Applied Energy 155 (2015) 334–348

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Cost-efficient demand-pull policies for multi-purpose technologies – The case of stationary electricity storage

Benedikt Battke [a], Tobias S. Schmidt [b,*]

[a] Swiss Federal Institute of Technology Zurich (ETH Zurich), Department of Management, Technology, and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56, CH-8092 Zurich, Switzerland

[b] Swiss Federal Institute of Technology Zurich (ETH Zurich), Department of Humanities, Social and Political Sciences, Energy Politics Group, Haldeneggsteig 4, CH-8092 Zurich, Switzerland

HIGHLIGHTS

- A definition of multi-purpose technologies (MPTs) is proposed.
- Opportunities for a cost-efficient demand-pull policy strategy for MPTs are derived.
- The multi-purpose character of stationary electricity storage (SES) is shown.
- An exemplary profitability assessment of one SES technology supports the argument.

ARTICLE INFO

Article history:
Received 20 February 2015
Received in revised form 3 June 2015
Accepted 4 June 2015

Keywords:
Vanadium redox flow battery
Techno-economic model
Learning curve
Innovation
Profitability
Subsidy

ABSTRACT

Stationary electricity storage technologies (SES) allow to increase the shares of intermittent renewable energy technologies in electricity networks. As SES currently exhibit high costs, policy makers have started introducing demand-pull policies in order to foster their diffusion and drive these technologies further down the learning curve. However, as observed in the case of renewable energy technologies, demand-pull policies for technologies can come at high costs in cases where the profitability gap that needs to be covered by the policy support is large. Yet, SES can create value in multiple distinct applications in the power system – making it a "multi-purpose technology". We argue that policy makers can make use of the multi-purpose character of SES to limit costs of demand-pull policies. We propose a policy strategy which grants support based on the profitability gap in the different applications, thereby moving down the learning curve efficiently. To support our argumentation, we firstly conduct a comprehensive literature review of SES applications exemplifying the multi-purpose character of these technologies. Second, we assess the profitability of one SES technology (vanadium redox flow battery) in five SES applications, highlighting a strong variation of the profitability gap across these applications.

1. Introduction

In recent years, many governments have introduced policies (e.g., feed-in tariffs) aiming to induce the diffusion of renewable energy technologies (RETs) [1–3], also called "demand-pull policies" [1] [6,7]. On the one hand, these policies had positive effects such as improved technological performance, massive reductions of RET costs, and reduced carbon emissions of the electricity sector [8]. On the other hand, such policies can results in high costs [9]. Above that, the resulting diffusion of RETs challenges power quality and security [10] as the power system has to cope with the intermittent and non-deterministic nature of most RETs [2,11]. In fact, several studies argue that the intermittency of most new renewable energies is a major bottleneck for a transition of the energy system [11–13].

To address intermittency issues, several technical levers exist [11]. Out of these levers, stationary electricity storage (SES)[2] is a promising response option to cope with the challenges induced by

* Corresponding author. Tel.: +41 44 632 04 86; fax: +41 44 632 12 89.
E-mail address: tobiasschmidt@ethz.ch (T.S. Schmidt).

[1] The core of the demand-pull argument is that firms direct their research and production efforts in response to changes in market conditions trying to satisfy unmet demand and thus driving technological change [4,5].

[2] In this paper we refer to SES as power-to-power storage technologies, however other energy storage technologies, like power-to-heat or power-to-gas are also multi-purpose technologies. Hence the concept developed in this paper also applies to these alternative electricity storage technologies.

http://dx.doi.org/10.1016/j.apenergy.2015.06.010
0306-2619/

intermittent RETs [14,15], since the practical potential of electricity demand side management is limited [16] and grid extensions are often impeded or delayed by public opposition [17]. However, given the high costs of most SES technologies and the resulting lack of profitable business options for private investors and companies, their diffusion rate is still very low [18,19]. Thus, in order to drive down SES costs further technological innovation and learning is needed [18].

Especially in the case of clean energy technologies such as SES,[3] demand-pull policies are widely seen as an effective tool to induce innovation and consequently cost reductions [20–22].[4] Economic theory suggests that in the presence of "learning-by-doing", diffusion of an technology triggers innovation resulting in cost reductions due to learning spillovers from production and use phases [24]. However, as firms investing in production of clean energy technologies are not able to appropriate the spillover effect completely, there is a strong rationale for policy intervention to correct for this market failure [25,26]. From an empirical point of view, the relationship between diffusion and innovation in form of cost reductions can also be described quantitatively by learning or experience curves – a concept that is widely used in studies on the energy sector [27–29,22].[5] Recent studies comparing learning curves across technologies have found evidence for steep learning curves for clean energy technologies indicating high endogenous learning potential [36,37]. Learning curves have also been applied to SES. For instance, Kromer and Heywood [38] use this concept to compare cost reduction potentials of different battery types showing that deployment leads to strong cost reductions in SES. Summing up, demand-pull policies for SES are seen as appropriate instruments to reduce costs by driving these technologies down the learning curve [39,15,40,21]. In fact, policy makers in several countries have started implementing support schemes for SES [41,42].

However, demand-pull policies can come at high costs in cases where the profitability gap that needs to be covered by the policy is large [9,43]. For instance, demand-pull policies for renewable energy technologies often result in high costs due to the typically higher life-cycle costs of renewable energy technologies compared to their conventional alternatives [8,44,45]. This may lead to higher public spending or increases of end-consumers electricity bills as seen, for instance, in Germany [43]. As the burden on public or private budgets need to be considered [46], the question arises, how can policy makers support the diffusion of SES while at the same time limiting the costs of these policies?

In this paper we argue that in order to limit costs, policy makers need to be more strategic and support technologies where their support comes at lower costs [40]. In the case of SES, policy makers can make use of a distinct feature of these technologies: their multi-purpose character. In contrast to RETs, which primarily create value through generating electricity, SES can create economic value in very different ways (e.g., improvement of power quality or power price arbitrage) making it a technology that can be used in multiple applications in the power system. As the profitability gap and hence the need for support can differ strongly across these applications, we propose that policy makers can implement a demand-pull strategy for multi-purpose technologies (MPTs) as SES that allows moving down the learning curve at the lowest costs. Policy makers can implement cost-efficient demand-pull policies by selecting first the MPT application with the smallest profitability gap, and thereby improving the profitability also in the MPT application that is likely to become highly relevant yet currently exhibits a larger profitability gap.

The remainder of this paper is structured as follows: In the theory section, the concept of multi-purpose technologies (MPTs) is defined (Section 2.1) and the idea of a cost-efficient demand-pull strategy for multi-purpose technologies is developed (Section 2.2). In the two subsequent chapters, the theoretical ideas are corroborated by applying them to the case of SES: While Section 3 demonstrates the multi-purpose character of SES based on a comprehensive literature review of SES applications, Section 4 addresses the profitability gap between distinct applications. To this end, we develop a probabilistic bottom-up life-cycle cost model for a specific SES technology (vanadium redox flow battery) using data for Germany (Section 4.1). The results of this modeling exercise show that the profitability gaps of this technology vary strongly across SES applications resulting in different support needs (Section 4.2). In Section 5 we synthesize the analyses discussing the assumptions and limitations, while we conclude in Section 6 by summarizing the main contributions and by indicating avenues for further research.

2. Theory – demand-pull policies for multi-purpose technologies

This section develops the main argument of this paper. We argue that policy makers can implement a strategic order of demand-pull policies in order to reduce the total costs of these policies in case a technology has multiple distinct applications. To this end, we first introduce the concept of multi-purpose technologies (Section 2.1), before the implications of this concept for demand-pull policies are derived (Section 2.2).

2.1. The concept of multi-purpose technologies

In economic literature, technologies have been distinguished by their variety of use cases. While on one side of the spectrum some technologies have primarily a single purpose (e.g., the coffee machine), other technologies boast a virtually unlimited number of applications throughout the economy making them so-called "general-purpose technologies" (e.g., personal computers or microprocessors) [47]. Building upon the notion of general-purpose technologies, the remainder of this subsection defines, describes and exemplifies the concept of multi-purpose technologies.

The roots of the general-purpose technology concept can be traced back to the early work of Griliches [48], Williamson [49] and David [50]. Yet, Bresnahan and Trajtenberg ([51], p. 84) were among the first to explicitly identify general-purpose technologies (GPT) as "characterized by the potential for pervasive use in a wide range of sectors and by their technological dynamism". Moreover, GPTs are described as spawning innovation and growth due to their complementary and enabling character in combination with other technologies [52]. Lipsey et al. ([47], p. 43) describe a GPT "as a technology that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many spillover effects".[6] Common examples of GPTs are computers or microprocessors [47].

However, several technologies exist (e.g., X-ray, lasers, anaerobic digestion) that have multiple distinct applications, yet lack other key characteristics of GPTs [57] placing them between

[3] SES can be regarded as clean energy technology as most SES applications in the power system support directly or indirectly the integration of RETs (cf. Section 2.2).

[4] A valid alternative for policy makers to foster technological learning are so-called technology-push instruments which emphasize the role of research and science in technological innovation [23]. However, the focus of this paper lies on demand-pull instruments.

[5] Thus, besides some caveats [22,30,31], learning curves have been included in modeling of energy systems [32,33] as well as applied to policy implications [34,35].

[6] Due to these characteristics the concept of GPTs had the most impact on academic literature on economic growth. Several studies, including yet not limited to Carlaw and Lipsey [53], David and Wright [54] as well as Majumdar et al. [55], focus on the impact of GPTs on productivity and economic growth. Other contributions investigate the relation of GPTs and wage inequality [56] or the influence of GPTs on aspects as interest rates, stock market performance or industry structure [52].