, the chosen **WORK PACKAGE** structure relies on a sound and multidisciplinary content-related methodology:

1. Ensuring the successful achievement of project goals and timely provision of deliverables in the most cost-effective manner incl. knowledge management & IPR protection.
2. Identifying the initial situation (user requirements, technology related frame work conditions, and market related issues by taking into account lessons learnt from the EU-CONCERTO Solution project) for the establishment of a reliable basement of further project work with strong focus to the market.
3. The development of the secure technical concept and design to guarantee optimised procedures for the demonstration.
4. Definition of the economic and legal feasibility of the foreseen technology with respect to the proposed application sites/possibilities.
5. Validating the given specification and testing the technical feasibility of creating prototype devices.
6. Addressing all aspects regarding the demonstration of the STOR-E devices and subsequently validation as well as monitoring by means of the performance assessment methodologies for quality assurance measures.

3 Inhaltliche Darstellung

STOR-E intends to find concrete scientific answers to specific aspects of interventions, taking into account the requirement of integration but also the need to limit the work to a feasible dimension. The main outcomes of **WORK PACKAGE 1,** the project management to co-ordinate STOR-E efficiently and effectively on all project levels are:

- D1.1: Kick-off meeting and related presentations and minutes - On 07.03.2011 the Kick-off meeting has taken place at EPFL in Lausanne.
- D1.2: Periodic reports – two interim reports have been provided. During the first two meetings the original implementation process was divided in 4 phases interrelated to the work plan of STOR-E: ● Phase 1 (till December 2011): Specifying the applications and assessing the accordance with legal requirements. Conducting simulations in order to figure out the exact size storage capacities and power rate towards an optimised system flexible to be adapted according to the user requirements. ● Phase 2 (till June 2012): Preparing the sites and completing the engineering phase by complying with the necessary CE certification. In January 2012, the consortium will make the decision if prototype production can be performed in parallel. ● Phase 3 (till November 2012): Implementing the prototypes on-site, conducting the test operations, monitoring and in-depth analyses. ● Phase 4 (thereafter): Running in standard operation and conducting the survey monitoring. As during the meeting at EPFL the laboratory prototype of the electricity story HyPES has still been only partly working and the work plan for the foreseen prototype in Hartberg has been requested to be postponed, a one year prolongation has been requested by the FFG. The request has been disapproved as one contractual obligation fixed an operational demonstration object in phase 1 couldn't be achieved so far.

- D1.3: 3 Progress and 1 final meetings and corresponding minutes - five project meetings were held two further meetings in Lausanne, two in Hartberg and one in Vienna.
- D1.4: Final report – final progress, financial and publishable reports are drawn up.

The main outcomes of **WORK PACKAGE 2,** the end-user requirement investigations for the three envisaged applications in Hartberg illustrated in figure 1 are:

- D2.1: Report on power requirement - HyPES within the frame of benchmarking storage technologies under discussions for the time being (incl. 3 reference implementation scenarios and grid integration requirements).
- D2.2: Selection and definition of the construction sites **-** Simulation results of Gaugl, Ökopark and Frutura led to the conclusion to select the Ökopark site.
- D2.3: Evaluation of specific requirements - considering the particular site constraints as well as balancing PV in close collaboration with WORK PACKAGE 3 and related cost regimes.
- D2.4: Definition of system / suppliers / operator's organisation forms and interfaces – a kind of summary report of all tasks and deliverables in WORK PACKAGE 2.

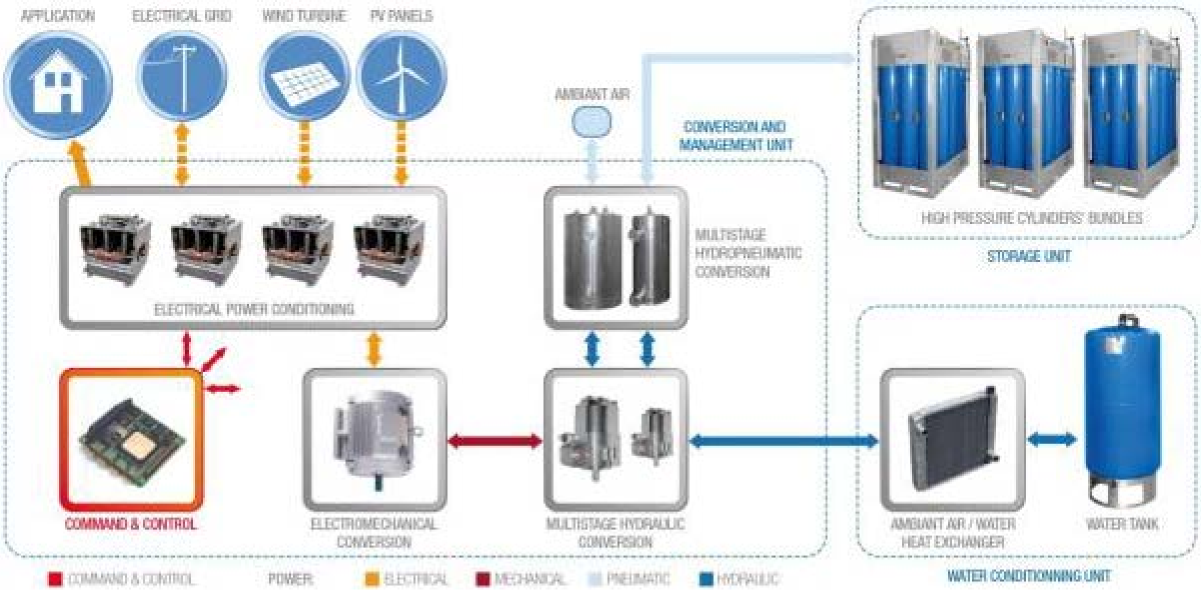

Figure 1: Main topology and bloc diagram of HyPES system.

The main outcomes of **WORK PACKAGE 3,** the Innovative Concept & Design for the three envisaged applications in Hartberg illustrated In figure 2" are:

- D3.1: Report on environmental impact statement / legal aspects - the environmental impact of two storage technologies, HyPES and lead-acid batteries have been assessed with the simulation tool GABI on selected environmental aspects. As no prototype operates in the field yet the assessment information has been referred to the laboratory prototype at EPFL and to a literature recherché respectively interviews with related industrial experts. Some legal aspects with regard to its site integration have been investigated in WORK PACKAGE 2 and are presented in corresponding deliverables (see above).

- D3.2-3.4:. Joint Deliverable D3.2 Analysis report & D3.3 Design workshop in the laboratory & D3.4 Specification of STOR-E – a 25kW/50kWh energy storage and management system based on HyPES technology combined with the existing photovoltaic application at Ökopark Hartberg has been designed and specified in detail. Experimental results are recorded on the laboratory prototype of HyPES system currently under testing in Lausanne. These results show the effectiveness of the HyPES technology to implement “quasi-isothermal” compression and expansion of air. Simulation and experimental results related to a new air compression/expansion called “Dry Piston” concept currently under study at EPFL are also presented in the deliverable as well. The goal of this study is to simplify the architecture of the electric-to-pneumatic conversion chain to increase its power density while maintaining the efficiency. The “Dry Piston” concept seems to be most suitable for low pressure applications, whereas “Liquid Piston” concept seems to be most suitable to high pressure applications.

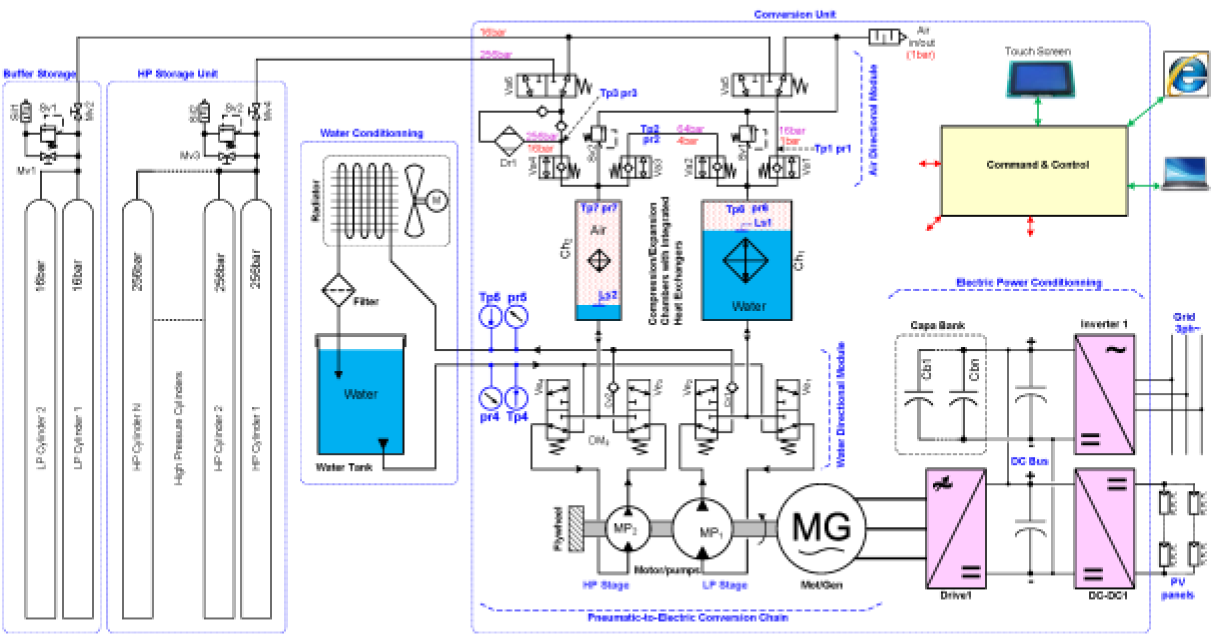

Figure 2: Simplified schematic diagram of the HyPES system in application to photovoltaic power smoothing or time-shifting.

The main outcomes of **WORK PACKAGE 4**, the Economic Analysis & Feasibility for STOR-E units are:

- D4.1: Survey on comparative analyses of techno-economic results of pre-projects – Figure 3 shows the characteristics of the marginal costs of **STOR-E** units depending on the volume for enabling technologies within the different market segments. According to the used approach the economic benefits are:

  1. Larger markets result in lower costs and encouraging more innovation.
  2. By repeating a common approach across Europe there would be a significant benefit arising from shared experience resulting in lower risk associated with each implementation and good practice in securing the supply of renewable electricity.
  3. The chosen market access would also support de-centralised energy supplies.

Categories / Purposes	SAS / UPS	Isolated Grid	Main Grid
Challenges	- Duration of autonomy - Maximum capacity	- Supply costs - Power quality	- Reserve capacity / reactive power - Load Management

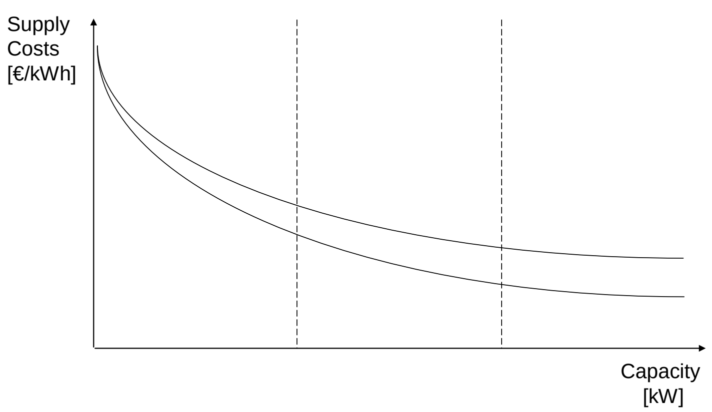

Figure 3 Qualitative characteristics of marginal costs per market segment

- D4.2: Survey about results of the economic analysis – The presented cost estimations are based on incomplete information available on today particularities regarding the manufacturing and mass production of HyPES system by giving the current development stage of the technology. Therefore some error margins of costs should be considered when using the given figures and diagram windows.
- It is difficult at the current product development stage where some manufacturing processes are still under evaluation to provide relevant cost information on HyPES systems. Nevertheless, a first estimation of the capital cost for HyPES systems, as well as the expected evolution of this

cost between the pilot state and the commercial state, is presented in Figure 4 using a benchmark provided by the Electricity Storage Association (ESA).

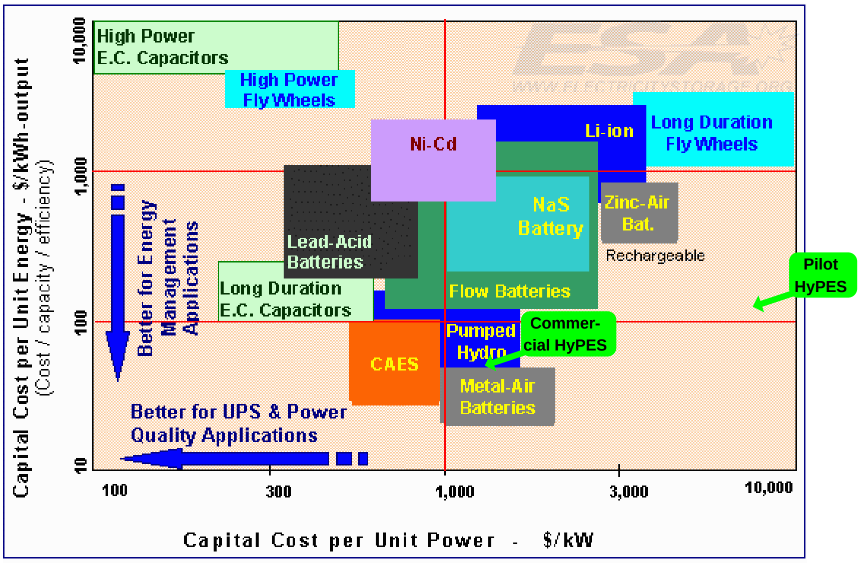

Figure 4: HyPES positioning with regard to capital cost. (Source: ESA & Enairys).

- D4.3: Report on economics of power storage – results of related simulation refer to the following patterns:
    - Overall yearly energy demand and production with and without storage
    - Energy purchased from and feed into the grid
    - Minimum and maximum power
    - Storage usage
    - Energy consumption of storage system (including losses)
    - Energy fee
    - Net usage charges

  The simulation shows comparative the energy flow of the system with and without a storage system. The energy cost and revenues as well as the net usage charges are compared and earnings respectively losses are shown. The presented model can be used to optimize the size of the alternative energy production, the size of the storage system and to compare different storage systems. By varying the different patterns of the model the most economical combination of coefficients can be evaluated.

- D4.4: Report on suitable STOR-E solution(s) – in the mainly commercial area the storage system can be operated for two main utilisation reasons:
    - To store PV energy for the own consumption.
    - To reduce the peak load of the interconnected distribution grid.

  The second point results in even higher savings, because the peak load demand is rated with costs by the distribution system operator (DSO).

- D4.5: Exploitation plan towards commercial/industrial infrastructures – One big market for storage systems is the implementation into uninterruptible power supplies (UPS). The primary task of an UPS is to supply (critical) loads like computer centres, hospitals, hotels and production plants with electrical power in case of voltage dips or black-outs. The standard EN 62040 sets out requirements for UPS and classifies them according to grid failures in three categories.

Class	Definition acc. EN 62040-3	Old Definitions
VFI	Voltage and Frequency Independent: UPS output is independent of grid, voltage and frequency changes within the limits of IEC 61000-2-2	On-line, Double Conversion, continuous operation
VI	Voltage Independent: UPS output depends on grid frequency, voltage is steady	Single Conversion, Delta Conversion, Line-Interactive
VFD	Voltage and Frequency Dependent: UPS output depends on frequency and voltage changes in the grid	Off-line, Stand-by

The design of an UPS must meet the requirements

- Area of application
- Switchover time
- Operating parameters (for example temperature)
- Consumer specifics (e.g. rated power, load behaviour, tolerance to network faults)
- Availability / reliability
- Efficiency
- Autonomy time
- Maintenance

In this context, the energy storage is of great importance. For this reason, the performance characteristics of the energy storage system are quite significant in determining the performance of the UPS system. The HyPES storage system is compared to two other commonly used energy storage systems for UPS and emergency power systems:

- Diesel generator
- UPS with lead acid batteries

It turns out that the results depend strongly on local conditions like energy cost, environmental parameters and operating time. Three different scenarios are analyzed in the following chapters:

- “Austria”: UPS functionality in a industrialized country with high grid reliability
- “Jamaica”: power black-out once a day for one hour
- “Senegal”: power supplied not from a grid but a photovoltaic plant; power supply for night hours from storage

The main outcomes of **WORK PACKAGE 5, the** Engineering of industrial prototypes for STOR-E units are:

- D5.1: Detailed planning of the industrial Prototypes – mainly the partners Stadtwerke Hartberg, EPFL and Spitzer have performed preparatory work on the deliverable by using results from WORK PACKAGE 2.
- D5.2 All permits and execution statements collected - mainly the partner Stadtwerke Hartberg, has prepared relevant papers for the local authorities.
- D5.3: Procurement documents released – not started yet.
- D5.4 Quality assurance protocol completed – not started yet.

The main outcomes of **WORK PACKAGE 6, the** Engineering of industrial prototypes for STOR-E units are:

- D6.1: Preparation of common reporting format and data collection – based on experiences with the SOLUTION project iC CES has performed preparatory work on the deliverable.
- D6.2: Evaluation report on the degree and quality of integration - not started yet.
- D6.3: Summary report on monitoring and presentation of results as well as benefits versus costs from demonstrators on a dissemination workshop – all partners (except Spitzer) have joined the final meeting organised in form of an internal workshop for discussing all relevant project results and draw some lessons learnt.

4 Ergebnisse und Schlussfolgerungen

Energy storage has a pivotal role to play in the effort to combine a sustainable energy supply with the standard of technical services and products. Energy storage is of growing importance as it enables the smoothing of transient and/or intermittent loads, and down-sizing of base-load capacity with substantial potential for energy and cost savings. In order to bring significant improvements in the foreseen extended supply of renewable energy compressed air energy storage (CAES) is one promising enabling option, which can tackle capacity ranges from a few kW to some hundreds of kW or in other words cover electricity needs from individual end-users and load groups through electrification processes with isolated grids towards interconnection networks. Load balancing and peak shaving are of importance for the extended utilisation of local potential renewable energy sources. Innovative and cost-effective electricity storage units are therefore concrete responses to mentioned challenges and related main project outcomes are highlighted thereafter:

● *Identification and mapping of three selected case study applications - Corresponding grid integration requirements have been analysed for all reference scenarios and are listed in the deliverables mentioned in section 3*.

● *Matlab/Simulink simulations on optimised case study dimensioning & integration -the Matlab/Simulink tool has been used to analyse the suitability of possible applications at three demo-sites în the municipality Hartberg (i) Gaugl Metallhandel GmbH, Tiefenbach ii) Ökopark Office Building, Hartberg and iii) Frutura Obst & Gemüse Kompetenzzentrum GmbH, Hartl in Hartberg. Ökopark Office Building has been selected as promising facility.*

● *Overcoming mayor technical challenges of envisaged prototype underpinned by labtests - there is a delay of about 2.5 years with respect to the originally planned deployment of this innovative technology.*

● *Analysis results of promising ways towards industrialization - the exploitation plan follows consequently the "Integrated resource efficient process optimisation across the entire industrial value chain".*

● *Economic analysis report and expected application potential Ecological perspective, advantages, disadvantages compared with competitive technologies – in order for overcoming limiting factors up-to-date analytical tools as been introduced needed to unlock the door to the solution of frontier fundamental/technological issues.*

Conclusions – The laboratory prototype of the electricity story HyPES is partly working at EPFL, and the first pilot system will be operational in Switzerland probably by the end of 2013. There is a delay of more than 2 years with respect to the originally planned deployment of this innovative technology. The state of development has been discussed with communal authorities and concluded that the HyPES technology is still at RTD level and not for demonstration as no prototype has been tested in the field yet. STOR-E may have `under- performed' to date as the prototype of liquid piston solution couldn't be brought up to pre-industrial state yet, but there are good reasons for this. There is a realistic prospect that the project could be brought to a successful conclusion if financial constraints ease and the project is extended beyond its original end date of July 2013. It is too early to draw final conclusions on the performance of the technologies, but the work done so far has not thrown up any insuperable technical issues. The problem for STOR-E has not been with technologies per se, but with the failure to implement them as intended, and this has been for non-technical reasons, such as the financial crisis with major impact on investments in projects like HyPES[1].

[1] HyPES – Hydro Pneumatic Energy Storage

5 Ausblick und Empfehlungen

The general design of the HyPES system and the related energy planning and balances are strongly dependent of the type of application. However, the main structure for a grid-connected photovoltaic power application involving this storage solution is illustrated in Figure 5.

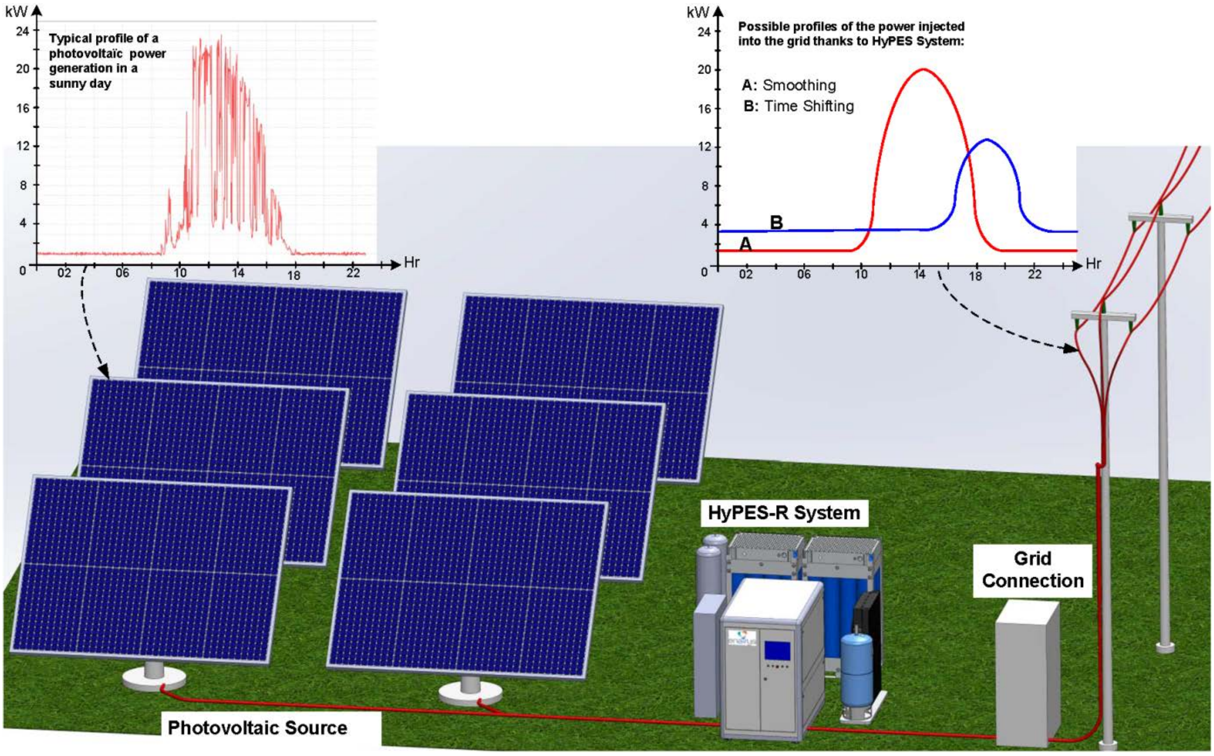

Figure 5 Illustration of the pilot installation for clean, photovoltaic power smoothing and management using HyPES system.

Selected results in the following may highlight achieved main outcomes of the STOR-E project:

1. Identification and mapping of three selected case study applications - by referring to the three reference implementation scenarios analysed in the deliverable D2.1: Report on power requirement, namely ● industrial/commercial: Energy & demand side management ● Photovoltaics: Balancing of on-site power and consumption ● wind power: Optimization of grid feed-in possible construction sites were identified representing the scenarios “Photovoltaics – balancing of on-site power and demand”.
2. The EPFL simulation tool for the mechanical displacement, for the thermal evolution and transfer, as well as for the fluid mechanics and thermodynamic evolution has been extended by Matlab/Simulink of 4E performing analyses on the suitability of possible renewable <-> HyPES sites in STOR-E. The mathematical basis used to develop this Matlab/Simulink tool is described in the schematic diagrams and specification of the model within the deliverables of WORK

PACKAGE 2. The simulation results respectively the Matlab/Simulink model will be used for storage applications beyond the project end.

3. Overcoming main technical challenges of envisaged prototype underpinned by labtests - Due to the use of environmental benign water (instead of usually utilised oil) it was time consuming to identify the engineering company with experiences able to design accurately the liquid piston part. Another challenge is related to the constant speed of the piston by variable flow volume of the water (similar e.g. to Kaplan turbines). In order to guarantee it water level control measurements under high pressure of 200 bars are foreseen and a solution could be found. The heat exchanger design has been leaking and challenges with brazing processes have been investigated for future manufacturing. A design with a three-standard-profile has been proposed as interim solution for the prototypes to be replaced by an optimum component at a later commercialisation stage.
4. Analysis results of promising ways towards industrialization – several ways regarding the industrialization and manufacturing of the HyPES System have been discussed mainly with potential investors and incubation consultants[2]. Thereafter it has been declared that manufacturing efficiency and quality will be more and more challenged by the design of products and/or services that have both unique performances and an optimal life cycle costs (including recycling at product end of life). With the two aspects the whole process follows sustainability criteria whilst becomes more economic. At least the latter might be achievable if the exploitation plan follows consequently the “Integrated resource efficient process optimisation across the entire industrial value chain”[3].
5. Economic analysis report and expected application potential ecological perspective, advantages, disadvantages compared to lead acid battery. The results of the economic simulation are presented in the deliverables of WORK PACKAGE 4 and show comparative the energy flow of the system with and without a storage system. The energy cost and revenues as well as the net usage charges are compared and earnings respectively losses are shown. The presented model can be used to optimize the size of the alternative energy production, the size of the storage system and to compare different storage systems. By varying the different parameters of the model the most economical combination of parameter values can be evaluated. Comparing the two storage technologies, HyPES and lead-acid batteries reveals that the environmental impacts are similar in three of eleven impact categories; these are: Global Warming Potential, Eutrophication Potential and Abiotic Depletion fossil and other seven at least of similar order. The significant higher acidification potentials of the batteries are mainly caused by the necessary lead.

6 Literaturverzeichnis

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[2] Greenovate! Europe E.E.I.G.: Summary Paper of “Resource Efficiency Potentials of Manufacturing Industries”, A comparison of resource saving potentials of single companies vs manufacturing value chains, Brussels, February 2013

7 Kontaktdaten

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