Accounting for socio-spatial impacts of energy storage technologies – Learning from energy infrastructures literature

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Abstract: Energy storage technologies are seen as critical to meeting decarbonisation policies in the UK as well as internationally. The focus in policy and practice to date has been to make energy storage technically viable, with little attention given to their impact on people, community, and places they inhabit. Studies show that energy infrastructures do have significant implications on people's social relations, energy practices, wellbeing, and health. However, accounting for these impacts in the context of energy storage has been fragmented and poorly defined. The purpose of this review is to bring together the disparate literatures covering impacts of energy infrastructures on people and inhabited places, with a view to draw attention to the multiplicity of effects energy storage may present. The literature review draws on semi-systematic methods, focusing on published international research. The benefits of the review are twofold. First, it provides novel insight for policy makers, practitioners, and academics on the complex impacts (social, technical, spatial) generated by energy infrastructures across sectors and scales, with a view to highlight the potential implications energy storage might have. Second, it helps understand the important role of energy storage systems in reducing carbon emissions and prepare for their predicted substantial growth across the UK and Northern Europe in the next 5 years.

Keywords: energy storage, built environment, carbon emissions, socio-spatial impacts, urban context.

1. Introduction

Renewable energy generation is currently at the forefront of decarbonisation agendas, both in the UK and internationally, with energy storage forming an integral part of these (IPCC, 2018, Simson, 2023). While planning and installation of energy storage technologies are accelerating, their social and spatial impacts are not studied (Sovacool, 2014). There has been established research on the wide range of social and spatial impacts of other energy infrastructures on people, though beyond energy storage. Studies exploring *spatial* changes as a result of local energy infrastructure developments, such as hydro-dams, wind farms and shale gas extraction plants, show impacts through community displacement, change in living conditions and changes in job security (Tilt et al., 2009, Égré and Senécal, 2003). Together with spatial impacts, scholarship also identified *social* impacts such as change in lifestyle and social beliefs, impacts on social equality and community health (Mottee et al., 2020, Stedman et al., 2012).

Theoretical and empirical research on energy infrastructures (e.g., windfarms, large hydro dams, solar farms, electricity lines, etc) characterises and accounts for diverse social and spatial impacts. However, research on energy storage implications to date has mainly focused on matters of social acceptability (Thomas et al., 2019, Devine-Wright et al., 2017). Acceptability studies generally explore reasons behind public support or opposition towards

potential energy storage deployment, without accounting for fine-grained social and spatial implications of energy storage installations.

While this area lacks research, there is a critical need to map and account for the likely impacts energy storage may have on people, communities, and places as well as ways this could be studied. This is especially pressing in the context of accelerated energy storage deployment in the UK and Europe which is predicted to grow exponentially in the next five years (Simson, 2023, Mexis and Todeschini, 2020). A review of published literature on the social and spatial impacts posed by energy infrastructures on nearby communities, how these impacts have been accounted for and in which contexts, can help provide not only knowledge on ways energy storage can be examined in future research but also the likely impacts that can be anticipated.

The following sections outline the methodological approach for the review, followed by a discussion on key themes found. The conclusion discusses the likely implications from the review insights and areas for future research.

2. Methods

It is worthy to note that, while over 80 energy storage projects are operational in the UK and more than 300 projects awaiting construction (Department for Business, 2023) there are no studies to date on their socio-spatial impacts. To begin to understand what potential implications these might pose on nearby communities, it is helpful to look at other technologies and their impacts. Thus, the review focuses on broader socio-spatial implications of global energy infrastructures and ways these have been measured.

Literature reviews can generally be classified as systematic, semi-systematic or narrative. Semi-systematic reviews help explore topics that have been studied differently by disparate disciplines (Snyder, 2019). A semi-systematic review was used to map common themes emerging across multiple disciplines covering socio-spatial impacts of energy infrastructures. The review was conducted in two stages. In first stage, a search protocol was developed, conducted, and papers selected. Searches were conducted using multiple databases (Google Scholar, Scopus, Science Direct and Web of Science). First searches focused on general queries: '*energy and social impacts'*, '*energy and spatial impacts*', and '*lived experiences of energy infrastructures'*. Three key themes emerged as part of this: sense-making, meaning-making, and place-making. These results led to targeted searches on '*energy infrastructures and sensemaking'*, '*energy infrastructure and meaning making*' and '*energy infrastructure and place-making'*. In total, after both searches, 89 papers were found, when searched 'in the title of the article' and in 'key words'. Inclusion criteria set were English-published peer-reviewed papers, all publishing years. Both qualitative and quantitative approaches were included to fully capture the range of methods used in energy and social sciences research. Exclusion criteria were editorials and reviews, studies not focused on social or spatial impacts, studies not grounded in theory, non-peer reviewed papers and non-English published papers. After removing duplicates and implementing exclusion criteria, 24 papers formed the final sample. The second stage was conducted via snowballing, utilising bibliographical references. Both inclusion and exclusion criteria were used to ensure that the review only targets research published in reputable journals (with an Impact Factor > 3), and papers are focused on spatial and social impacts of energy infrastructures. A further 17 papers via snowballing were included.

3. Overview of key themes identified in literature

Three key themes emerged in the review including 15 studies that explore how people make sense of new energy infrastructure technologies (*Sense-making* and *meaning-making* theme); people's identities with place in the context of new energy infrastructures (Place-making theme with 13 studies) and a third theme focused on methodological and theoretical insights (theories and methods theme) with 13 studies.

Sense-making and meaning-making studies on energy infrastructures reveal how people register new energy developments. Such research can provide valuable insight into the social impacts operational energy infrastructures pose on nearby communities and people. As Burdge and Vanclay define them, social impacts refer to any 'social and cultural consequences to human populations' generated by any public or private development, in this case energy infrastructures, which alter the way people 'live, work, play, relate to one another, organize to meet their needs, and generally cope as members of society' (1995:1). In this review, identified papers highlight social changes, such as shifts in attitudes, lifestyle and identity (Jacquet and Stedman, 2013) emerging in relation to new local energy infrastructure developments.

One extensively studied energy infrastructure is wind farms. Kim and Jung (2019) in their study of four Korean wind farms, identified implications on identity and perception: residents see their community as mechanical after wind farm installation, due to noise and visual impact; attitudes: people fear the unknown and the potential implications of wider novel technologies on health and general wellbeing; and lifestyle: some residents, although recently moved to the area contemplated relocation. Similarly, Papazu (2017), in studying the sudden opposition to a new energy development in an energy community, identified lifestyle discrepancies between novel technologies and the community as main reason.

Intertwined with sense-making and meaning-making, studies on *place-making* contribute to a richer understanding of 1) how spatial impacts unfold and 2) the role place identity plays in forming these impacts. One key insight provided by place-making research reveals that in some cases, new energy infrastructures greatly impact on place identity and community perception (Bailey et al., 2016). In doing so, social relations between community members see negative shift (Gailing et al., 2019). Consequentially, social cohesion – the bond formed between residents – can suffer.

Research methods across sensemaking and place making vary, with some papers relying on case-studies (Gailing et al., 2019, Fast and Mabee, 2015), questionnaires, semi-structured interviews (Bergquist et al., 2020), narrative semi-structured interviews (Bailey et al., 2016) and experimental methods (Winthereik et al., 2019, Papazu, 2017). Following up on the first two themes, the theories and methods section addresses how social and spatial impacts are measured and accounted for.

The way people make sense of and give meaning to new energy developments has been studied by different disciplines, using a wide range of theories. To form a comprehensive picture of commonly used theories, the following frameworks were identified: Science and Technology Studies (STS), Social Construction Studies and Social Acceptance. Out of the 15 papers that discussed social and spatial impacts through sense making, 4 drew on analytical concepts found in STS; 3 used social construction theories and 8 focused on social acceptability. Within the second theme of *place-making*, with 13 papers, 1 focused on Territory-Place-Scale-Network Theory (TPSN), 10 papers on place identity and 2 papers on place attachment. To ensure diversity, the review looked at several energy infrastructure

technologies, in order of research focus: wind farms, hydro dams, solar farms, hydrogen plant, shale gas plants and electricity lines.

Table 1 illustrates all three themes (sense and meaning making, place making and methods and theories), common paradigms used, as well as the theoretical frameworks utilised and their unit of analysis.

Table 1 Key themes and theoretical frameworks identified in reviewed literature.

Impact	Theme	Field	Theory	Use of Theory	Unit of Analysis
Social	Sense and Meaning Making	Science and Technology Studies (STS)	Actor-network Theory (ANT)	Explores human-technology nexus, under the premise that everything in the social and natural world exists in constantly changing networks	People=Technology (does not differentiate between actors' nature)
		Social Construction Studies	Social Representation Theory (SRT)	Understands information processing mechanisms as a two-step process (anchoring and objectification)	People-focused
			Risk Perception Theory	Studies people's perceptions on rapid change and associated risks	People-focused
		Social Acceptance	Social Impact Assessment (SIA)	Primarily predicts social impacts of infrastructures and other planned developments	Technology-focused
Spatial	Place Making	Socio-Spatial Studies	Territory-Place-Scale-Network (TPSN)	Explores the role of four actors in socio-spatial relations	Multiple foci
			Place Attachment Theory	Studies people-place bonding, accounting for emotions, memories, knowledge, beliefs, and behaviours	People-focused
			Place Identity Theory	Integral part of place attachment, explores the construction of personal identity and physical environments	People-focused

3.1. Theme 1- Sense making and meaning-making

Theme 1 included 15 papers that discuss social impacts generated by energy infrastructure installations as follows: lifestyle (6 papers), attitudes (5 papers) and identity (4 papers). Lifestyle was addressed as disruption to lifestyle and risk of disruption. Attitudes were studied

in terms of positive/negative change following energy infrastructure installation. Finally, identity was covered as positive/negative change as well as risk of negative change.

Papers covering *attitudes,* such as acceptability (Devine-Wright et al., 2017, Devine-Wright and Devine-Wright, 2006) or learning to live with novel technologies (Winthereik et al., 2019, Gailing et al., 2019), show that energy infrastructures affect people's perceptions both positively and negatively. General post-installation attitudes can vary depending on 1) local, regional and national scale (Devine-Wright and Batel, 2017), and 2) factors such as demographic (del Río and Burguillo, 2008, Soini et al., 2011), past experiences (Kim and Chung, 2019), media coverage, socio-cultural and economic values (Delicado et al., 2016) or duration of exposure to technology (Sherren et al., 2019). While some studies indicate that attitudes vary from one to technology to another (Irie et al., 2019), other argue that experiences vary from one research participant to another regardless of technology (McLachlan, 2009, Groth and Vogt, 2014, Owens, 2016).

Research on small-scale energy infrastructures, such as electrical substations or similar, are very fragmented (Terrapon-Pfaff et al., 2019). Conversely, studies on the impacts of developments such as wind, hydro and solar energy infrastructures are abundant, and can, at minimum, provide a gateway to exploring other technologies, such as energy storage. In this review, *lifestyle* impacts are covered in terms of disruption (Kim and Chung, 2019) and potential disruption (Papazu, 2017). Disruption to daily routine is related to aesthetic characteristics (large wind farms obstructing views), noise and landscape modifications (residents felt that their area does not look the same anymore; from *natural* to *mechanical* neighbourhood). *Identity* studies encompassed both lifestyle and attitudes. Kim and Chung (2019) and Tilt and colleagues (2009) show permanent residents' identity to their neighbourhood negatively shifted, in light of wind farm and, respectively, large dam infrastructure installations.

Common trends across social implications are disruption to familiar routines (daily life, social relations, change in landscape) and fear of the unknown (change in wellbeing, lifestyle) (Jacquet, 2009). Both trends can have long term implications. One study on shale gas plant installation showed that fear of the unknown led to mental health concerns in local residents, even in pre-installation phase (Stedman et al., 2012). Social impact is also closely linked to implications on *place* (spatial impacts). Impact on identity, for example, is twofold, as it can affect the way residents identify with the neighbourhood both socially and spatially. The following section will elaborate on spatial impacts and how they unfold.

3.2. Theme 2- Place making

Research on place-making mechanisms accounts for the spatial implications of energy infrastructures. As well as reconfiguring the *social* patterns discussed above, energy infrastructures can also re-shape *spatial* configurations. Place attachment, closely linked to place identity, is a complex phenomenon, incorporating feelings, emotions and perceptions formed by residents towards their community (Peng et al., 2020). Studies on energy infrastructures and place-making processes show that the identity formed by an individual for the place they live in highly influences how they see and perceive novel additions to their environment, such as wind farms, dams, solar farms, and others. The 8 papers identified on place-making generally address place identity and place attachment, with identity and attachment are considered interchangeable.

Papers such as Kim and Chung (2019) and Tilt and colleagues (2009), for example, address both place making and sense making. For place making, they identify negative changes to (permanent and new) residents' feeling of belonging, which in some cases turns

into relocation. Other papers like Bailey and colleagues (2016), show that in some cases place attachment is stronger in permanent residents, and therefore the impact on these groups is higher. In contrast, further research highlights that longevity is not always relevant, whereas active citizenship and place-bonds are (Bailey et al., 2016). Bergquist and colleagues (2020) show that spatial implications are also connected to residents' lifestyles; for example, for farmers, a wind farm installation might threaten agricultural activities, while for others (Jacquet and Stedman, 2013) there is fear of neighbourhood dynamic change. Culture and heritage also present a main factor in negative attitude shifts, whether related to energy infrastructures, such as power lines (Soini et al., 2011, Bailey et al., 2016), or renewable energy installations (Delicado et al., 2016).

Overall, identity matters tend to be multi-dimensional, with crossovers between social and spatial implications, and span over different cultures, scales (urban, rural, semi-rural), as well as over different technologies, as previously discussed. The next section reviews common frameworks and methods used to measure these impacts and discusses advantages and limitations of each, as well as how these can be used to study the potential implications of energy storage installations.

3.3. Theme 3- Theories and Methods

3.3.1. Sense-making and meaning-making theories

Energy research on social attitudes provides a starting point in investigating the people-technology relationship. Dominant areas of attitude scholarship are social acceptability (Devine-Wright et al., 2017) and risk (Joffe, 2003). Social acceptability is widely studied in relation to renewable energy infrastructures and is most often framed using NIMBY (Not-in-my-Backyard) literature. NIMBY 'describes opponents of new developments who recognise that a facility is needed but are opposed to its siting within their locality' (Burningham et al., 2006:2). However, it received extensive criticism for its over-simplistic nature (Devine-Wright and Howes, 2010, Warren et al., 2005), with scholars showing that *identity*, in some instances, is more important than *proximity to development* in forming attitudes (Phadke, 2011, Wester-Herber, 2004).

For a more comprehensive measurement of social acceptability, some studies use the Social Impact Assessment (SIA) framework. SIA has the overarching goal to create more sustainable transitions, by predicting positive and negative implications of planned infrastructural developments (Vanclay, 2003). Describing best practices, Égré and Senécal (2003) put forward an extensive agenda, covering key stakeholders, demographics, potential impacts and solutions as well as post-installation monitoring. SIA is versatile and could be used for different technologies (like energy storage), however it requires adjustments to account for different settings (Kirchherr and Charles, 2016). Other limitations include large number of stakeholders involved and a lack of willingness to participate.

Although acceptability studies can provide useful insight into public opinion on novel technologies and their deployment, they are most often prospectively used and do not measure impact post-installation (Vanclay, 2012). To gain an in-depth understanding of the people-energy infrastructure nexus, research needs to focus on how people ***experience*** energy infrastructures, including storage (L'Orange Seigo et al., 2014). *Experiences* are deep-rooted socio-psychological mechanisms, through which individuals make sense of and give meaning to reality and associated changes (Weick et al., 2005, Sommer and Baumeister, 1998). In turning the 'unfamiliar into familiar' (Batel and Devine-Wright, 2015:315), like in the case of a new technology, people use images and metaphors. The theory measuring this, Social Representation Theory, is known as SRT (Moscovici, 1988). While most studies use SRT

prospectively to understand how sense-making forms opinions (Devine-Wright and Devine-Wright, 2006, Batel and Devine-Wright, 2015), others employ it retrospectively. A study of two hydrogen plants (Scotland and England) showed that the Scottish community used SRT to make sense of the newly installed technology, and attach more positive attributes to it, compared to the English community, where feelings of anxiety towards an unfamiliar technology were greater (Sherry-Brennan et al., 2007). Novel technologies, argues Sherry-Brennan (2007), can be seen as risky. Risk perception can be influenced by media coverage (Scheufele and Lewenstein, 2005), views held by key community actors, cultural values, and previous personal experiences with energy infrastructures (Jacquet and Stedman, 2013). SRT could be a way to understand the origins of perceived risk, and to grasp how a novel technology might be psychologically registered by local communities. However, SRT, in its quest to unpick highly complicated psychological mechanisms, is context-dependent and cannot provide broad insights (Joffe, 2003).

Another field concerned with the relationship between people and new technologies is Science and Technology Studies (STS) (Asdal and Moser, 2012). The Actor-Network-Theory (ANT), developed through STS, questions how technological advances shape social orders (Latour, 2005). The ever-evolving relationship between people and emergent technologies was studied via STS and to some degree, ANT, on Samsø island, Denmark (Papazu, 2017). Here, residents turned Samsø into the first 'renewable energy island' (Nader, 2010:504). In a decades-long process, they built (physically and mentally) a renewable energy reality, wherein they lived with the novel technology and assigned positive meanings to it.

Meaning making can equally be as revealing to understand the implications of newly installed energy technologies. Interwoven with sense-making mechanisms, meaning-making helps people process social change. *Memory* (collective and individual) is integral to meaning-making processes (Küpers and Batel, 2023). Memories historically acquired by community members constitute a big part of how their lived experiences with energy developments unfold. Kim and Chung (2019) showed that in light of wind farm developments, four South Korean communities created new place meanings based on individual memories. When residents felt that their familiar environment is disrupted by unfamiliar elements (wind turbines), they developed negative meanings for their community. By contrast, in the face of change in Samsø, people worked collectively to create positive new realities of their island, allowing their memories and place meanings to positively change over time. Similar to this example, in the hydrogen plant study (Sherry-Brennan et al., 2007), the Unst (Scotland) community found positive outcomes and meanings following installation.

3.3.2. Place making theories

Meaning making is closely linked to community (physical and perceptive meaning). A seminal framework for understanding the 'spatialities of energy transitions' (Gailing et al., 2019:1113) is Jessop's TPSN – standing for Territory (inside-outside border), Place (proximity), Scale (hierarchy of social relations) and Network (interconnectivity between nodes of energy and social relations). TPSN argues that the people-energy nexus is multi-dimensional, formed of multiple scales, networks and interdependencies (Jessop et al., 2008). For example, a German study (Gailing et al., 2019) shows how neighbourhoods shifted identity (from *a* neighbourhood to *an energy* neighbourhood) as a result of energy systems installations. However, the framework received criticism for characterising places in only four dimensions without considering other factors (e.g., how people's lived experiences with place or legislators' responses to place influence spatiality) (Jones et al., 2013, Tan, 2016).

The question of interdependency between people and their physical environment is further posed by the theory of *place attachment*. Place, as seen by Relph (1976), is constructed by people through emotions, memories, beliefs, behaviours and previous experiences. The notion of place-making is a central concern in the Place Identity Theory (White et al., 2008), for example. The intricacies between place attachment and place identity can be difficult to break down, although it is commonly believed that individuals build place identity using two constructs: internal and external thoughts. Internal thoughts include mental images, metaphors and descriptions applied to the area of residence. External thoughts deal with physical appearance, symbolics shapes (area landmarks, language, etc) and institutional shapes (street, neighbourhood, area, etc) (Peng et al., 2020). In relation to energy projects, place attachment and/or identity can shift both positively and negatively. For example, one study looking at a tidal energy project in Northern Ireland highlighted that, instead of disrupting identity to place, the project enhanced it. This shows that if the energy development is registered mentally by residents as place-enriching, rather than place-destroying, place identity levels can rise (Devine-Wright, 2011). Similarly, Soini's (2011) power lines study also shows that external thoughts can shift from negative (project makes environment less desirable to live in) to positive (seeing project as area enhancing), thus potentially impacting on place attachment levels.

3.3.3: Methods: advantages and limitations for energy storage research

Measuring social impacts through sense and meaning making theories can take different forms. Some of the identified papers draw on traditional methods, such as semi-structured interviews (Kim and Chung, 2019), case-studies (Tilt et al., 2009) and participant observation (Papazu, 2017); while others employ experimental methods: story-telling, poetry (Winthereik et al., 2019), and archival research (Devine-Wright and Devine-Wright, 2006).

Several studies highlight the importance of understanding socio-spatial relations using multi-dimensional methods (Jones et al., 2013, Tan, 2016, Moore and Hackett, 2016). One example of how this might take form is Winthereik and colleagues' (2019) work which uses a mix of storytelling, poetry, walks and experiential imagery to grasp people's emotional engagement with the newly developed marine energy industry in Denmark. Positioned within STS, the *Energy Walk* encourages participants to let *senses* take over rational thoughts. The intentional shift from purely observational methodologies (interviews, questionnaires) to experiential exercises physically places the individual next to energy installation, creating a more dynamic interaction. Experiential methods might provide unique insight into how people make sense of new energy technologies. For energy storage, such methods can help us understand how people *experience* installations. The combination of storytelling, walks and imagery, in particular, can be of great help in 1) understanding whether the installations are visible to residents (Sherren et al., 2019), 2) measuring perception (sense and meaning making) and 3) measuring the effect these have on people's identity with place. While multi-dimensional methods can be a unique measuring tool for a unique setting, they also have drawbacks, and raise questions of prescriptiveness. In other words, how can we distinguish between people's organic experiences and the in-built experiences created by researchers through these methods?

4. Discussion and Conclusion

This review set to explore and highlight the wide range of implications energy infrastructures pose on individuals, communities, and places they inhabit. The social and spatial impacts discussed here, although observed in other technologies, provide a starting point for further

research into potential energy storage impacts. By employing semi-systematic methods, the review focused on three key themes found in the disparate literatures on energy infrastructure impacts: *sense and meaning making*, *place-making* and *theories and methods*. Each theme brings different aspects of the people-energy nexus to light. Sense-making and meaning making studies highlight how people experience energy infrastructures, while place-making studies showed place identity and its construction to be crucial to how people make sense of and live with energy infrastructures. Finally, the third theme indicates a diversity of theoretical and methodological insights that are drawn upon in study of impacts of energy infrastructures that would be useful in the study of energy storage effects. Although not without limitations, all methodologies provide a different lens to see not only a highly dynamic world, but the complexities involved in how people live with novel energy technologies. Attempting to understand how emotions, memories, and general attitudes are shaped, can be very beneficial to 1) account for deeper social and spatial implications and 2) attempt to predict future social and spatial implications of other new technologies, such as energy storage. This review acknowledges that no one study can account for how each individual experiences novel technologies (Soini et al., 2011).

In effect, the paper expands knowledge on how energy storage socio-spatial impacts might be accounted for in 3 ways: 1) it presents the different social and spatial implications (changes in lifestyle, attitudes and identity) that other energy infrastructures pose on individuals and their communities in order to 2) highlight the importance of studying energy storage installations socio-spatial impacts, and 3) provides novel insight into how we can account for these impacts, which can better inform policymakers, technology developers and wider academia (Krumm, 2022).

In conclusion, it is widely agreed that energy infrastructures form an integral part of the societal fabric, and it is critical to understand how people 'metabolize' (2007:1) and live with new technologies (Mordini, 2007). In light of decarbonisation agendas and the increasing levels of energy storage installations deployment in the UK, it is crucial to account for their social and spatial implications (Devine-Wright et al., 2017). Accounting for these impacts is critical to community wellbeing, as it provides a richer understanding of how the storage installations impact on daily routines, social relations, and local identities. Ultimately, gaining a richer understanding of these implications allows for a better consideration of their deployment and ensures decarbonisation efforts are more efficient and sustainable long term.

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