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An interdisciplinary review of energy storage for communities: Challenges and perspectives

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ABSTRACT

Given the increasing penetration of renewable energy technologies as distributed generation embedded in the consumption centres, there is growing interest in energy storage systems located very close to consumers. These systems allow to increase the amount of renewable energy generation consumed locally, they provide opportunities for demand-side management and help to decarbonise the electricity, heating and transport sectors.

In this paper, the authors present an interdisciplinary review of community energy storage (CES) with a focus on its potential role and challenges as a key element within the wider energy system. The discussion includes: the whole spectrum of applications and technologies with a strong emphasis on end user applications; techno-economic, environmental and social assessments of CES; and an outlook on CES from the customer, utility company and policy-maker perspectives. Currently, in general only traditional thermal storage with water tanks is economically viable. However, CES is expected to offer new opportunities for the energy transition since the community scale introduces several advantages for electrochemical technologies such as batteries. Technical and economic benefits over energy storage in single dwellings are driven by enhanced performance due to less spiky community demand profile and economies of scale respectively. In addition, CES brings new opportunities for citizen participation within communities and helps to increase awareness of energy consumption and environmental impacts.

1. Introduction

The pressure to cut greenhouse gas (GHG) emissions and to save fossil fuels has directed attention to solutions that can contribute to meeting society's energy needs while minimising associated GHG emissions. The most widely endorsed solutions are renewable energy (RE) technologies and energy efficiency, while nuclear energy and carbon capture and storage are generally viewed more critically. RE has been the fastest growing technology and since 2011 accounted for more than half of all capacity built in the power sector. In 2013, 22% of the global electricity supply was provided by RE sources (a 51.3% increase from 2004) [1]. While the main contributor to that share, hydro (76.4% of the global renewable electricity generation), is a dispatchable supply source (run-off river installations to a lesser extent), the faster growing technologies, namely wind turbines and solar photovoltaics (PV) energy are stochastic since their generation profiles are intrinsically linked with the weather conditions [2]. Another important characteristic of solar PV and wind systems is their modularity. Solar and wind generators have been extensively installed within distributed power generation systems, i.e. close to the demand centres. This is particularly the case for PV since 48% and 34%, respectively, of the total installed capacity correspond to installations with a nominal power

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Nomenclature

CAPEX	capital expenditure
CES	community energy storage
CHP	combined heat and power
DHW	domestic hot water
DSO	distribution system operator
ES	energy storage
EV	electric vehicle
FiT	feed-in tariff
FC	fuel cell
GHG	greenhouse gas
HP	heat pump
IRR	internal rate of return
LCA	life cycle assessment
Li-ion	lithium-ion
PbA	lead-acid
PCM	phase change material
PEM	polymer electrolyte membrane
PEMFC	polymer electrolyte membrane fuel cell
PV	photovoltaics
RE	renewable energy
RTP	real-time-pricing
SOFC	solid oxide fuel cell
ToU	time-of-use

lower than 50 kW_p in the UK and 40 kW_p in Germany, respectively [3,4]. In contrast, the power capacity of both wind generators and wind farms are increasing due to economies of scale.

From the demand side perspective, key challenges arise from the decarbonisation of heating demand and the transport sector. In this context, coupling of low GHG electricity generation with heat pumps (HPs) and electric vehicles (EVs) are currently being proposed in several countries. For example, HPs accounted for 9% and 12% of the space heating supply in Germany and Switzerland in 2012 respectively [5], but this share is 30% for newly built houses in Germany. By 2030, between 17% and 29% of space heating demand in Germany is expected to be provided by HPs according to market forecasts [6]. In view of further R & D needs and regulatory gaps [7] as well as prevailing market forces and consumer preferences, these technologies are expected to become dominant only within the 2030–2050 timeframe.

Against this background, technologies providing additional flexibility to energy systems should be implemented, however without relying on fossil fuels. Energy storage (ES) is attracting increasing attention as it improves the dispatchability of RE technologies while handling different energy carriers such as electricity, heat and gases and creates a more integrated energy system. Communities are becoming an attractive scale for the deployment of both low carbon technologies and energy efficiency measures such as building envelope retrofit [8]. Within the ES domain, community energy storage (CES) is emerging as a modular concept to be implemented close to energy consumption centres in connection with RE plants owned by end users. CES could support further the penetration of distributed RE technologies through: i) allowing end users to shift surplus generation to meet their demand load later; ii) maintaining grid stability (i.e., by supplying matching capability, compensating peak demand and offering solutions for related balancing issues); iii) internalising system benefits into economic revenues when taking part in different markets e.g., electricity wholesale and frequency markets; iv) and catalysing grassroots initiatives with the participation of community members that facilitate the socio-economic development of the district/community.

Several review studies on ES have been published given its relevance for future energy systems. Some of the first reviews, for example by Ibrahim et al. [9], Chen et al. [10] and Huggins [11], discussed the ES concept and mission including the whole spectrum of ES applications, technologies and related key technical characteristics such as capacity, efficiency and durability. Other authors reviewed a part of the full spectrum of ES applications and related technologies, e.g. the review of electricity storage applications by Brunet [12]; a review of ES technologies for wind power applications by Díaz-González et al. [13]; and the review of phase change materials (PCMs) for building applications by Cabeza et al. [14]. Given the continuous attention to ES, recent reviews have become more specific, focussing on the recent development of a particular technology, application, scale and/or country. Some examples are the evaluations of Stan et al. on lithium-ion (Li-ion) batteries for power and automotive applications [15]; Niaz et al. on hydrogen storage [16]; Lyons et al. on demonstrations projects in UK distribution grids [17]; a comparative analysis of the life cycle cost of different ES technologies by Zakeri et al. [18]; and a comparison of daily and weekly schedule including cost optimisation for different storage technologies by Ho et al. [19].

Considering the increased self-generation of energy and the modularity of several ES technologies, communities have been recently suggested as a key scale for energy systems [20,21] and ES in particular, allowing to make use of significant technical advantages [22–24]; to exploit economic benefits [23,25] and to engage local communities and promote social development linked with local RE supply [26–29]. Some reviews on CES have already been published. For example, Zhu et al. discussed distributed ES using battery technology for residential community applications [30]. B.P Roberts analysed its role for the development of smart grids [31] while Asgeirsson provided a brief update on the status of CES projects funded by Department of Energy (USA) [32]. All these previous studies and reviews on CES (and distributed ES in general) share similar characteristics. Firstly, the main focus was on technologies and applications supporting optimum electricity grid performance. Secondly, electricity and heat storage were discussed independently even though technologies such as HPs and combined heat and power (CHP) units connect both demands. Finally, no particular interest was paid to the role of end users (customers who consume and potentially generate energy, electricity and heat at home) although they are an important driver of the energy transition by purchasing and using RE and/or other lower carbon technologies.

For these reasons, there is a need for a more comprehensive review on CES that considers the multiple benefits of CES holistically: a) including CES applications depending on the involved stakeholder, i.e. end user, utility company and/or distribution system operator (DSO); b) considering different temporal ES scales for both electricity and heat; c) analysing the impacts of CES across the three pillars of sustainability (namely economy, environment and society); and d) discussing the role of different stakeholders such as end users, utility companies and policy-makers. The first objective of this review is therefore an in-depth analysis of CES applications, technologies, type of assessments and potential role of various stakeholders interested in the deployment of CES. Secondly, we also critically discuss the potential advantages of CES over other scales such as single-home and grid-scale storage as well as mechanisms to foster the uptake of CES systems. For low carbon energy systems, energy storage is an extra and still high-priced component therefore selecting the most advantageous location and scale to manage both renewable energy supply and demand is a priority.

2. Scope of this review

CES has been suggested as an intermediate solution between single-home ES systems and grid-scale ES systems, for balancing local inter-