A Uniform Techno-Economic and Environmental Assessment for Electrical and Thermal Storage in Switzerland

Scope of project

The aims of the task «Integrated Assessment of Storage» are to develop a uniform techno-economic, environmental and social assessment method for electrical and thermal storage and apply this method to different energy storage technologies and applications. This report describes the work undertaken at the University of Geneva (UniGE), at Paul Scherrer Institute (PSI) and at Hochschule Luzern (HSLU) in 2015. UniGE and HSLU focus on techno-economic assessment and PSI performs environmental assessments applying life cycle assessment (LCA). All institutions contribute as a team to the development and assessment of different energy storage (ES) technologies and applications.

Status of project and main scientific results of workgroups

The research in progress and related outputs refer to the analysis of different ES technologies for the Swiss Energy transition.

Techno-economic and environmental assessments of power-to-gas (P2G) systems

Power-to-gas systems generating hydrogen and/or methane can be used for linking the heat and mobility sectors, which are traditionally high carbon intense, with renewable energy supply. P2G systems can act as ES by counterbalancing intermittent electricity generation and energy demand. A thorough analysis of the implications of operating P2G systems considering various boundary conditions is key for understanding the performance, economic and environmental benefits of P2G plants.

We quantify both economic and environmental impacts of power-to-gas systems using a dynamic power-to-gas model. The proposed methodology assumes that power-to-gas systems participate in the Swiss wholesale electricity market and considers four services in addition to low carbon gas generation. These saleable services offer potential revenue streams which can considerably improve the economic viability. Both techno-economic and life cycle assessments are utilized to determine key performance indicators, namely system energy consumption, levelised cost, greenhouse gas emissions and further environmental indicators.

As shown in Figure 1, the modelling results indicate that technical and economic benefits increase with the electrolyser rating but those improvements are more substantial for systems on the kW scale while levelling off for larger systems

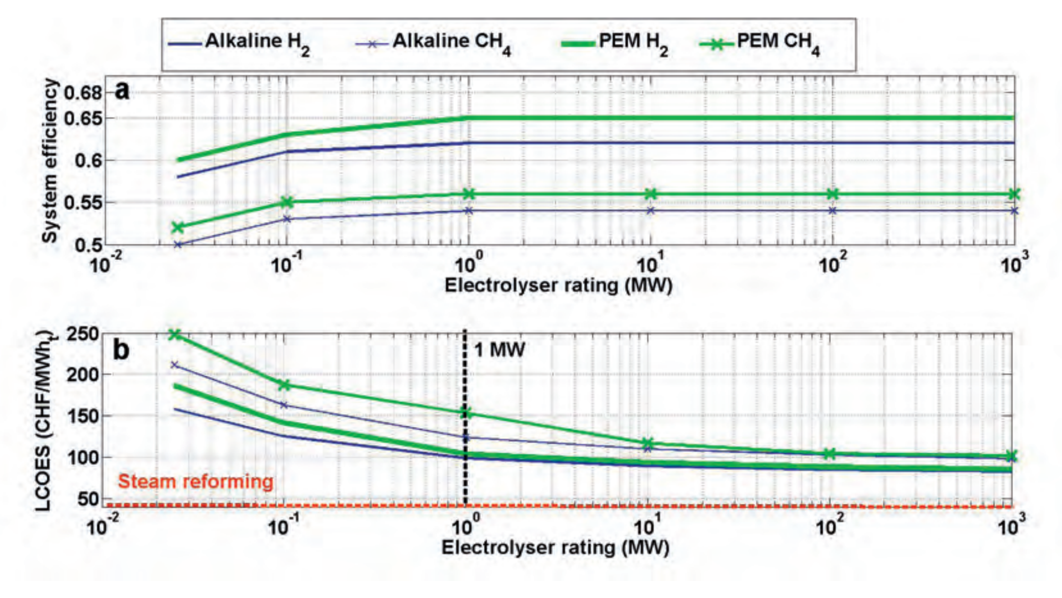

Figure 1:

(a) life cycle system efficiency and (b) levelised cost (CHF/MWht) as a function of the electrolyser rating for P2H and P2M depending on the electrolyser technology (alkaline and PEM). The horizontal axis is represented in logarithmic scale. The discount rate was assumed to be equal to 8 %.

List of abbreviations

CAES	Compressed Air Energy Storage
CES	Community Energy Storage
ES	Energy Storage
GHG	Greenhouse Gas
IRR	Internal Rate of Return
LCA	Life Cycle Assessment
Li-ion	Lithium-Ion
MCDA	Multi-Criteria Decision Analysis
P2G	Power-to-Gas
PbA	Lead-Acid
PEM	Proton-Exchange Membrane
PV	Photovoltaics
RE	Renewable Energy

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(MW scale). Besides, higher capacity factors (by approximately 11 %) are needed for proton-exchange membrane (PEM) electrolysers compared to alkaline electrolysers in order to minimise the levelised cost.

LCA shows that potential mitigation of greenhouse gas (GHG) emissions by using P2G mainly depends on the type of electricity generation and the source of CO_2. Additionally, the methodological approach for dealing with CO_2 capture and supply in LCA is important – system expansion is recommended (Figure 2).

Techno-economic assessment of battery storage for single home photovoltaics (PV) units and demand management

The use of batteries in combination with PV systems in single homes is expected to become a widely applied energy storage solution. Since PV system cost is decreasing and the electricity market is constantly evolving there is marked interest in understanding the performance and economic benefits of adding battery systems to PV generation under different retail tariffs. The performance of lead-acid (PbA) and lithium-ion (Li-ion) battery systems in combination with 3 kWp PV generation (standard size) for a single home in Switzerland is studied using a time-dependant analysis. The performance and economic benefits are analysed as a function of the battery capacity, from 2 kWh to 20 kWh. Firstly, the economic benefits of the two battery types are analysed for three different types of tariffs, namely a dynamic tariff based on the wholesale market (one price per hour for every day of the year), a flat rate and a time-of-use tariff with two periods. Secondly, the reduction of battery capacity and annual discharge throughout the battery lifetime are simulated for PbA and Li-ion batteries. It was found that although the levelised value of battery systems reaches up to 28 % higher values with the dynamic tariff compared to the flat rate tariff, the levelised cost increases by 94 % for the dynamic tariff, resulting in lower profitability. The main reason for this is the reduction of the number of equivalent full cycles performed with by battery systems with the dynamic tariff. Economic benefits also depend on the regulatory context and Li-ion battery systems achieved an internal rate of return (IRR) up to 0.8 % and 4.3 % in the region of Jura (Switzerland) and Germany due to higher retail electricity prices (0.25 CHF/kWh and 0.35 CHF/kWh respectively) compared to Geneva (0.22 CHF/kWh) where the maximum IRR was equal to –0.2 %. This latter result is shown in Figure 3.

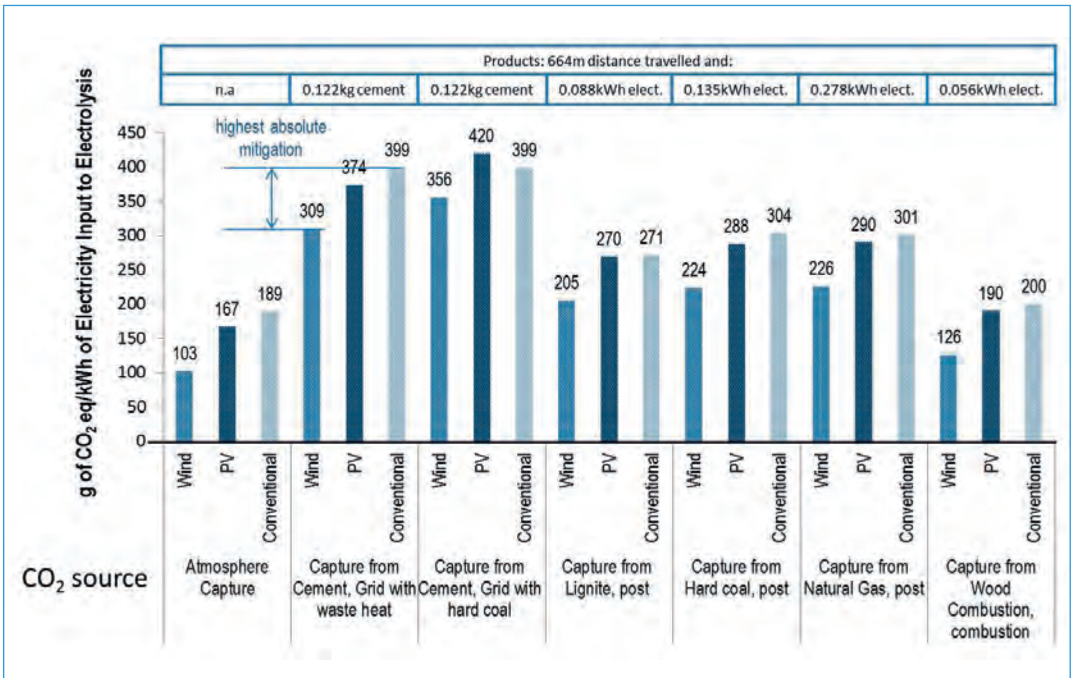

Figure 2:

Life cycle GHG emissions from P2G systems using wind or PV electricity for electrolysis and different sources of CO2. The synthetic natural gas is used for driving a passenger vehicle. System expansion approach applied for CO2 capture. The functional unit 1 kWh of electricity corresponds to 664 m, i.e. the distance one can drive with the amount of synthetic natural gas generated by 1 kWh of electricity input to electrolysis.

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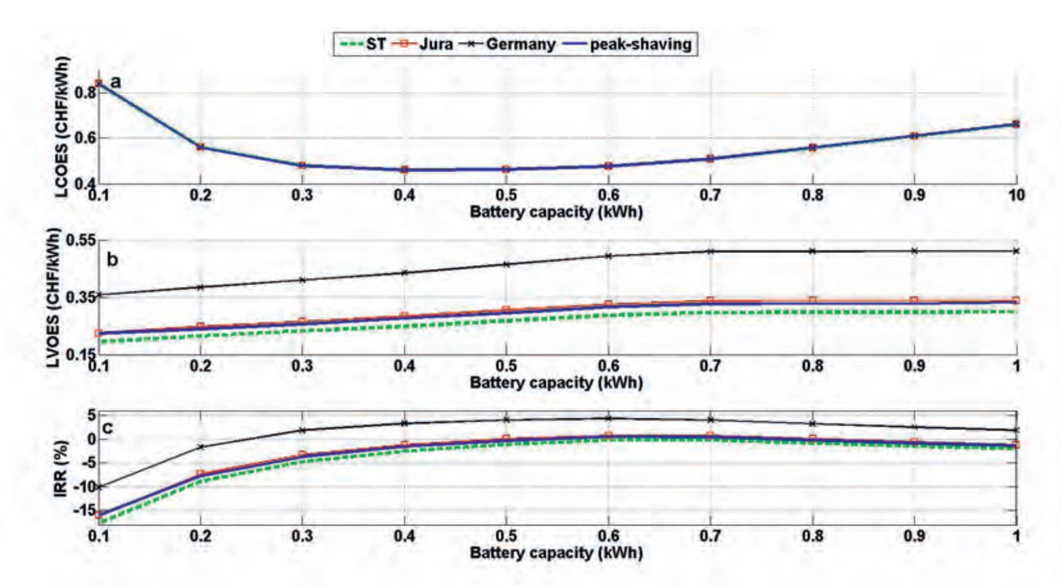

Figure 3:

(a) Levelised cost of energy storage LCOES[i] (CHF/kWh),

(b) levelised value of ES LVOES[ii] (CFH/kWh) and

(c) internal rate of return IRR[iii] (%) for Li-ion batteries performing PV energy time-shift for three alternative scenarios in addition to the reference case for Geneva (Switzerland). The discount rate was assumed to be equal to 4 %.

[i] The levelised cost has been widely utilized as a measure of the overall competiveness of different generating technologies but the concept has also been extended to ES. The levelised cost of ES, LCOES (CHF/kWh), represents the total present cost (CHF) associated the battery discharge (kWh), i.e. including capital and operational expenditures.

[ii] The levelised value of ES (CHF/kWh) is used to quantify the profit associated with the battery discharge based on a life cycle approach i.e. accounting for the evolution of energy prices, battery ageing, etc.

[iii] The internal rate of return, IRR (%), is the discount rate which balances the different annualized cash flows (both expenses and profits) associated with the battery investment. If the LVOES is higher than the LCOES, the IRR is higher than the assumed discount rate r (%).

Assessment of energy storage technologies for different storage time scales

The objective of this analysis is to benchmark large scale electricity storage systems for different time scales corresponding to different applications. The methodology applied considers the technical, economic and environmental performance of storage and includes multi-criteria decision analysis (MCDA) as an integrated assessment approach. Specifically, pumped hydro storage, compressed air energy storage (CAES), battery and power-to-gas are compared for different storage time scales corresponding to short-, medium- and long-term (seasonal) storage. The criteria matrix in MCDA will include the levelised cost of stored energy as indicator for the economic performance, while life cycle GHG emissions, acidification, particular matter, etc. will represent the environmental performance. Life cycle assessment is applied as the methodology for environmental assessment. To consolidate the results, a sensitivity analysis is carried out investigating uncertainties in terms of technology and environmental performance as well as costs. Based on the results, conclusions on the performance of the considered storage technologies for different time scales are drawn. A sample result of cost comparison is shown in Figure 4. It is shown that the operational cycle of the energy storage is an important differentiating factor with regards to the applicability of different technologies.

A review of community energy storage (CES)

The energy system is experiencing an energy transition in which both renewable energy (RE) and energy storage (ES) technologies are expected to contribute to assure a decarbonised and affordable energy supply. Given the modularity of RE technologies and their increasing penetration in the consumption centres, there is increasing interest for ES located very close to consumers which is able to raise the amount of local RE generation consumed on site, provides demand side flexibility and helps to decarbonise both the heating and transport sectors. We are in progress performing a holistic review of community energy storage (CES) in order to understand its potential role and challenges as a key element within the wider energy system. Some novel aspects included in this review are the analysis of the whole spectrum of applications and technologies which can serve as CES systems with a strong emphasis on end user applications; a multidisciplinary assessment of CES including techno-economic, environmental and social analyses; and the review of the CES outlook from a customer, utility company and policy maker perspective. Some interesting findings of this review are: CES can be more effective in (dynamically) balancing local supply and demand than ES located in the distribution system as well as more cost-effective than ES located in single dwellings; PbA

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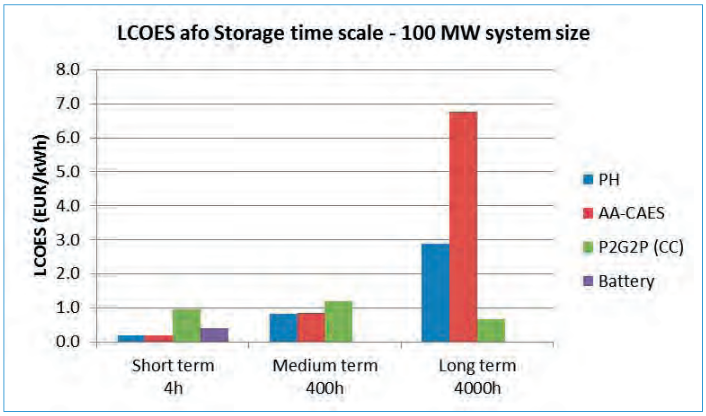

Figure 4: Levelised cost of energy storage LCOES (CHF/kWh) for pumped-hydro (PH), compressed air (AA-CAES), hydrogen (P2G2P) and battery storage depending on the time scale.

batteries are more competitive at the moment than Li-ion batteries for demand load shifting (battery capacity sized according to peak demands loads) while Li-ion batteries are more competitive for PV energy time-shift (battery capacity sized according to surplus PV generation); and the community approach serves as a catalysis for implementing RE technologies, energy efficiency in addition to ES technologies, i.e. grass-root initiatives involving the community members.

Analysis of the impact of the penetration of renewable energy and low carbon technologies in distribution grids

This an ongoing collaboration with the SCCER-FURIES (ZHAW and EPFL). Given the expected penetration of PV energy, wind energy and other low carbon technologies in the context of the Swiss energy transition, this collaboration aims at analysing different technological options from a techno-economic point of view.

The first study investigates

- the techno-economic benefits of battery storage systems on distribution grids with high penetration of PV respect to its size and location in the network; and
- how battery storage systems compare with PV curtailment.

Specifically, batteries installed next to the PV systems (i.e. individual dwellings) are compared with a single large battery installed next to the distribution transformer from cost and value perspectives.