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Exploring emerging battery technology for grid-connected energy storage with Constructive Technology Assessment

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ABSTRACT

The last decades have shown an increasing amount of research into expectations of science and technology. Especially for emerging technologies, expectations held by different stakeholder are guiding the direction of research and development. In this article the results of an investigation into the expectations of specific actors regarding the development of emerging battery technology for applications in the power grid are presented. It is set up as an explorative study within the framework of Constructive Technology Assessment (CTA). A number of studies since the 1990s have indicated a growing need for energy storage options in the power grid, where batteries appear to be capable of providing a range of valuable services to the grid. Cost-effectiveness on a large scale will however require considerable technical improvements. The configuration of energy storage may differ in the specific location and exploitation of the storage assets, as well as in the investments in new storage capacity. In this study the visions and expectations of several relevant actors are analysed using interviews and surveys in terms of expectations of technological development, expectations concerning stakeholder roles, and channels of interaction between the relevant actors. The results indicate a divide in expectations between the user side of the technology (the electric power industry) and the development side (academic researchers). Opinions differ with respect to the obstacles to technological development, the actors relevant in early technological development, and the most suitable channels for interaction between these actors. It follows from the theoretical background that conflicts in expectations provide the opportunity for the acceleration of technological development and adoption through stakeholder participation. Small interactive workshops, where conflicts identified in this paper are discussed, were identified as a suitable channel in order to reach consensus in visions and expectations for battery technology.

1. Introduction

New developments in energy production and the behaviour of consumers require changes in the configuration of the power system, in order to assure an efficient and reliable power supply. Energy storage may be one of those changes, as a means to smoothen out the intermittent energy production by renewable energy sources (RES). Battery systems are often mentioned as a suitable technology for this purpose. However, the general consensus seems to be that before one can make a viable business case for batteries, the technology first has to develop further. Different chemistries, such as Lithium-Polymer, Lithium-Sulphur and Metal-Air batteries, are promising new battery types that could make distributed energy storage economically viable. But in order to develop new systems and maximize the value proposition of decentralized storage, different parties will need to cooperate and experiment with new systems in real practice.

For the storage of electric power to become widely adopted in the electric power system, it will require both technical innovation to produce better storage technologies as well as system innovation within the energy industry to integrate electricity storage in the supply chain. Innovation of large socio-technical systems are usually complicated processes that may take a long time and include a lot of contingencies. This is partly due to the inherent dependence on many different actors, making the system difficult to steer. Also, big socio-technical systems are characterized by stability and lock-in effects where swift changes are hindered by sunk costs in technologies (power plants, lines and cables, etc.), skills and belief systems (Verbong and Geels, 2010).

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It is crucial for technology forecasting and public planning to better understand long term patterns of innovation of certain energy technologies, such as energy storage. Particularly in the context of climate change and the ongoing energy transition (Huenteler et al., 2015). Constructive Technology Assessment (CTA) has been suggested as a suitable framework for the analysis of the social aspects of technological development of battery development. CTA has been developed as a soft intervention practice aimed at aligning expectations of different stakeholders in order to facilitate this kind of innovation. The involvement of different stakeholders in the design process of emerging technologies should result in the adoption of new technologies that are better suited for the needs and expectations of society (Baumann et al., 2014; Schot and Rip, 1997; te Kulve, 2012).

This paper presents the results of a study of the expectations of different stakeholders regarding the development of emerging battery technology for applications in the power grid. The research is set up as an explorative study within the framework of CTA. This consists of a review of scientific literature on storage technology and related power grid developments, and empirical research with surveys and interviews about the expectations held by experts and stakeholders on the issue. In this paper we first present an introduction of sociotechnical systems and the relevant concepts for CTA. This is followed by the research methodology before the results of the literature review and the empirical research are presented. Furthermore, the results are discussed in light of the theory, as well as recommendations for further research.

2. Constructive Technology Assessment: an approach to analyze emerging technologies and market uncertainties

According to Robinson (2010), CTA focuses on the wider interaction of the broad range of actors (including society) that have a "stake" in the development, deployment and use of new technology fields. This approach is based on theory of sociotechnical systems. In this theory technology is viewed as part of a seamless web of highly related heterogenic elements, such as organizations, institutions, resources, scientific elements and legislation. Societal functions such as transport and energy supply are results of such clusters of heterogenic elements which can be named socio-technical system (Geels, 2005). In order to understand how technological development takes place in an existing or changing socio-technical system, multi-actor dynamics have to be taken into account (van Merkerk and van Lente, 2005; Parandian, 2012).

Technological development, in its core, is a process driven by the decisions of the actors involved. In the early phases of technological development it is hard, if not impossible, to accurately anticipate the technical and economic impacts that a technology may have. Decisions are made in a context of uncertainty. Therefore, decisions are based on a system of beliefs: visions and expectations held to be true by the actors, but with little basis in reliable facts (van Lente, 2012). Emerging technologies and changes in science do not pre-exist themselves. Rather, their potential is shaped by expectations and visions. These two factors are told to play a significant role in mobilizing resources on a macro level (e.g. national policy through regulation and research patronage), the *meso* level of industry sectors, and at a micro level within engineering and research groups and in the work of single engineers or researchers (Borup et al., 2006).

Despite this context of uncertainty, it is important to make decisions in the early development phases. This is because technology is still malleable in early development, but loses this quality during development due to a process called entrenchment. This is related to the power-control dilemma, first posited by Collingridge (1980) and described by Berkhout (2002, p.3) as follows:

> "During the development irreversibilities can arise that set the technology on a certain trajectory that determines the outcomes of technological change. …. This dilemma describes a double bind on technological development because, on one side, one only has the opportunity to steer technological change in the early development of technology, before entrenchment has set in, but on the other hand, one only has the knowledge to know how to influence technological change in the late development of technology, when it is already too late."

Constructive Technology Assessment (CTA) offers an opportunity to account for this dilemma by broadening the design of new technologies through feedback from technology assessment activities into the development process. CTA involves the identification of stakeholder expectations, and ultimately aims at aligning these expectations to influence, rather than assess, technological development (Schot and Rip, 1997; van Merkerk, 2008).

In the following paragraphs the concepts behind the approach taken in this work are explained. Important concepts include emerging irreversibilities and the operationalisation of expectations of technological development into general expectations, positionings and spaces. Some general patterns in actor dynamics are also discussed.

2.1. Emerging irreversibilities

Entrenchment of technologies is the result of several irreversibilities that emerge during the development of a technology. From conception of a technological possibility, to its diffusion into the market, a technology becomes gradually more entrenched. This entrenchment is steered by the actions of the actors involved, for instance by the investors and developers that drive the development into a certain direction. Van Merkerk and van Lente (2005) introduce the term emerging irreversibilities to refer to patterns that enable certain actions and interactions, while constraining others. This process is driven by the fact that almost all resources are limited, including human and of course financial resources. This means that for any resources put into a certain project, another will have to do without. The first decision in distributing resources creates a disparity between different options. As these decisions are based on the beliefs of stakeholders, studying these beliefs provides insight into the irreversibilities that are emerging. Based on this, stakeholder beliefs are taken to be the best indicator for the futures of emerging technologies, and the object of analysis in this paper.

2.2. Expectations of emerging technologies

Expectations can play a big role because of the inherent uncertainty of technological development. Decisions have to be made within the context of uncertainty, and treating expectations as facts decreases the subjective degree of uncertainty. As such, expectations have three effects that make up their impact: legitimization, heuristic guidance and coordination (van Lente, 2012): expectations that are circulating among stakeholders raise attention to a technology and legitimize investments that carry high risks with them (as investments in emerging technologies generally do). Expectations offer direction when there is no objective way of deciding between many possible different paths that may be taken in scientific research and technology development, much like a heuristic deals with complexity and uncertainty. Finally, expectations move across boundaries, thereby providing coordination between distinct groups and communities, and across levels (Borup et al., 2006). Coordinated action across different research groups leads to mutually reinforcing research efforts in one specific direction, and coordination across levels (the research groups, sectors and innovation networks, and governments and society) leads to a wider economic and social basis for technological development. Through these effects, expectations constitute themselves as driving forces of the emerging irreversibilities discussed above.

The power of expectations depends on the degree to which they are shared (Borup et al., 2006). The 'sharedness' ensures that actors act accordingly to these expectations. Expectations thus inspire new technological developments that subsequently have to be protected by other