Economics of Energy Storage Technologies - Implications for policy makers and deployment support

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Frontiers in Energy Research Seminar, ETH Zürich

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PhD overview

Research question

How can policy makers support the diffusion of multi-purpose technologies effectively (to induce innovation) and efficiently (at minimal economic costs)?
– The case of energy storage technologies

Methods

- Probabilistic techno-economic modeling storage technologies and applications
- Regression analyses of patent data
- Literature review
- Expert interviews

Theory

- Energy economics
- Innovation economics

Opening comments

1. The presentation strives to provide a **synthesis of 3 academic essays and 1 report,** thus it does not follow the standard procedure of a focused academic presentation

2. These results can be framed in different perspectives (Investor, Technology provider, Utility,…) – typically and **today I assume a policy makers perspective**

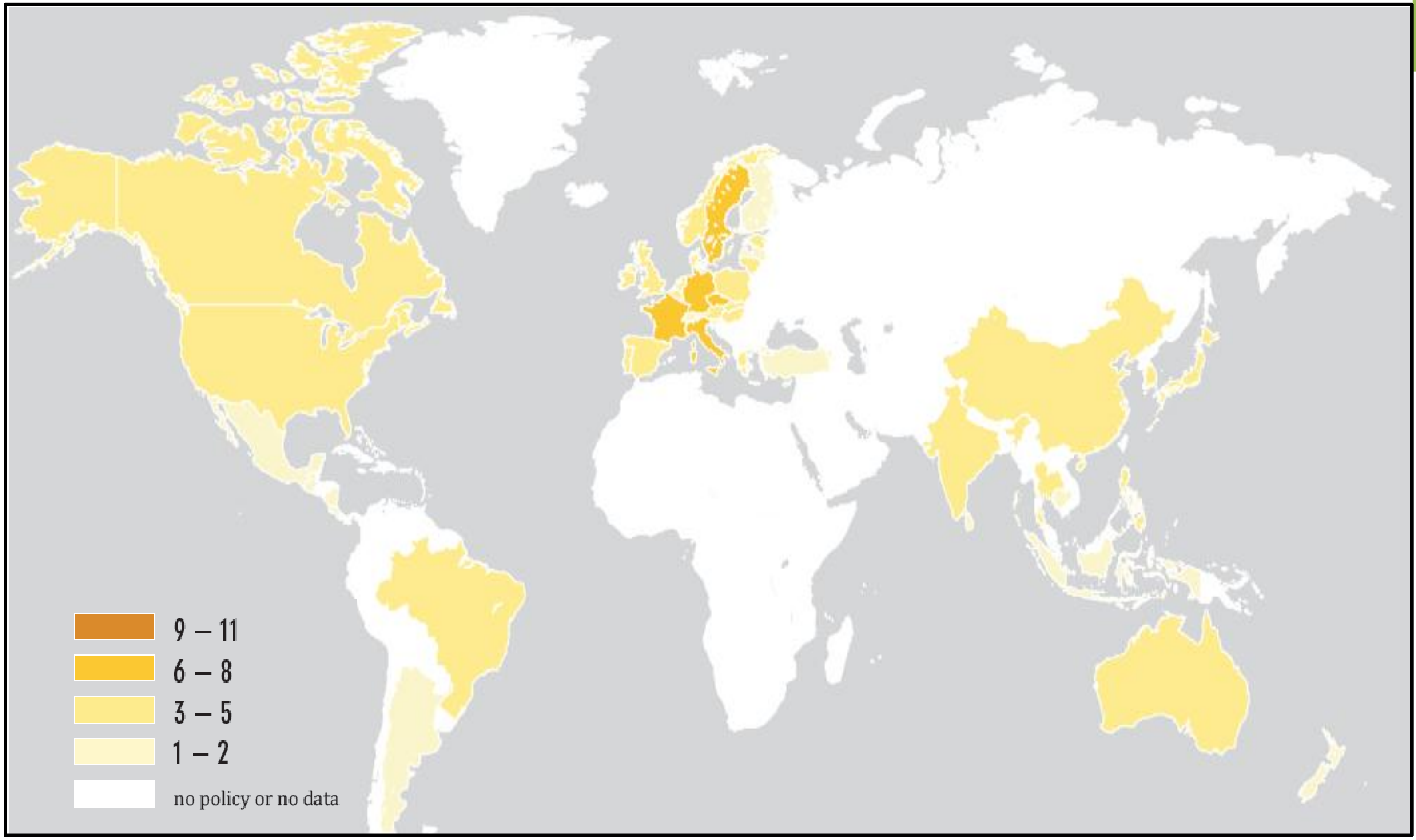
3. Although this presentation addresses the question how to support storage technologies, **no recommendation shall be made whether it is desirable or not for governments to support storage**

Agenda

- **Intro: The key difference between storage and renewables: Multiple applications**
- Analyses: How to choose which storage application to support
- Assessment example and conclusion

In the recent years, support schemes for renewables have been introduced in many countries in the world

Number of renewables support policies by country



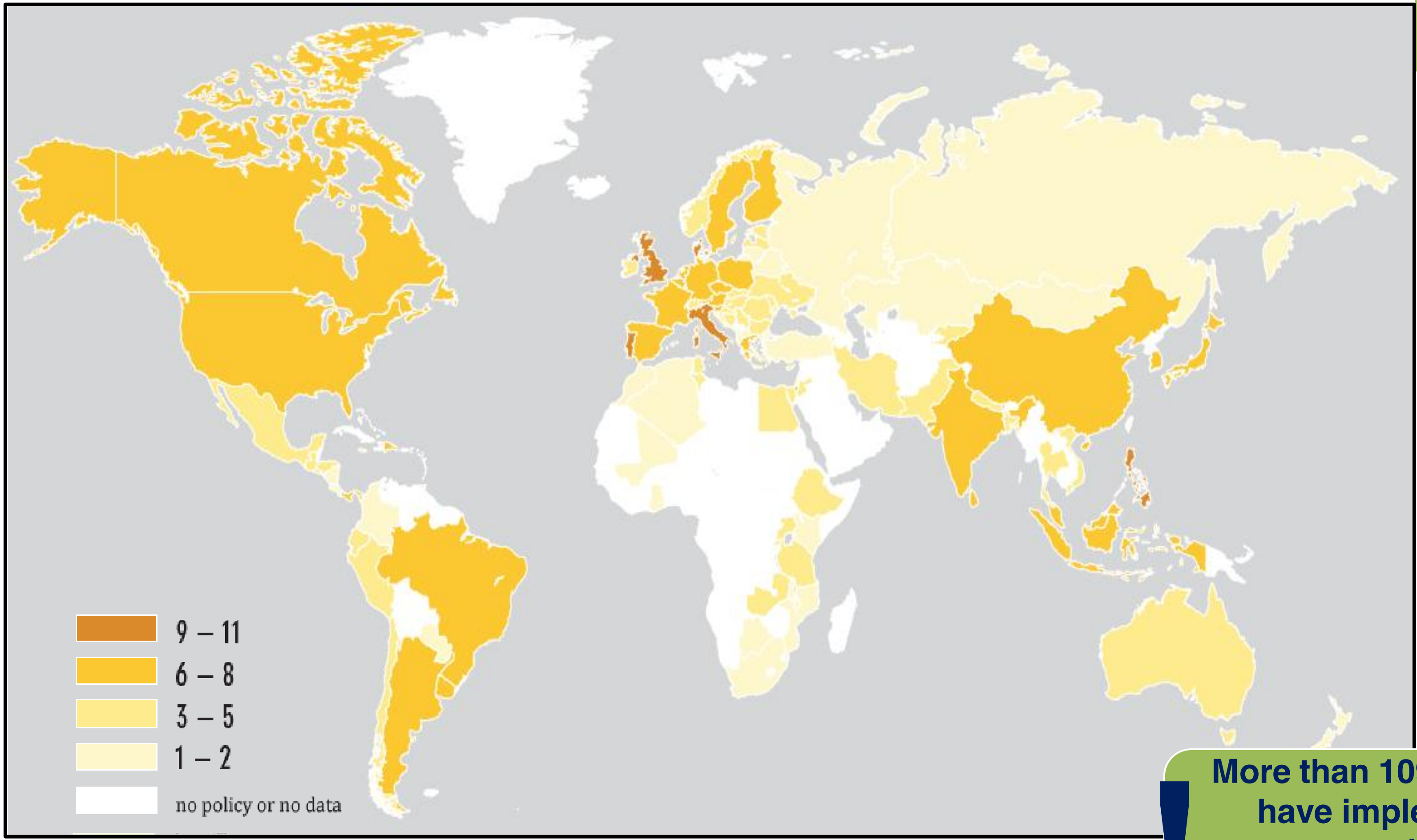
2005

SOURCE: REN21 – Global Renewable Status Report, 2011

In the recent years, support schemes for renewables have been introduced in many countries in the world

Number of renewables support policies by country

2011



! More than 109 countries have implemented support schemes for renewables

SOURCE: REN21 – Global Renewable Status Report, 2011

Also for storage, governments around the world have or are about to introduce market support schemes

Motivation

- Increasing renewable penetration
- Need for “flexibility resources”
- Difficulty of expanding grid transmission capacity
- Industrial policy

Examples of regulation supporting storage

- Support schemes of **federal** (FERC, DOE,..), **national** (NERC), **ISO** (PJM, CAISO,..) and **state layer** (New York, California,..)

- **Specific regulation** for energy storage at **least in 7 countries**
- **Ongoing discussion** in almost any country

- Besides research and demonstration projects, **no explicit support schemes**
- However, driven by ambitious targets for renewables, **storage regulation and targets are expected to be introduced**

- Indian policy makers are explicitly **“encouraging”** the construction of storage facilities

! Policy makers will leverage their experience made with renewables

SOURCE: IEA, European Commission, U.S. Department of Energy, Greentechmedia, Expert interview

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However, storage and renewables are fundamentally different

RENEWABLES

- Clear characteristics as **Generation** device consistent with existing regulatory framework
- **1** source of economic value creation **accessible by the operator**

Power generation

≠

STORAGE

- Hybrid device overlapping with **Generation**, **T&D Infrastructure**, and **Consumption** challenging existing regulation
- **4** different sources of economic value creation **distributed across stakeholder**

Power quality

Power reliability

Increased utilization of existing assets

Arbitrage

! Differently designed support schemes necessary

Specifically, 14 storage applications across the value chain emerge from these 4 sources of value creation

Value creation \ *Location along value chain*	*Generation*: Fossil	*Generation*: Renewable	*Transmission & Distribution*	*End-consumer*: Industrial	*End-consumer*: Private
Power quality		**RET Smoothing**	**Area & Frequency Regulation** **Support of Voltage Regulation**	**End-consumer Power Quality**	
Power reliability	**Black Start**		**Reserve Capacity**	**End-consumer Power Reliability**	
Increased utilization of existing assets	**Load Following**	**RET Firming**	**T&D Investment Deferral**	**Increase of Self-consumption**	
Arbitrage		**RET Arbitrage**	**Wholesale Arbitrage**	**End-consumer Arbitrage**	

! Policy makers have to choose which application to support

SOURCE: Battke, B., Schmidt, T.S., "Cost-efficient demand-pull policies for multi-purpose technologies – The case of stationary electricity storage", Under Review at Energy Economics (2013)

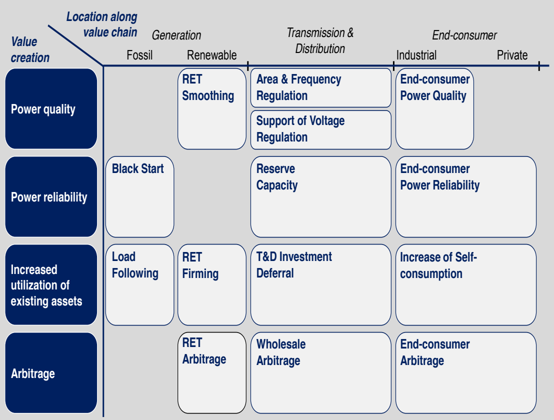
Contents

NOT EXHAUSTIVE

Policy makers can choose which storage application to support along several decision criteria

Detailed further on following slides

14 different storage applications



Decision criteria to choose an application to support

1. **Gap-to-profitability**
2. **Level of competition** between storage technologies
3. **Combinability** of applications
4. **Market size** of the application
5. **External effects** (e.g, impact on the environment or electricity system)
6. **Ease of implementation** / consistency with existing regulation

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1 GAP-TO-PROFITABILITY – SCOPE

7 different applications were assessed

Only costs assessment

Costs and profitability assessment

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SOURCE: Battke, B., Schmidt, T.S., "Cost-efficient demand-pull policies for multi-purpose technologies – The case of stationary electricity storage", Under Review at Energy Economics (2013)

1 GAP-TO-PROFITABILITY – METHODOLOGY

Techno-economic model for 4 different battery technologies

LITHIUM-ION | **LEAD-ACID** | **SODIUM-SULFUR** | **VANADIUM REDOX FLOW**

A — MODULE A: TECHNOLOGY COST CALCULATION

COST / TECHNOLOGY DATA

- Stochastic input parameters
  - Energy capacity costs
  - Roundtrip efficiency
  - Calendrical life
  - Cycle life[a]
- Deterministic input parameters
  - Power conversion system costs
  - Balance-of-plant costs
  - Operations & maintenance costs

PROFITABILITY CALCULATION

(LCOE; MONTE CARLO SIMULATION)

B — MODULE B: APPLICATION VALUE CALCULATION

BENEFIT / APPLICATION DATA

- Stochastic input parameters
  - Economic value[b]
  - Electricity price
- Deterministic input parameters
  - Required power rating
  - Required energy rating
  - Cycle frequency
  - Discharge duration
  - Discount rate

[a] Cycle life as function of average depth-of-discharge
[b] Based on market prices, costs of competing technologies or inherent value

SOURCE: Battke, B., Schmidt, T.S., "Cost-efficient demand-pull policies for multi-purpose technologies – The case of stationary electricity storage", Under Review at Energy Economics (2013)

1 GAP-TO-PROFITABILITY – METHODOLOGY

Costs of batteries were assessed using the levelized costs of electricity approach (LCOE)

$LCOE_{SA}$

Operating parameters

- System lifetime [years]
- Battery lifetime [years]
- Depth of discharge (DOD) [%]
- Cycles at DOD [# of cycles]

Investment costs

- Energy related costs [€/kWh]
- Power related costs [€/kW]
- Balance of plants costs [€/kW]
- Power conversion system [€/kW]

Losses

- System efficiency [%]
- Self-discharge [%/day]

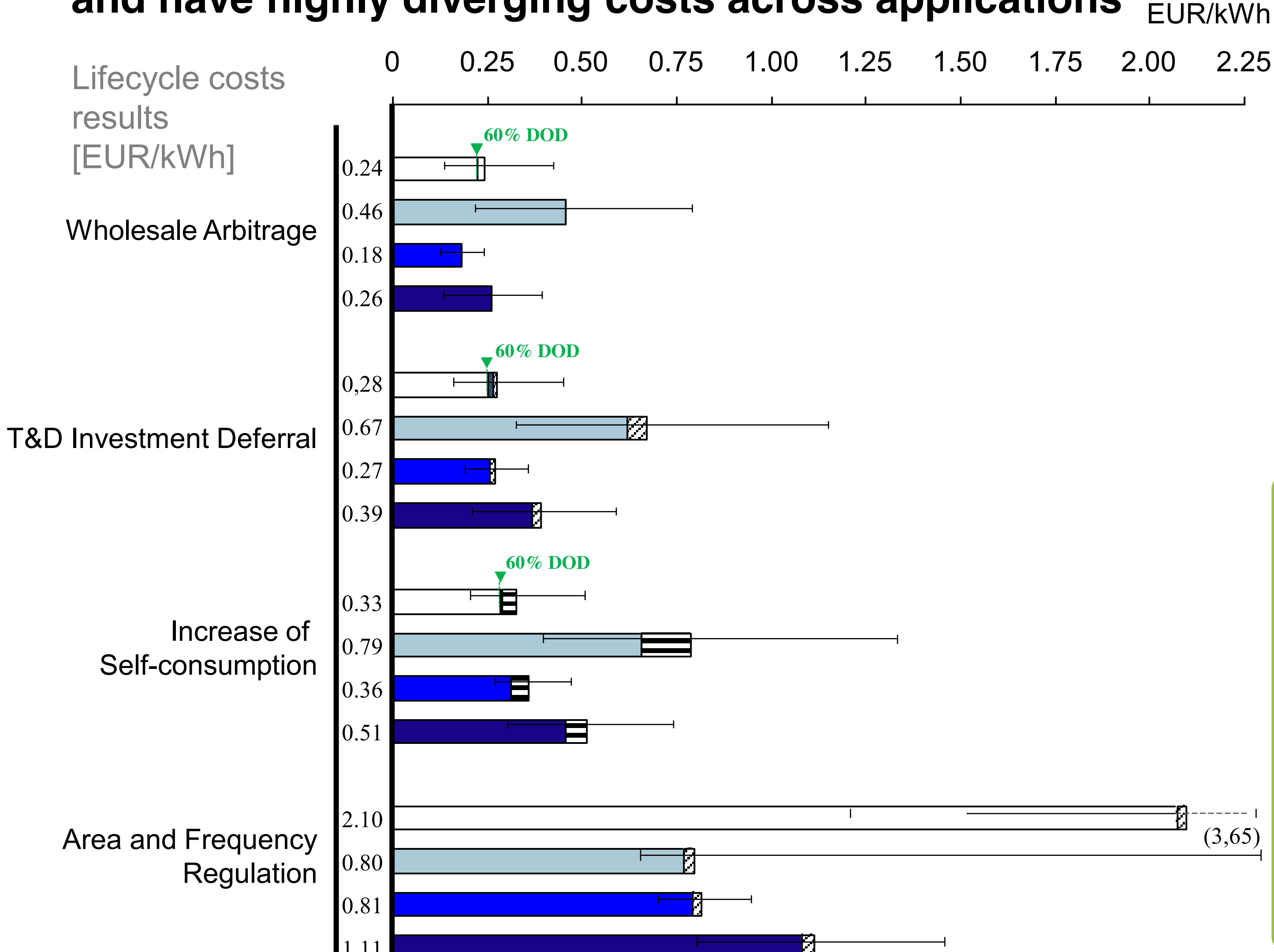
Operating costs

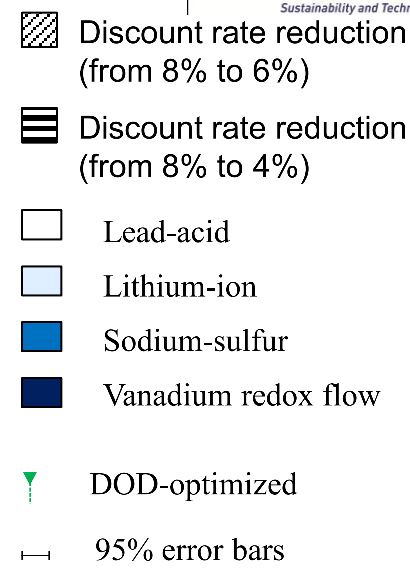
- Operations and maintenance costs [€/kW p.a.]
- Replacement costs [€/kWh]
- Discount rate [%]

$$\text{LCOE} = \frac{\sum_{n=0}^{N}\left(CAPEX + OPEX / (1+i)^{n}\right)}{\sum_{n=0}^{N}\left(kWh_{initial,net} * (1 - Degrade)^{n} / (1+i)^{n}\right)}$$

1 GAP-TO-PROFITABILITY – COSTS RESULTS

LCOE of batteries still exhibit a high degree of uncertainty, and have highly diverging costs across applications





- **Costs** vary significantly across technologies and applications
- **Ranking** of technologies differs by applications
- High level of **uncertainty** present in battery technologies – esp. for lithium-ion batteries

SOURCE: Battke, B., Schmidt, T.S., Grosspietsch, D., Hoffmann, V.H. "A review and probabilistic model of lifecycle costs of stationary batteries in multiple applications", Renewable and Sustainable Energy Reviews (2013)

1 GAP-TO-PROFITABILITY – METHODOLOGY

There is no price tag for the *value of storage applications*. The value can be estimated by a combination of market signals, cost of competing technologies and the intrinsic value.

Evaluation heuristic for storage applications

Evaluation of the economic value of an stationary electricity storage application based on…

1 ***Do price signals from markets or contracts exist for the application?***

Yes → **…price signals from markets or contracts for this application**

No ↓

2 ***Is inherent value of the application higher than the costs of the best non-storage technology?***

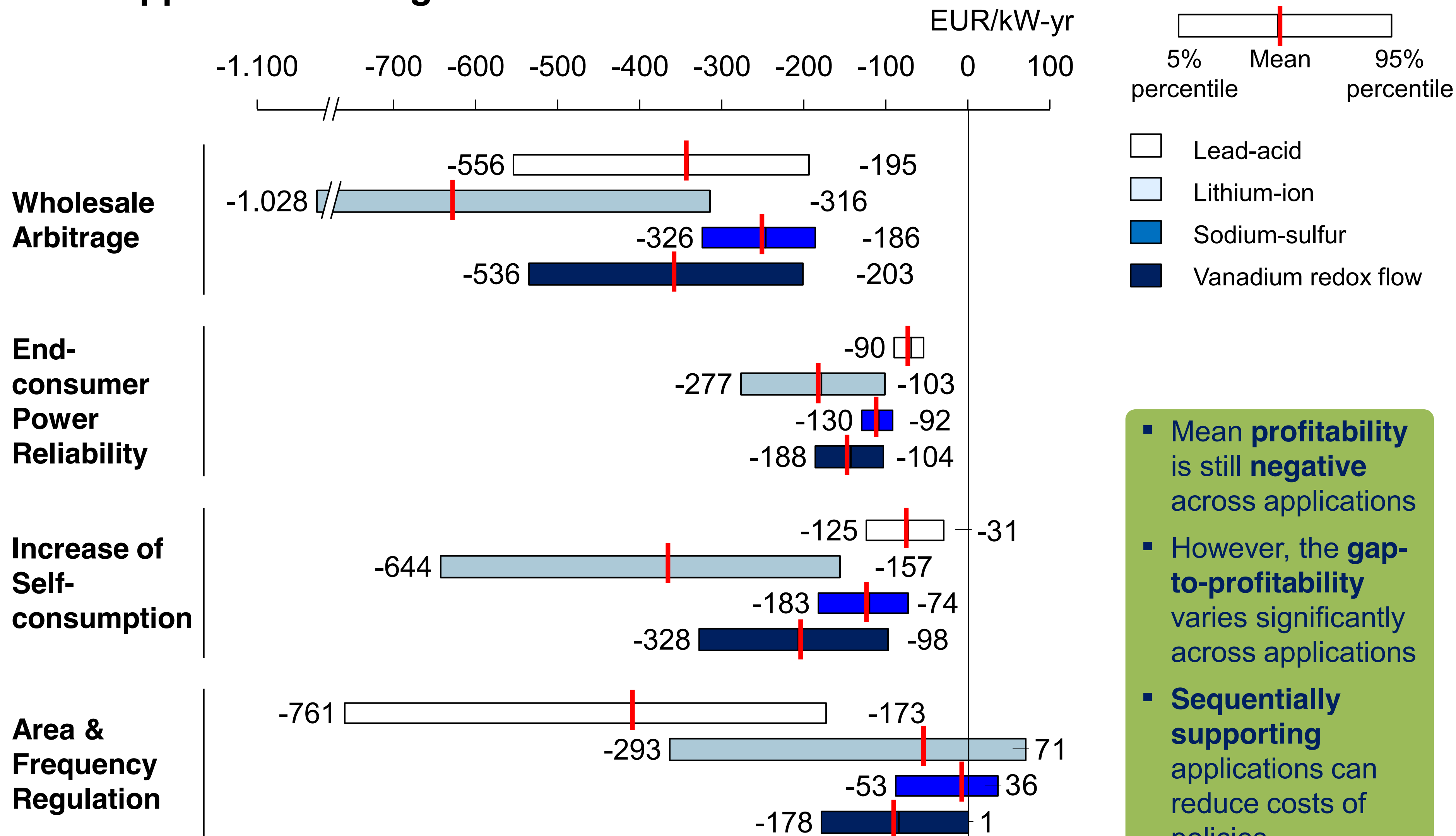
Yes → **…the costs of the best non-storage technology to fulfill the application**

No → **…the inherent value of this application**

SOURCE: Battke, B., Schmidt, T.S., "Cost-efficient demand-pull policies for multi-purpose technologies – The case of stationary electricity storage", Under Review at Energy Economics (2013)

1 GAP-TO-PROFITABILITY – PROFITABILITY RESULTS [EUR/kW-yr]

The mean profitability of batteries serving one application is negative



- Mean **profitability** is still **negative** across applications
- However, the **gap-to-profitability** varies significantly across applications
- **Sequentially supporting** applications can reduce costs of policies

SOURCE: Battke, B., Schmidt, T.S. (2013)

Policy makers can choose which storage application to support along several decision criteria

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Detailed further on following slides

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2 LEVEL OF COMPETITION – SCOPE & METHODOLOGY

We modeled the investor decisions in batteries to understand the level of competition between technologies

Phenomenon

- Simulation of **4 battery technologies** that are most promising for grid-scale storage: Lead-acid, lithium-ion, vanadium-redox-flow, sodium-sulfur

Data

- Based on literature review and expert interviews

Calculation

- Given the technological uncertainty present in battery technologies, **modeling of rational actors investment decision in battery technologies**
- Level of competition between battery technologies calculated as the **percentage of actors that deviate from the majority investment decision**
- Investment decisions of 1,000 actors modeled for 30,000 different points in the application landscape

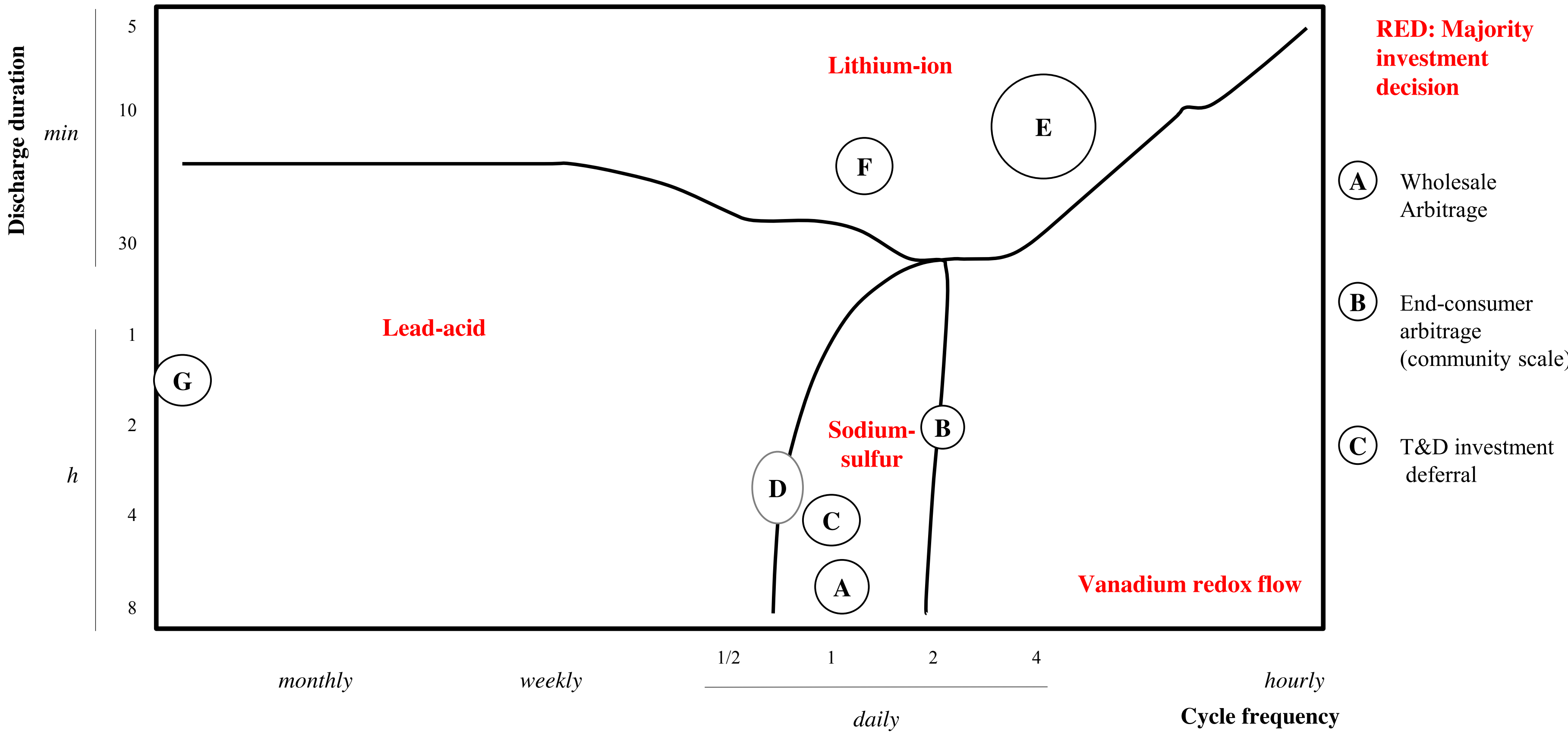
Level of competition between battery technologies

SOURCE: Schmidt, T.S., Battke, B., Grosspietsch, D., Hoffmann, V.H. "How to avoid premature lock-in in one technology – Evidence from modeling of multi-purpose technologies", forthcoming

2 LEVEL OF COMPETITION – RESULTS (1/2)

There is *no silver bullet* – (almost) each storage technology has its sweet spot in the application landscape.

Leading technologies in the application landscape (along discharge duration and cycle frequency)



Ⓓ Increase of self-consumption[b] Ⓔ Area and frequency regulation Ⓕ Voltage regulation Ⓖ Power Reliability

SOURCE: Schmidt, T.S., Battke, B., Grosspietsch, D., Hoffmann, V.H. "How to avoid premature lock-in in one technology – Evidence from modeling of multi-purpose technologies", forthcoming

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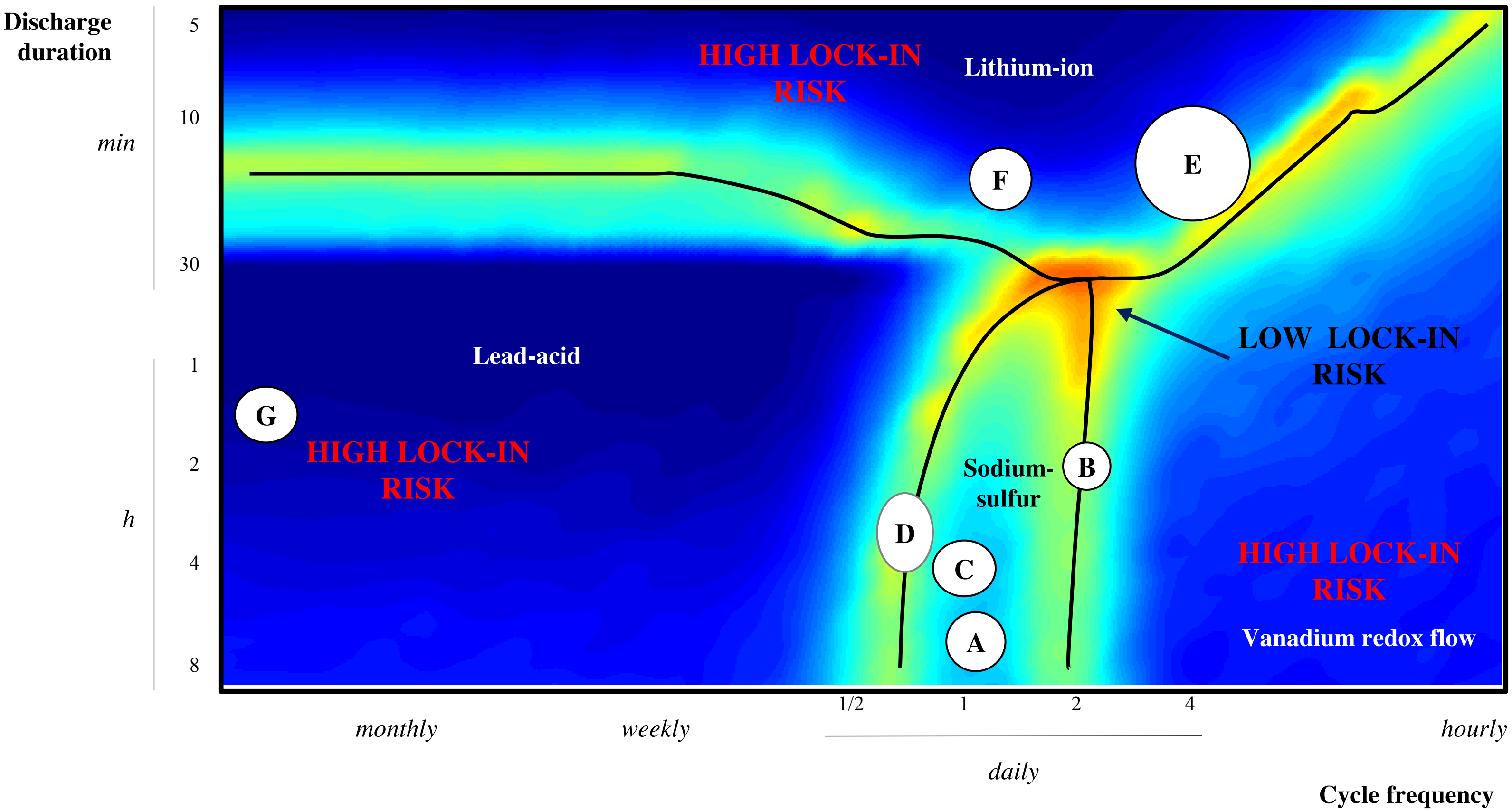
In some applications, a clear leader exists, while others are characterized by fierce competition

Level of competition between technologies in the application landscape



COLOR SCHEME: Level of competition between technologies

- (A) Wholesale Arbitrage
- (B) End-consumer arbitrage (community scale)
- (C) T&D investment deferral
- (D) Increase of self-consumption[b]
- (E) Area and frequency regulation
- (F) Voltage regulation
- (G) Power Reliability

! Supporting applications with a high level of competition reduces the risk of technological lock-in

SOURCE: Schmidt, T.S., Battke, B., Grosspietsch, D., Hoffmann, V.H. "How to avoid premature lock-in in one technology – Evidence from modeling of multi-purpose technologies", forthcoming

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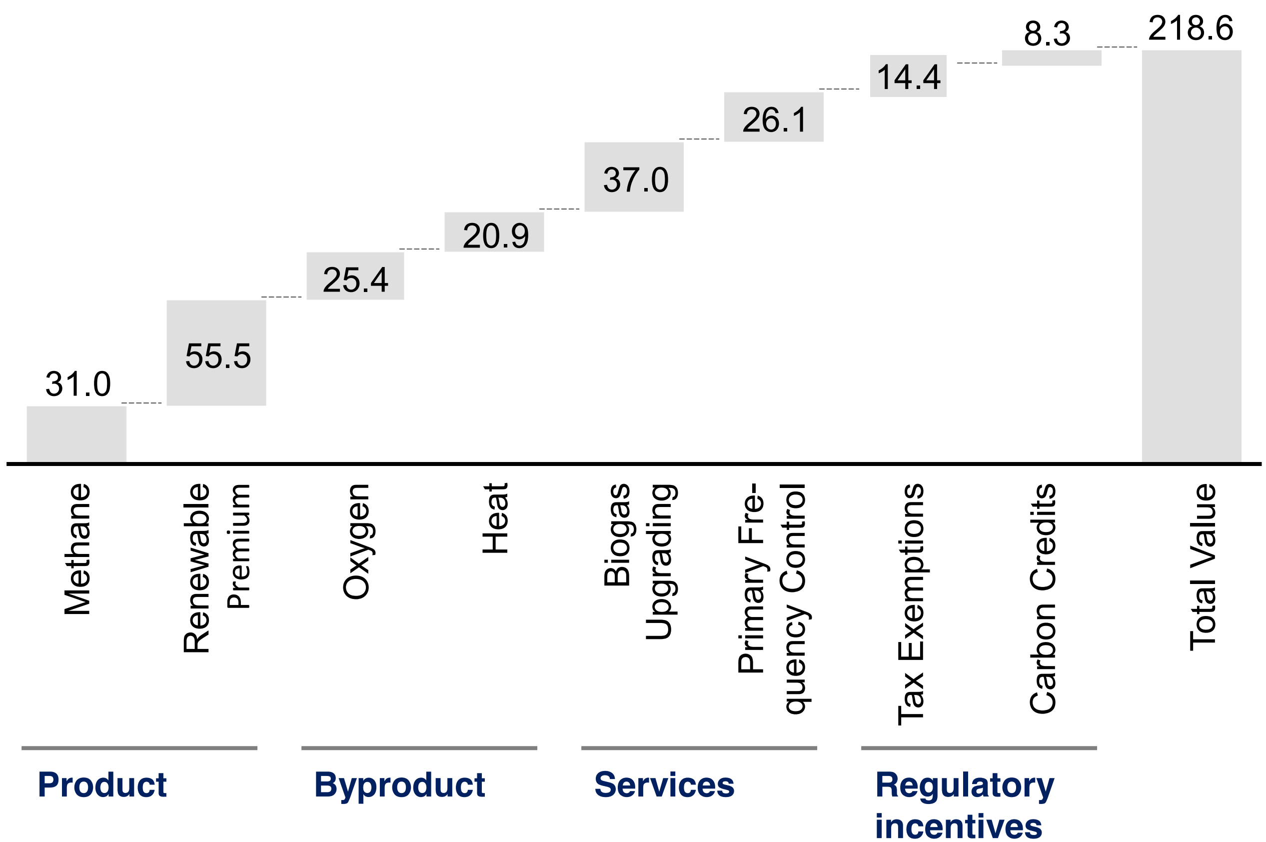
Electrochaea
Renewable Natural Gas

Combining value sources can change the economics of storage technologies strongly

Techno-economic model of a power-to-gas plant in Switzerland

Breakdown of economic value for base load operation [CHF/MWh]



! Analysis to be done for electricity storage technologies

SOURCE: Report "Assessment of Power-to-Gas in Switzerland", D. Hofstetter, B. Battke, B. Cox, J. Hughes, Electrochaea, Zürich, forthcoming

Contents

- Intro: The key difference between storage and renewables: Multiple applications
- Analyses: How to choose which storage application to support
- **Assessment example and conclusion**

A first exemplary assessment of 3 applications gives a rough indication of potential results

First estimate

- Favorable assessment
- Medium assessment
- Unfavorable assessment

Exemplary assessment

Decision criteria to choose an application to support	Wholesale/renewable Arbitrage	Increase of self-consumption	Area & Frequency Regulation
1 Gap-to-profitability	Unfavorable	Medium	Favorable
2 Level of competition	Unfavorable	Unfavorable	Medium
3 Combinability of applications	Favorable	Favorable	Unfavorable
4 Market size	Favorable	Favorable	Unfavorable
5 External effects	Favorable	Medium	Favorable
6 Ease of implementation	Favorable	Medium	Favorable

!
- Trade-off between decision criteria
- No clear “winning” application

Conclusion

1. **Storage is fundamentally different** from renewables – the **multiple application** of storage is the key differentiating parameter

2. If policy makers want to support storage, they have to **choose which application to support**

3. The **six decision criteria** presented in this talk can aid policy makers in this decision

Contact

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Some practical insights on energy storage technologies

Storage demand and applications

1. *Systemic demand* in Europe – as a function of renewable build-up and grid quality – is limited in the near future. However, *markets* for storage will develop independently from systemic demand.
2. Storage is a *multi-purpose technology.* Its applications or markets can be defined best by the mechanism they create economic value across stakeholders

Technol-ogies and costs

3. A broad *variety of storage technologies* can serve these applications. However, they a) still exhibit a high degree of uncertainty, and b) have highly diverging costs across applications.
4. There is *no silver bullet* – (almost) each storage technology has its sweet spot in the application landscape. Thus, choosing applications implies choosing technologies.
5. Technologies are in *competition* across the application landscape. In some areas, a clear leader exists, while others are characterized by fierce competition.

Value and profitability

6. There is no price tag for the *value of storage applications*. The value can be estimated by a combination of market signals, cost of competing technologies and the intrinsic value.
7. Understanding *regulation* is pivotal to any economic assessment. However, this is a challenging task as storage falls “between” existing regulatory frameworks.
8. Today, it is difficult to make money with the operation of storage facilities. The mean profitability of batteries serving one application is negative.
9. However, *combining applications* improves the picture. A simulation of a Power-to-Gas facility in Switzerland reveals that base load operation combining all value sources is most attractive (yet still negative).