A Constructive Technology Assessment of Stationary Energy Storage Systems
- A prospective Sustainability Analysis with the focus on electrochemical storage systems –

Manuel Baumann
1. Introduction

- Bachelors degree “European energy economics”
- Masters degree in "Energy and ecologic management"
- since 2012 Research associate at ITAS

Field of work:

- Mobile and stationary electro chemical storage systems
- Description of real condition requirements during operation phase
- Creation of technical and economical scenarios for energy storage systems
1. Introduction: Supervisors

- Principle supervisor: Dr.-Ing. Marcel Weil

- Second supervisor: Prof. Dr. Antonio Moniz

- Me

Phd Thesis
1. Introduction: Formal frame

- Organisational Structure:
  - Helmholtz project „stationary and mobile electrochemical Energy Storage“
  - Related Institutions within the project: KIT, RWTH Aachen, DLR…..
  - Related Institutions within the Thesis: UNL – FCT, KIT-ITAS
Phd-Thesis

Problem Definition

Classification

In & Outputs
Problem Definition

Classification

Energy storage

Renewable Energy Sources

110/380 kV

10/30 kV

230/400 V

Decentralized Energy Sources

Pumped Hydro Power

Power Plants

Renewable Energy Sources

Industry

Energy storage

Inv. Power flow

V2G

Energy storage

Decentralized Energy Sources

Electric vehicles

Source: Own figure inspired by Tomic et. al 2005
Problem Definition

Classification

Fluctuating Energy Sources Integration

~50 Hz

Transmissions & Distribution deferral

Dramatic example

Generation Demand

Ancillary services provision

Dipl. Ing. Manuel Baumann

Energy Storage

End user storage

Decentralized energy generation storage

Energy Storage
Different possibilities of Energy Storage:
- Mechanical (pumped hydro storage, CAES ……)
- Electrochemical (batteries…)
- Chemical (hydrogen, wind gas…..)
- Thermal (molten salt, ice storage…..)
- Electro static (capacitors, SMES….)

Focus: electrochemical Energy Storage
- Don´t require specific geologic and orographic conditions less landscape concerns
- Especially interesting for low to middle voltage areas
- ……
Electrochemical Energy Storage Technologies
Example A: Sodium Sulfur Battery

- Already commercially used for Grid applications

- High energy density
- Acceptable Efficiency grades (~ 80 %)
- High cycle stability
- Calendaric life time
- Good cost performance
- High self discharge grades
- Poor power density
- Thermal management system + insulation
High Power Performance

Specific Energy [Wh/kg]

Specific Power [W/kg]

Optimum

Pb
NiCd
NiZn
NIMH
NaNiCl
ZnBr
Li Ion
Zn - Air
Ultracapacitor

High Capacity (amount of stored energy)
Global Environment

Economic process

Policy

Energy system

People Assets

Energy Storage?

Ren. En.

Resources

Raw fuels

Global Environment

Local env.

Energy system

Technology

Regional Environment

Global Environment

Decision making & Technology development

Own figure inspired by Wang et al. 2009
It is insufficient to exclusively look at the operation phase to assess a complex technology (Grunwald et al. 2002)

Can lead to misleading interpretations which can disregard social or ecological impact factors over the whole life cycle of a technology
With an life cycle thinking

Sustainability: a balance of social and economic activities as well as the environment (Wang et al. 2009)
Classification and aim
Is this a Technology Assessment (TA) Problem?

- TA : „scientific and communicative contribution to solve technological related societal problems“ (Grunwald, A. 2002)

- Develop aggregated reports for decision makers about the actual level of knowledge and abilities regarding potential impacts (Grunwald, A. et al. 1999)
Constructive TA*:

- “Constructive” TA is based on a seamless web of related highly heterogenic factors which also underlie dynamic new switch stands (Grunwald, A. et al. 1999)

- Expectation of minimizing mismatches, wrong investments, possible social conflicts, and environmental impacts of a new technology in an early development stage (Shot & Rip, 1997)

- Assist rational decision making as well as development in energy system options, planning, management and economy for a sustainable development (Wang et al, 2009)

*Final classification of the work has to be worked out*
The academic question is……...

How to evaluate different energy storage technologies in a prospective manner with a full integrated sustainability approach to form a base for decision making?

Source: kommunikationsabc.de
Economic, tecnological and ecological comparison of (electrochemical)
Energy storage technologies based on a life cycle sustainability Analysis (LCSA) and multi criteria Analysis (or evaluation) (MCA)

Develop a new LCSA-MCA model through new combined highly interdisciplinary approach
1. Definition of the field of technology

2. Investigate actual state of development and further development requirements

3. Identify possible bottlenecks

4. Investigate future trends

5. Identify application fields & market potential

6. .....
- Develop an Energy Storage Technology database
- Relevant values based on literature and manufacturers
- Sources: Scopus, Science Direct, IEEEXplore, Interviews etc.
Definition of different application fields / system integration scenarios

Identify application fields of different Energy Storage technologies

**Application fields**
- Load Leveling,
- Ancillary services.....

**Reference**
- Resolution, time period specific cycles, probabilities......

**Source: Database Technology Characteristics**
- Cycle lifetime
- Charge and discharge duration
- Charging Parameters:
  - U(t), I(t), T(t)

**Benchmark:**
- (allow a comparison of a used battery with other battery types)
  - SOC(t), SOH(t), TCell(t) within one application field

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**Scenario A**

**Scenario B**

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**Scenario Building**
Technical Analysis
Economic analysis - LCC
Environmental impact analysis - LCA
Societal impacts
Based on comprehensive literature research (developed data base)
- Life Cycle Sustainability Assessment (LCSA)

LCSA = LCA + LCC + SLCA

LCSA  Life Cycle Sustainability Assessment
LCA   Environmental Life Cycle Assessment
LCC   LCA-type Life Cycle Costing
SLCA  Social Life Cycle Assessment
Life Cycle Assessment – LCA
Life Cycle Costing – LCC

Source: superinvest.de & adpic.de
Ecologic perspective to assess environmental aspects and potential impacts associated with a product regarding their complete life cycle (cradle-to-grave)

- Choice of right components or entire technologies
- Standardized methodology (ISO 14040)
- Techno-economic perspective to evaluate costs
- Similarity to LCA
- Dynamic investment calculations (Net Present Value method (NPV) Annuity….)
Can be very detailed, potentially expensive and time consuming

Huge amount of Data required (equal production process etc.)

How reliable is my database and is there even data available?

………

High amount of uncertainties & many assumptions!
- Deterministic methods (LCA+LCC)
  - Different scenarios equal best, worst and base case
  - To show possible spreads of an performance/result and future developments.

![Diagram showing Energy Storage Technologies and results categories](image)

- LCSA
  - Economic analysis-LCC
  - Environmental impact analysis - LCA
  - Societal impacts SLCA

Hopefully here?

Results!?

So my result will be.....?
- Probabilistic methods to assure deterministic approach
- Monte Carlo Simulation (numerical solution of mathematical problems)
- Create adequate number of simulations

There will be probability Y that the technology C will be „awesome“ to „good“ regarding performance X (e.g. Results will be mean, median, percentiles …)
- Again: Adequate amount of data is required

- When there is not enough data, adequate assumptions have to be done

- Command variables, input values and related distribution functions as well as connecting functions have to be known

**Rubbish in, rubbish out……**
Social Life Cycle Assessment - SLCA

Source: carokee.net
The societal perspective for e.g. reaction of residents, local added value or contribution to regional development etc. (Zschieschang, 2012)

Important criteria for peoples acceptance of energy systems (Wang et al, 2009)

- Base for political, legislative and administrative framework
- Tendency of institutional actors, policy of public information

High similarity to LCA (yet some differences)

Mainly qualitative and only partially quantitative approach possible
There is no really standard to make a SLCA

SLCA is/was rarely used for the energy sector
- Only a few studies (e.g. Gallego et al. 2009 & 2010, Oberschmidt 2010)

Which impact categories to include in the assessment and how to measure these?
- Interviews with decision makers and stakeholders?

How to weight a social criteria?
- Subjective, objective or combined?

Perception of social impacts is very variable
- Equal vagueness of human feelings and recognitions (Wang et al. 2009)
Difficult approach

No possibility to cope with uncertainties

Methodology/approach not clear yet

Develop a complex equation to solve problem:

Engineer + SLCA =

Source: philosophiesofmen.blogspot.com
LCSA – Results?
Results Technology A1 vs. Technology A2 within application X

LCA - Ecology

A1
- GWP
- NOx
- Acidification
- Toxicity
- Ressource depletion
- PM

A2
- GWP
- NOx
- Acidification
- Toxicity
- Ressource depletion
- PM

SLCA - Society

A1
- Local added value
- Health
- Safety
- Local employment

A2
- Local added value
- Health
- Safety
- Local employment

LCC - Economy

A1
- O&M Costs
- Local employment

A2
- O&M Costs
- Local employment

How compare the alternatives?
multi-criteria evaluation or analysis (MCA) to consolidate different category dimensions for one evaluation scale

Suitable to address complex problems with high uncertainty

- Identify adequate weighting methods
- Identify proper multi-criteria decision analysis or evaluation methods
- What criteria are even relevant from a stakeholders view?
- How aggregate them?

methods most suitable to solve the problem?
Example for a multi criteria evaluation of different storage technologies

Equal weight (only techno-economic factors)

Comparison of different battery systems regarding technological aspects, without consideration of a specific application field and weighting system. (Weil, M.; Decker, M.; Fleischer, M.; Frankenberg, A. 2011)
Phd-Thesis

Model & Simulation

LCSA

I

Problem Definition
Classification

Technical Analysis
Scenario development

Economic analysis-LCC

Environmental impact analysis - LCA
Societal impacts

Multi-criteria analysis

Decision Making & Technology Development Support

II

III

IV

In & Outputs

I

II

III

IV

In & Outputs

I

II

III

IV

In & Outputs
- **Technical:** usability regarding different application fields
- **Economical (LCC):** Costs of storage in €/kWh
- **Environmental (simplified LCA):** Env. impact factors
- **Societal (SLCA):** Impacts on society
- **Total (multi-criteria analysis):** Evaluation and comparison

Form a base for decision making

Complex, new approach.
„Some“ Academic Claims

? Will this highly interdisciplinary approach work?

? Normativity of chosen criteria (consensus about economic and societal criteria within society)?

? Is the approach to complex?

? Multi-criteria weighting regarding the relevance?

? Is their data available?

? How cope with uncertainties?

? Trade offs (grade of detail)?

! Not enough space……….!
## Proposed Timetable

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<th>No.</th>
<th>Working packages</th>
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Muito Obrigado!
Perguntas?


