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# Techno-Economic Assessment for Optimal Energy Storage Mix

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**Abstract**

A wide variety of energy storage methods are currently employed around the world, including electrical storage, thermal storage, chemical storage. The correct storage mix will satisfy a range of constraints relating to the specific nature of electricity generation and demand connected to the grid, the physical nature of the landscape and it's geology as well as the political environment. Finding synthesis among these conflicting concerns is a difficult task and the lack of a clear vision for energy storage can lead countries to adopt a disjointed approach to energy storage. This paper addresses this by presenting a framework based on the Analytical Hierarchy Process (AHP) that may be used to identify the most attractive storage mix for three scenarios: renewable integration, load shifting and power quality. Our analysis shows that for the power quality scenario, the most appropriate choices are supercapacitors, SMES and flywheel storage. For renewable integration the best options are pumped hydro and hydrogen storage. Both technologies are able to store excess renewable energy for relatively long period, making them an ideal way to deal with the intermittency of renewables. For load shifting purposes, pumped hydro storage is the optimal choice but limited due to the number of new storage sites available to construct, followed by thermal storage and batteries (VRB, ZnBr and NaS). These technologies are characterized by quick response time, high power density and low losses.


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## 1. Introduction

Energy storage is likely to form an important part of future energy systems where variable and uncontrollable renewable generation makes a substantial contribution to energy supply. Energy storage provides flexibility within the energy system, reducing the need for new generation capacity and facilitating better use of low-carbon power. Where many Governments have enacted programmes to support the growth of renewable energy, few have


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recognized the importance of storage. In Japan, for instance, 15% of supplied electricity has been cycled through a storage facility whereas in Europe closer to 10% of supplied energy passes through a storage medium with Germany being the leading nation [21]. Identifying the best storage mix for a country is a complex task that must consider not only the techno-economics of the technology, but also metrics, effects on energy security, carbon emissions, locational and geographical constraints as well as social aspects. This paper focuses on the process of identifying the most promising energy storage options at grid and national level. The paper focuses in UK as a case study. The application of the Analytical Hierarchy Process (AHP) is considered to explore the potential for a range of forms of energy storage to meet energy system challenges in the UK. A review of different energy storage options and a description of the three scenarios considered is provided in [15].

## 2. Methodology

Defining the correct mix of energy storage technologies requires economics to be balanced with a series of other concerns reflecting grid requirements, locational constraints and societal values. This section presents a means of measuring and comparing these concerns to identify promising technologies.

### *2.1. Energy Storage Cost*

A mathematical model has been developed to assess potential cost estimation for various energy storage options. The model is based on methods developed by [10] and [14]. The total storage cost $TSS_s$ is the annualized cost of the storage system per annum and is calculated as follows:

$$TSS_c = Cost_{CC}(\$) + Cost_{O\&M}(\$) + Cost_{ARC}(\$) \quad (1)$$

Where $Cost_{cc}$ is the total capital cost that includes the storage cost ($Cost_{storage}$), power conversion system cost ($Cost_{PCS}$) and the balance of plant cost ($Cost_{BOP}$).

$$Cost_{CC} = Cost_{storage} + Cost_{PCS} + Cost_{BOP} \quad (2)$$

$$Cost_{storage} = \frac{(C_E \times E)}{\eta} \quad (3)$$

$$Cost_{PCS} = C_p \times P \quad (4)$$

$$Cost_{BOP} = C_{BOP}(\$/kW) \times P \text{ or } Cost_{BOP} = C_{BOP}(\$/kWh) \times E \quad (5)$$

where $\eta$ = system efficiency (%)
$E$ = energy storage capacity (kWh)
$C_E$ = energy cost ($/kWh)
$C_p$ = power cost ($/kW)
$P$ = power capacity (kW)

The capital recovery factor (CRF) was multiplied with the initial capital cost to annualize the cost across a technology's lifetime.

$$AC = Cost_{CC} \times CRF \quad (6)$$

$$CRF = \frac{i(1+1)^L}{[(1+i)^L - 1]} \quad (7)$$

where $i$ = discount rate (%)
$L$ = lifetime of storage technology (years)

$Cost_{O\&M}$ is the operational and maintenance cost associated with the storage system to maintain the system in good condition. The annualized O&M cost is simply calculated by multiplying $Cost_{O\&M}$ with the power capacity (P).

$$Cost_{O\&M}(\$) = C_{O\&M} \times P \quad (8)$$

### *2.2. The Analytical Hierarchy Process*

In order to go beyond the simple cost model, a decision-making model has been developed using the Analytical Hierarchy Process (AHP). The AHP method was initially proposed by [11] and is based on pairwise comparisons. Further detailed descriptions of the AHP can be found in [12, 13]. AHP converts a subjective assessment of relative importance into a set of weights, which structures the problem in a hierarchical way. The first step in utilising AHP is to define a set of alternatives (i.e. storage technologies) to be considered and the criteria upon which these