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Monitoring innovation in electrochemical energy storage technologies: A patent-based approach

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HIGHLIGHTS

- Grid effects of intermittent sources show increasing need for decentralized storage.
- Novel patent classification is applied to monitor competing technologies.
- Up-to-date geographical, organizational, and qualitative insight is given.
- Redox flow patenting shows strong growth, lithium also strong absolute numbers.
- Revealed patents allow the expectation of improved modules in the future.

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ABSTRACT

Due to the suitability to balance the intermittency in decentralized systems with renewable sources, electrochemical energy storage possibilities have been analyzed in several studies, all highlighting the need for improvements in relevant techno-economic parameters. Particularly a reduction in the costs per cycle is much needed, which could either come from innovation in more cost-efficient manufacturing methods, a higher endurance of charge/discharge sequences or higher capacities. Looking at patent applications as a metric allows us to determine whether the necessary technological progress is indeed occurring, as the mandatory publication of the underlying inventions provides access to otherwise hidden R&D activities. Our paper contributes to the literature with a compilation of technological classes related to important battery types in the novel Cooperative Patent Classification (CPC), which can be used to identify relevant patent applications of the competing technologies. Using the worldwide patent statistical database (PATSTAT), we find that promising technologies have been showing increasing patent counts in recent years. For example, the number of patent applications related to regenerative fuel cells (e.g. redox flow batteries) doubled from 2009 to 2011. Nevertheless, the volume of patent filings in technologies related to lithium remains unchallenged. Patent applications in this area are still growing, which indicates that the introduction of improved modules will continue. Using citation analysis, we have identified important patents and organizations for relevant candidate technologies. Our study underlines that electrochemical storage, and in particular lithium-based technologies, will play an increasingly important role in future energy systems.

1. Introduction

1.1. The importance of innovation research in energy storage technologies

The diffusion of intermittent renewable energy sources reveals the lack of appropriate decentralized energy storage solutions for grid support and residential applications. The effects of intermittent energy sources start to become visible on a national scale for countries with high penetration of renewable energies. While increasingly frequent periods of negative electricity prices [1], caused by temporary oversupply, may only seem bizarre, it underlines the importance of energy storage to prevent inverse events of electricity shortage, which could jeopardize grid stability. Due to the suitability for the desired decentralized structure, electrochemical energy storage possibilities have been analyzed in several studies, all highlighting the need for improvements in relevant techno-economic parameters [2–6].

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To support the much-needed progress, understanding innovation in electrochemical energy storage revealed in patents is an important research, as well as public policy, issue for several reasons: firstly, as the economic potential for further improvements is tremendous, it is likely that novel ideas are first patented before scientifically published, if at all. Consequently, it is likely that important know-how concerning batteries is revealed in patents. Secondly, policy-makers considering financial support for energy storage need to have information on the innovative performance in their respective jurisdictions, as this is essential for a well-informed decision about optional technology push or market pull subsidies. The same is true for venture capitalists and capital markets, which are important to bring products from initial R&D to product development. Thirdly, grid designers and (renewable) energy scenario researchers need to know, whether and which, electrochemical energy storage systems could dominate markets in the future. Moreover, the scholarly literature on innovation in energy storage has, up to this point, only encompassed technologies relevant for electric mobility registered at the United States Patent and Trademark Office (USPTO) [7]. Further research drawing a global, organizational and qualitative perspective including technologies relevant for stationary energy storage is therefore a pressing need as "energy storage is very much the key to unlocking the door of renewable energy" [5].

1.2. Electrochemical energy storage technologies

Over the past few decades, differences in supply and demand in electricity grids have already had to be matched. To store the excess capacity at night and ensure availability during high consumption hours, energy has been stored in the gravitational potential using hydropower plants for many decades. Storing significant amounts of energy, however, requires large facilities which have a strong impact on the local environment. Furthermore, not all countries have the geographical profile to build pumped hydro storage plants [6].

Following the transition in the energy generation technology, a structural change from a centralized to a more decentralized system architecture has also been initiated by the introduction of feed-in tariffs. Production of energy at the location of consumption reduces the necessity of electricity transmission through grids. As transmission costs can comprise up to a third of present-day consumer electricity fees, a decentralized system architecture has economically significant advantages. The financial support by feed-in tariffs worldwide has led to a rapid increase in installed renewable energy capacities. This has caused new record values for renewable energy generation, such as for example more than 73% of the national supply on May 11, 2014 in Germany [8,9]. Fig. 1(b) shows the total German energy production and consumption series for a week including a record day in 2013. On June 16, 2013, where renewable energy accounted for 60% of the power, wind energy contributed with approximately 9 GW and photovoltaics with 20 GW. With spot prices assuming negative values, it becomes apparent that already at the present renewable ratios, matching supply and demand becomes increasingly difficult. Next to just meeting demand and supply, it has also been pointed out that power quality becomes a problematic topic with increasing shares of renewables [10].

When analyzing the size distribution of registered renewable energy plants in Germany as shown in Fig. 1(a), it can be seen that all categories – from small kW sized to large MW sized plants – contribute substantially to the overall capacity. Thus, also small- to mid-scale storage systems are needed. Due to their high modularity, electrochemical energy storage in batteries is an important alternative to mechanical and other technologies, such as superconducting magnetic storage, for example.

In the 90s, alkaline, NiCd and NiMH batteries were very common among secondary cells [2]. With the advent of mobile electronics, they entered many households in flashlights, wireless phones and other devices. By combining several thousand cells, a MW ranging energy storage project had already been realized in 2003 (e.g. [11]). Due to the maturity of the technology, NiCd and NiMH secondary cells are therefore candidates which remain to be monitored.

In starter batteries of internal combustion engine vehicles, lead-acid batteries are widespread and have gained broad market diffusion. In China for example, lead-acid batteries have had the greatest share in usage for PV/wind systems. This can be explained by their maturity and cost competitiveness [17].

Increasing requirements in energy density by consumer electronics due to the advent of laptops and smartphones have caused the widespread use of lithium batteries. Next to their high density [20], also the high efficiency of more than 90% [4] renders lithium batteries a promising technology.

Redox flow batteries represent an interesting novel approach to storing larger quantities of energy electrochemically. Due to the in principle high number of cycles, cost competitiveness could be achieved. Also, the storage tanks have very good scalability, rendering flow batteries ideal for larger quantities [4].

Yet another possibility, which is relevant particularly for grid-scale application, is sodium-sulfur batteries, operating at high temperatures. The suitability for large powers, the high efficiency on

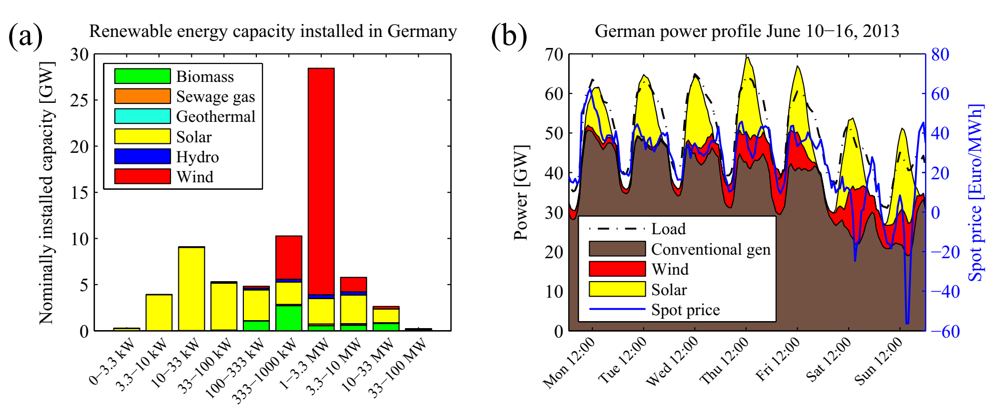

Fig. 1. (a) Installed renewable energy generation capacity per nominal power of individual plant in Germany as of December 31, 2012 (data from [12]). It is apparent that small systems contribute substantially to the overall generation capacity, showing the high degree of decentralization. (b) Overall German power profile showing negative spot market prices on a Sunday with low demand and record renewable energy values (depiction following [13], data sources: load [14], production [15], spot prices [16]).