Journal of Energy Storage 2 (2015) 43–46

Contents lists available at ScienceDirect

Journal of Energy Storage

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

Economic top–down evaluation of the costs of energy storages—A simple economic truth in two equations

Christoph Rathgeber*, Eberhard Lävemann, Andreas Hauer

Bavarian Center for Applied Energy Research—ZAE Bayern, Walther-Meißner-Str. 6, 85748 Garching, Germany

ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form 28 May 2015
Accepted 8 June 2015
Available online 25 June 2015

Keywords:
Sensible heat storage
Latent heat storage
Thermochemical heat storage
Storage capacity costs
Present value annuity factor

ABSTRACT

Energy storage is a key technology for increasing energy efficiency and a more extensive integration of renewable energies. Besides technical and physical limits, cost uncertainty is a major barrier to the development and utilization of energy storage systems. In this work, an economic top–down approach has been worked out following the assumption that the maximum acceptable costs of energy supplied by a storage should not exceed the cost of energy from the market. Thereby, maximum acceptable storage capacity costs are calculated from the interest rate assigned to the capital costs, the intended payback period of the user class (e.g., industry or building), the costs of energy from the market, and the annual number of storage cycles. The main findings of the top–down evaluation are: first, for a fixed cycle period, the maximum acceptable storage capacity costs depend on the user's economic environment. Second, seasonal thermal energy storage with up to 2 cycles per year requires storage costs below 3 €·kWh_{cap}^{-1} in the building sector and below 0.4 €·kWh_{cap}^{-1} in the industry sector, respectively. Third, short-term storages with for example 300 cycles per year allow 300 times higher storage costs. Therefore, if the annual number of storage cycles is sufficiently high, several energy storage technologies are economically viable. In this case, systems should be compared with regard to technical or physical attributes.

1. Introduction

Besides technical and physical limits, cost uncertainty is a major barrier to the development and utilization of energy storage systems [1]. In this work, an economic top–down approach has been worked out following the assumption that the costs of energy supplied by an energy storage should not exceed the costs of energy from the market[1] (hereinafter referred to as *REC* = reference energy costs). This assumption can be taken as a kind of *first law of economics*[2] of energy storages. Following this assumption, the maximum acceptable storage capacity costs (hereinafter referred to as SCC_{acc}) are calculated from the interest rate assigned to the capital costs, the intended payback period, the reference energy costs *REC*, and the annual number of storage cycles.

Detailed information about the storage technology or implementation are not required for this approach. As an example, the economics of thermal energy storage systems are analyzed in this article. However, the top–down evaluation is not limited to thermal energy storage, it can also be applied to, e.g., electrical energy storage. In this case, *REC* correspond to the costs of electricity.

2. Methods

Using the interest rate assigned to the capital costs and the payback period, the present value annuity factor, *ANF*, can be calculated to determine the present value of the energy storage capital. The present value is a future amount of money that has been discounted to reflect its current value. An annuity is a payment of the same amount at regular time intervals [3]. The annuity factor, *ANF*, as a function of payback period n and interest rate i can be calculated via Eq. (1):

$$ANF = \frac{(1+i)^n \times i}{(1+i)^n - 1} \qquad (1)$$

Interest rate i and payback period n depend on the user class. Three classes of users are referred to in the following discussion. In the *industry* sector, high interest rates of 10% and above and short payback periods of 5 years and below are usual. For *building* applications, moderate interest rates of 5% and longer payback

* Corresponding author.
E-mail address: christoph.rathgeber@zae-bayern.de (C. Rathgeber).

[1] Communicated, e.g., by Dr. Rainer Tamme, German Aerospace Center (DLR), in many presentations since 20 years.

[2] There are different definitions. We refer to the very basics [2].

http://dx.doi.org/10.1016/j.est.2015.06.001
2352-152X/

Nomenclature

ANF	annuity factor/year^{-1}
i	interest rate
n	payback period/year(s)
N_{cycle}	number of storage cycles per year/year^{-1}
REC	reference energy costs/€·kWh$_{en}^{-1}$
SCC_{acc}	maximum acceptable storage capacity costs/ €·kWh$_{cap}^{-1}$

Subscripts

acc	acceptable
cap	capacity
en	energy

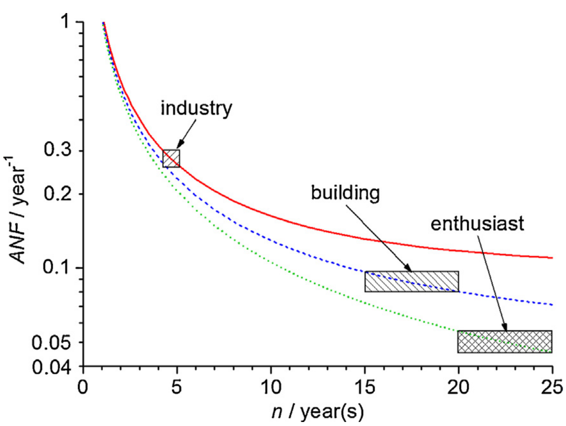

Fig. 1. Annuity factor, ANF, as a function of payback period n for three user classes (industry $i = 10\%$, building, $i = 5\%$ and enthusiast $i = 1\%$); framed regions indicate acceptable annuity factors for these users.

periods of 15–20 years are acceptable. In addition, one might also assume a user that can tolerate even longer payback periods of 25 years and low interest rates of 1%. The latter user class has probably political or ecological reasons for the investment and is hereinafter referred to as *enthusiast*. In Fig. 1, the annuity factor, ANF, is plotted as a function of the payback period n for interest rates of 10% (red solid line) indicating *industry*, 5% (blue dashed line) indicating *building*, and 1% (green dotted line) indicating *enthusiast*.

In the industry sector, a payback period of 5 years yields an ANF of about 0.26. Therefore, a range of ANF from 0.25 to 0.30 is considered as storage capacity cost annuity for industrial users. In the building sector, ANF are within 0.07–0.10, and in the case of enthusiasts, consequently, low ANF between 0.04 and 0.06 can be achieved.

The maximum acceptable storage capacity costs SCC_{acc}, calculated in € per kWh installed storage capacity (€·kWh$_{cap}^{-1}$), are simply the product of the substituted reference energy costs REC, given in € per kWh energy (€·kWh$_{en}^{-1}$), and the number of cycles per year N_{cycle} divided by the annuity factor ANF:

$$SCC_{acc} = \frac{REC \times N_{cycle}}{ANF} \quad (2)$$

Eq. (2) neglects operating costs and changes of REC over the payback period. Nevertheless, this analysis illustrates the relationship between acceptable storage capacity costs, the frequency of storage handling and the costs of reference energy that is substituted by the storage system.

Table 1
Economic boundary conditions: costs of substituted reference energy REC and storage annuity factor ANF calculated via Eq. (1).

User class	REC/€·kWh$_{en}^{-1}$		ANF/year^{-1}	
	(min.)	(max.)	(min.)	(max.)
Industry	0.02	0.04	0.25	0.30
Building	0.06	0.10	0.07	0.10
Enthusiast	0.12	0.16	0.04	0.06

Similar to the annuity factor, a range is considered for the substituted reference energy costs REC. As the focus of this work is to evaluate the costs of thermal energy storages, REC given in Table 1 correspond to heat or cold supply costs. Table 1 summarizes the economic boundary conditions of the three user classes that are taken into account in this top–down evaluation.

As an aid to orientation, expectable ranges for the costs of substituted reference energy REC and the storage annuity factor, ANF, are considered. In this way, a high and a low cost case are analysed for each user class. The high case considers the max. REC and the min. ANF, and the low case the min. REC and the max. ANF, respectively. Future changes of the reference energy costs REC can be taken into account by adjusting the values of REC given in Table 1 appropriately, e.g., by considering average REC for the intended payback period. According to Eq. (2), SCC_{acc} is proportional to REC and, hence, an increase in REC will cause a similar increase in SCC_{acc}.

3. Results and discussion

The maximum acceptable storage capacity costs SCC_{acc} for the three user classes calculated via Eq. (2) are plotted as a function of the annual number of storage cycles N_{cycle} in Fig. 2.

Solid lines indicate the high case of each user class and dashed lines the low case, respectively. A double-logarithmic scale was chosen to visualize both SCC_{acc} of long-term storages with only few cycles per year and short-term storages with several hundreds of cycles per year.

The results of the top–down evaluation as shown in Fig. 2 indicate:

- For a fixed cycle period N_{cycle}, SCC_{acc} depend on the user's economic environment. The low case of the industry sector and the high case of enthusiasts differ by a factor of about 60 in costs.
- For seasonal storage with exactly 1 cycle per year, SCC_{acc} are between 0.07 and 0.16 €·kWh$_{cap}^{-1}$ in the industry sector, between 0.60 and 1.43 €·kWh$_{cap}^{-1}$ for building applications, and in the range of 2–4 €·kWh$_{cap}^{-1}$ for enthusiasts. In the case of a 6000 m^3 seasonal hot water storage in Munich [4,5], which is part of a local solar thermal heating system and operated for 1.6 cycles per year, SCC_{acc} range between 0.96 and 2.29 €·kWh$_{cap}^{-1}$ in the building sector—which is usually targeted for seasonal thermal storage (cf. dotted lines in Fig. 2). Considering district heat costs in Germany of 0.08 €·kWh$_{en}^{-1}$ as REC [6], SCC_{acc} of this application are limited to 1.28–1.83 €·kWh$_{cap}^{-1}$.
- Short-term storage with several hundred storage cycles per year allows several hundred times higher storage costs because of the larger energy turnover. For example, a mobile sorption heat storage delivering surplus heat from a waste incineration plant to an industrial drying process [7,8] is operated for 240 cycles per year. For industrial users, SCC_{acc} between 16 and 38 €·kWh$_{cap}^{-1}$ have to be achieved in order to render this storage economically competitive. Considering gas prices for industrial consumers in Germany of 0.04 €·kWh$_{en}^{-1}$ as REC [9], SCC_{acc} of this mobile storage are limited to 32–38 €·kWh$_{cap}^{-1}$.