When is Energy Storage Valuable? The Impact of Carbon Policy, Resource Availability, and Technology Efficiency on a Renewable-Thermal Power System

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Overview

Concerns about climate change have spurred governments to reduce carbon emissions by supporting adoption of renewable energy (RE) technologies. For example, in Germany, the share of RE in the power sector increased to 30% in 2014 as compared to less than 5% in 1990 due to policy measures such as feed-in tariffs (von Hirschhausen, 2014). Due to the intermittent and location-specific nature of RE technologies, energy storage has become important because it could be used to smooth out temporal disparities in residual demand. Using stylised equilibrium models, Sioshansi (2010, 2014) investigates the welfare implications of storage ownership, market power, and device efficiency. Focusing on a numerical study of the California power sector, Bushnell (2003) also uses an equilibrium approach to illustrate how producers with market power have the incentive to withhold hydropower generation during peak hours and to move it to off-peak hours instead. Thus, the marginal value of water is lower in an industry with market power and may even be negative as posited by Crampes and Moreaux (2001). Indeed, restructuring of the electricity industry has provoked interest in how hydropower producers' incentives to shift generation between peak and off-peak periods are affected (Mathiesen et al., 2013), but a comprehensive analysis of carbon policy, RE resource availability, and storage efficiency on producers' incentives and the value of storage has been lacking. In this paper, we address these aspects in order to specify the conditions under which RE producers with storage are inclined to shift deployment of the resource and its implications for the marginal value of RE storage.

Methods

We develop an equilibrium model with an RE and a thermal producer. Although the marginal cost of RE generation is zero, there is a finite amount of the RE resource, D, that must be fully used by the RE producer across periods 1 (off-peak) and 2 (peak). Furthermore, there is an inefficiency, F, associated with the RE storage device. By contrast, the thermal producer has a linear marginal cost of generation and may be subject to a carbon tax, T, but has no capacity constraint. Given linear inverse demand functions for each time period, we find the Nash-Cournot equilibrium between these profit-maximising producers (Crampes and Moreaux, 2001).

Results

Focusing on interior solutions under both perfect competition and Cournot oligopoly, we first prove analytically that the main result of Bushnell (2003), i.e., more off-peak RE production under Cournot oligopoly as compared to perfect competition, holds without a carbon tax. However, for a certain threshold of the carbon tax, the incentive of the RE producer to generate more in the off-peak period under Cournot oligopoly is mitigated by the fact that the marginal value of RE storage, μ, increases with the carbon tax (***Figure 1***). This unambiguously decreases thermal generation in both periods under Cournot oligopoly but makes it possible for peak thermal generation to increase under perfect competition. Thus, the carbon tax depresses peak RE production less under Cournot oligopoly than under perfect competition, which means that the main finding of Bushnell (2003) may not hold with a carbon tax. Intuitively, under perfect competition, the imposition of a carbon tax has the *direct* effect of increasing the marginal cost of thermal generation, which reduces thermal output (and increases RE output) in both periods. At the same time, there is an *indirect* effect that increases the marginal value of RE storage, μ, as the RE resource becomes relatively scarce with a carbon tax. This intertemporal effect reduces RE generation in both periods but more so in the peak period due to the inefficiency of storage. Consequently, this countervailing indirect effect may actually increase peak-period thermal generation as RE output shifts from the peak to the off-peak period (***Figure 2***). Investigating RE resource availability, we find that it unambiguously decreases the marginal value of RE storage (***Figure 3***), which leads to more (less) RE (thermal) output with a greater impact in the peak period under both perfect competition and Cournot oligopoly. Finally, more inefficient RE storage, i.e., higher F, has contrasting effects on the marginal value of RE storage under perfect competition and Cournot oligopoly (***Figure 4***). A *ceteris paribus* degradation in efficiency monotonically increases the marginal value of RE storage under Cournot oligopoly as there is less (more) period-1 RE (thermal) production and a higher RE storage value in order to preserve the RE resource for period 2. Under perfect competition, this result holds only if RE storage is relatively efficient, i.e., if RE storage is relatively inefficient, then a *ceteris paribus* degradation in its efficiency actually increases (decreases) period-1 RE (thermal) production and lowers RE storage value as it is not worthwhile to preserve the RE resource.

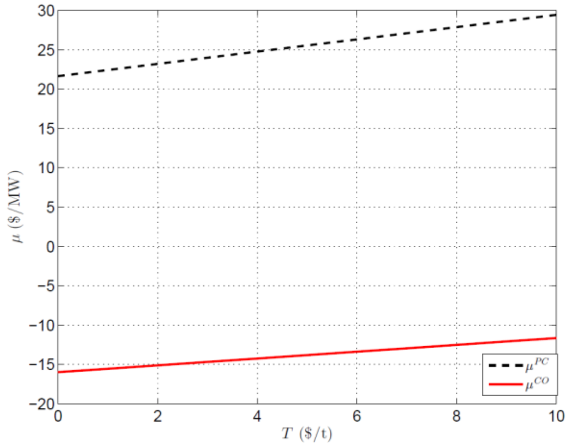

Figure 1. Impact of Carbon Tax on RE Storage Value

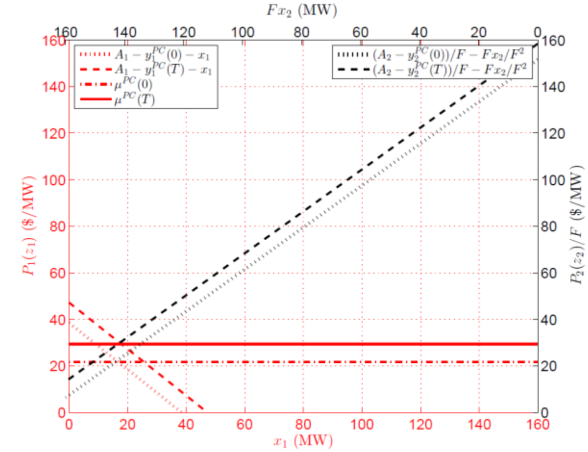

Figure 2. Impact of Carbon Tax on RE Generation under Perfect Competition

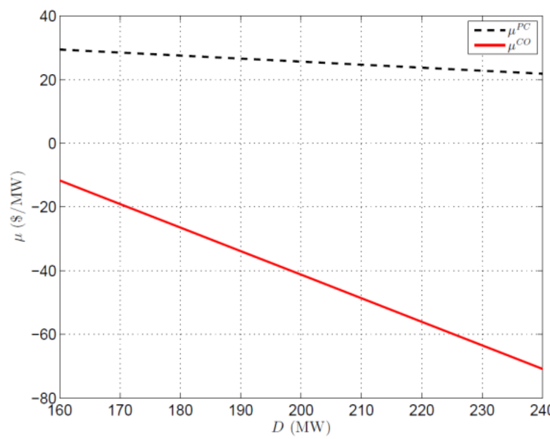

Figure 3. Impact of RE Availability on RE Storage Value

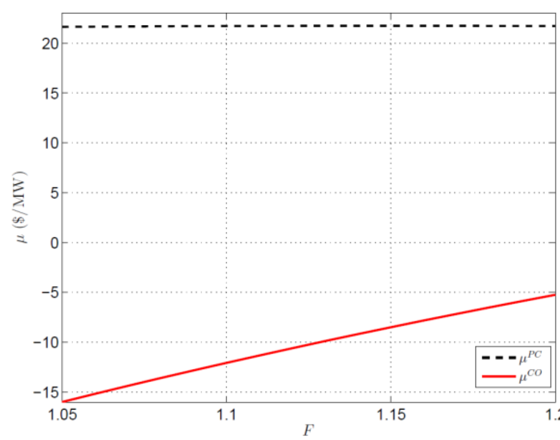

Figure 4. Impact of RE Storage Losses on RE Storage Value

Conclusions

We examine the implications of policy interventions and technological change on the marginal value of RE storage. Via a stylised equilibrium model, we specify why findings from the storage literature may not hold and how incentives for storage investment may be affected. Hence, these results may inform the regulatory process governing market design of a power sector with increasing capacities of RE generation and storage.

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