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Assessing energy storage technology options using a multi-criteria decision analysis-based framework

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HIGHLIGHTS

- Individual energy systems have their own specific technical, and non-technical needs.
- A framework is presented for assessing energy storage options against these needs.
- It uses multi-attribute value theory and is tested in Cornwall, UK.
- It promotes engagement with stakeholders which can inform decision makers.
- It is less complex than alternatives and so can be used by non-expert actors.

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ABSTRACT

With the growing adoption of intermittent renewable energy generation the role for energy storage to provide a number of service needs is being increasingly recognised. However, 'energy storage' encompasses a family of technologies, each with its own set of performance, cost and physical characteristics, at different stages of development. At the same time, each energy system – however defined – has specific needs; and energy systems are themselves part of a wider socio-technical system which has aims beyond the confines of the energy 'trilemma'. As energy storage technologies develop, funding is becoming available to demonstrate their application in realistic environments. However, with multiple technical and non-technical factors to consider, it is challenging for many decision makers who often have limited expertise and resources to select which projects to support.

In this paper we first describe a novel framework for assessing the wider benefits that could come from deploying energy storage using Multi-Attribute Value Theory (MAVT), a form of Multi-Criteria Decision Analysis. We then use the framework to assess six potential energy storage projects through a combination of technical analysis and stakeholder input in the county of Cornwall in the UK: a region that has good solar and wind resource with relatively low demand and constrained network infrastructure. The projects assessed were: power to gas, a distributed battery system, battery storage integrated with solar PV and demand from Cornwall Airport Newquay, liquid air energy storage, battery storage integrated with wave energy, and thermal energy storage at a new residential development.

We conclude that MAVT can provide a straightforward and user-friendly approach, which can be easily used by decision makers for assessing energy storage projects across a range of criteria and promoting engagement with stakeholders. This approach also allows the subjectivity of decision-making, a potential limitation, to be explored through a sensitivity analysis. The use of MAVT can lead to important insights for the development of energy systems, which in this study included the importance of local priorities to decision-making.

In this case, battery storage with PV and demand from Cornwall Airport Newquay was the top-ranking project, performing well across a range of attributes including the maturity of the technology, its ability to defer grid upgrades and economic viability.

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1. Introduction

The growing need to decarbonise economies alongside the decline in cost of renewable energy technologies (RETs) over the last two decades means that in many countries and regions RETs now meet a significant proportion of the energy demand. According to the International Energy Agency RETs provided 23% of global electrical energy demand in 2015 and this is expected to rise to 37% by 2040 [1]. Many RETs use intermittent sources (wind, solar) so generation is variable, wind and solar generation met 3% and 1% respectively of global electricity demand in 2015 and this is expected to rise to 10% and 6% by 2040 [1]. As RETs reach a greater level of grid penetration there is a need for additional balancing measures to ensure supply meets demand [2].

Energy Storage (ES) technologies are one of the principle balancing measures, allowing energy to be stored at times when generation is greater than demand, and to be supplied when generation is less than demand [3]. Electrical Energy Storage (EES) can provide a range of applications from ancillary services such as frequency response and voltage support to longer term bulk energy storage [4,5]. Thermal Energy Storage (TES) can also provide benefits to energy systems, particularly when combined with the provision of heat or coolth, given that energy demand for heat is often larger than for electricity [6]. For example, electrical energy generated by renewables at times of low demand can be stored thermally and then used as heat or electricity at peak times [7]. Strbac et al. find that “achieving deep decarbonisation at efficient cost will require a significant increase in system-wide flexibility from the current levels”; additional ES can play a key role in providing new sources of flexibility [8].

Whilst ‘energy storage’ is often referred to in general terms, there are a range of technological options available, each able to provide different energy system services across varying time and energy scales. Each technology is unique with its own technical and physical characteristics [9], so a multi-dimensional assessment must be made when considering which ES options could meet a system need. Although there are existing tools for assessing conventional energy technologies against multiple criteria, such as those described in [10,11], ES options present unique challenges [12] that merit specific attention. Fundamentally ES is a family of enabling technologies designed to improve the performance of a network or system rather than simply generate or deliver an energy service, this makes it more complex to identify the benefits provided.

Furthermore, there are other factors including economic, environmental and social benefits [13], such as employment opportunities [14], reduction in CO_2 emissions and other pollutants [15], and energy justice [16], which influence decision-makers. Despite this, commercial deployment of energy storage focuses mostly on techno-economic assessments [17], with limited consideration of the environmental and social factors [18].

Due to this multi-dimensional nature of ES options, to allow a range of views on a holistic set of factors to be considered, it is important that any assessment framework developed can be adopted by, and allows the participation of, a wide-group of decision-makers and stakeholders, many of whom operate at a local-level including local authorities, private businesses and community groups. These organisations play an important role in facilitating the transition to a sustainable energy system [19], however many have limited resources and/or technical expertise [20]. It has been acknowledged that for these reasons many decision-makers can have difficulties with models which aim to assist with decision making in complex systems such as the energy system [21]. Therefore, a framework for assessing options which is not overly complex or time consuming is required.

This paper introduces a framework based on Multi-Attribute Value Theory (MAVT), a form of Multi-Criteria Decision Analysis (MCDA), for assessing ES options. MAVT has not been used to assess ES options previously, while MCDA has been used in only a handful of instances to assess specific ES technologies, in part due to the challenges discussed above. Refs. [22–24] focus on how ES can be used to improve the power quality of electricity networks, [25] assesses ES options for the integration of wind power in the United States, and [26] aims to identify an ES system for a coastal town in Pakistan. In all of these cases, and indeed in most energy planning cases, the methodologies are complex and resource-heavy. Furthermore, although [25] is informed by a narrow range of expert opinion, none of the studies uses stakeholder engagement to assess the wide range of factors which can influence the decision-making process.

The framework presented in this paper is novel as it takes into account a broader set of factors than previous studies and combines technical input with a participatory process of stakeholder engagement for assessing ES options.

The participatory nature of the framework promotes engagement with stakeholders from a range of disciplines allowing a holistic set of factors related to the energy system and other relevant societal aims to be taken into account. In partnership with local stakeholders the methodology has been tested in the county of Cornwall, a rural part of the UK which has a high concentration of renewable generation and a constrained network. The strengths and weaknesses of the approach are considered, and policy insights identified as a result of the use of this framework are discussed.

1.1. Cornwall

Cornwall is the most south-western county in the UK, at an extremity of the national transmission network. A single 400 kV line ends approximately halfway through Cornwall at Fraddon. The low-voltage distribution network is owned and operated by the Distribution Network Operator (DNO), Western Power Distribution (WPD).

Cornwall has the best solar resource [27], and one of the better wind resources in the UK [28], consequently it has a high level of grid-connected renewable generation. At the end of 2016 Cornwall had 130 MW of installed wind capacity and 553 MW of solar PV capacity [29], representing 1.1% and 4.6% of national capacity [30], for a county whose electricity consumption is only 0.9% of the UK total [31]. Table 1 gives a full breakdown of installed capacity and corresponding generation in Cornwall.

Fig. 1 shows the estimated monthly electricity demand, and solar PV and wind generation for Cornwall in 2016. The methodology used to produce Figs. 1 and 2 is described in Appendix A. Fig. 1 shows that local variable RET generation can meet over 40% of demand in May, June and July when solar generation is at its peak and demand is at its lowest. However, monthly data does not reveal the daily patterns in generation and demand; Fig. 2 shows the hourly demand and variable RET generation for a typical weekday in June. It shows that during the daylight hours when solar generation is making a considerable contribution, local RET generation can meet a significant proportion of

Table 1
Installed capacity and electricity generation in Cornwall, (all data taken from [29], except Gas/Oil where installed capacity was taken from [30] and generation was calculated using an average load factor taken from [32]).

Technology	Installed Capacity (MW)	Generation (GWh)
PV	553	509
Wind	130	281
Hydro	0.7	2
Landfill Gas	14	83
Anaerobic Digestion	0.2	1
Other Biomass	1.3	6
Municipal Waste	26.3	0[1]
Gas/Oil	140	1
Total	866	883

[1] Cornwall’s energy from waste plant was installed by 2016 but not operational until 2018 [33].