Beyond energy services: A multidimensional and cross-disciplinary agenda for Home Energy Management research

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Abstract

Home Energy Management (HEM) has a significantly growing impact on strategic energy policy, digital equity, as well as housing development and transport issues. With the proliferation of home working, reliance on electricity for heating and cooling and the increasing needs for electric charging for transportation, there is an urgent need to develop novel ways for efficient management of home energy use. Current efforts focus on HEM technologies at individual household levels, without considering the social or spatial context or their collective community-wide interrelated dependencies.

We propose a multifaceted agenda at the intersection of disciplinary domains to tackle this problem by using a multidimensional lens that draws on energy behaviour, architectural research, biomimetics, and computational design, simultaneously. Optimal and effective behavioural patterns can be extracted and abstracted from nature, informing a more collective and interrelated behavioural dependencies approach that considers the complex multidimensional energy use patterns of different housing typologies. This paper discusses the analytical benefits of this new research approach through a study of home energy management behaviour. The approach though could be expanded to consider other similar empirical contexts whereby sustainable multidimensional resource management is sought such as water use, food distribution as well as transport and mobility.

Keywords: architecture, biomimetics, computational design, cross-disciplinary methods, home energy management

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1.Introduction

Use of innovative cross-disciplinary and multidimensional methods in the study of complex interrelated phenomena, particularly in the context of home energy management, are scarce. It is well established that study of energy can not be confined to a particular disciplinary approach or a specific technology [1]. Whilst prior research has called for new approaches to use of cross disciplinary methods in energy studies [2], focus has tended to be on the merging of the social and technical, overlooking the spatial dimension. Where space has been considered, it has been viewed mostly through a geographical, territorial lens [3] and as 'the relational proximity of one element in the system to another' [4:334]. Approaches to studies of space through an architectural, designed perspective as an 'existential' and not only geographical dimension – able to uncover meanings present in an environment from individuals to communities of dwellers [5] are largely missing in energy research.

One of the most critical environmental, economic, spatial and social challenges facing societies across the globe is the management of energy as a resource that powers human needs in multiple ways across many socio-spatial dimensions of activity [6]. Home energy management (HEM) presents a multifaceted interrelated set of issues where use of energy for varied and diverse domestic activities, including car charging, begin to overlap and impact on issues of inclusion, equity and justice across many communities and in multiple spatial configurations. Yet, despite its inherently complex and multidimensional empirical context, as well as its multiple potential disciplinary perspectives and contributions, research on use of HEM has overlooked the potential for cross-disciplinary and multidimensional methods focusing mostly on the specification of management devices and technical scope of device features [7].

HEM devices and technologies have been studied extensively [8], however, there is insufficient evidence to date on how those devices and the energy use of individual households constitute the broader energy management regime. Home energy behaviour may reflect the individual values of each household, but how do those values reflect upon the collective? The energy management infrastructure has traditionally been developed in a top-down manner with energy firms largely dictating the technology implemented in households. This model, however, ignores the interconnected ways that households operate and the impact of individual units on the grid. Exceptions include study by Todd-Blick et al., [9] that recognises this heterogeneity of use and demand response, however, primarily from the point of view of the individual user and for the individual's benefit. The role of energy use in neighbouring homes is currently invisible within individual household management scenarios. Technology, people and infrastructures are interrelated, underpinned by a need for understanding and meeting collective values.

There is an urgent need to understand energy from the perspectives of individuals living in their homes alongside each other not as isolated users [10]. This understanding will help identify new dimensions of HEM that reflect the social and spatial aspects of energy use and management. Such novel dimensions have the potential to allow the development of a bottom-up, collective energy management approach that can add value to the existing energy infrastructure. Cooperation and collective action in energy transitions can be driven by increased information, frequent communication between stakeholders, predictable, understandable changes in systems, and the involvement of users with a longer-term vision [11]. The involvement of individuals and communities in new energy governance structures can be hindered by the lack of communication and understanding of how such structures and communities of use might work in practice and in the everyday [12]. Intermediary organisations – or other conduits – facilitate information exchange from the national level (where policy, planning and targets are set) to the local level (where energy resources are used) [12]. This faciliatory role is often taken by local government and, in some cases, community energy organisations.

Nevertheless, despite the emerging recognition that involvement and participation matter for energy transitions, energy users are often treated as customers and passive consumers, rather than important actors. As Ryghaug et al., [13] have argued, engagement with energy users as key actors might allow for the development of new notions of energy citizenship. It is necessary for HEM research to find the middle ground between a focus on energy citizenship and community demand needs, to explore how communities can form new solutions to participate in localised energy systems. Such a focus requires the simultaneous consideration of energy users not only as individuals, but also as part of a broader collective. Without a renewed approach, the potential for context-driven localised digital and energy home transformation processes will continue to be overlooked, making considerations of energy justice and digital equity a set of one-dimensional outcomes and policy factors [14].

Energy transitions are at the centre of complex, multi-scalar, multi-actor policy debates that require cross disciplinary and multidimensional approaches to understand the interrelated, varied components present within energy systems – as well as how they can shift and adapt [15]. A mantra of crossdisciplinarity, as a means to understand this complexity, has been invoked across research and scholarship for some time [16]. A crossdisciplinary approach requires thinking not only in terms of the instrumental role of methods, but also reflecting upon how particular discipline-specific epistemologies interact, complement, and contrast with one another. HEM provides a fruitful ground for such experimentation and exchange [16], involving discussions of the built environment, new monitoring technologies, and individual and collective practices of consumption. Complexity is not only inherent in the technological systems that may be formulated and installed – but also in the homes that communities live in, the way that individuals behave across different spatial configurations, and the institutional rules and social norms that may govern such processes.

Study of complex interrelated phenomena has historically been approached through a systems lens at a theoretical level [17]. Ecosystem concepts have recently emerged as a visible stream in sustainability, environmental science, organisation and management research. The ecosystem concept promises a broader, systems view of organisational and technological phenomena beyond traditional firm, value chain or network boundaries. Numerous ecological research investigations have been conducted to understand how patterns emerge at multiple scales to find new insights into tackling persistent problems in large-scale systems [18]. To comprehensively understand urban systems as a complex spatial structure, greater consideration to a meta-ecological system as a subset of levels is needed. As an interconnected hierarchal unit, the energy flow through an urban setting exhibits similar energy flows of other species within their natural territories. Incorporating understandings of how ecosystems work into urban design is a step towards more sustainable built environments [19] and could well provide a similar move in HEM and wider processes of decarbonisation.

Adopting an ecosystem approach, however, presents a range of methodological challenges for researchers, including defining the boundaries for the ecosystems, how to examine their structure and relationships, and how to explain the inherent dynamics and co-evolution including their spatial properties. This is reflected specifically in households, where the apparent boundaries of the built edges, do not always match or correspond to evolving socio-spatial temporal edges.

2. A new multidimensional research avenue - learning from cross-disciplinary methods

Whilst studies have offered approaches to manage energy demand through communicating, via HEM technologies, the optimum energy use of a home compared to average households, these have been largely derived from technical data and guidance, rather than socio-technical evidence. In addition, any empirical evidence on energy management has largely shaped the design of HEM technology to inform and communicate use, rather than mediate or change sociospatial behaviour. In principle, HEM technologies communicate to users' data about their energy patterns and behaviour, with the aim to influence energy saving behaviour. In this sense, technologies can increase awareness, visualise, provide feedback or incentives to the user [20, 21 and 22], without necessarily addressing adaptive behaviours per se or taking into consideration the role of the collective social and spatial spheres. There is an established connection between the way in which individuals explore new technology and exploit known assets in the social and spatial spheres [23, 24]. Individuals are characterised by an *activity space* of repeatedly visited locations within which they move during their daily activities, with this spatial signature varying in size and spatial shape [25]. Spatial methods developed in architecture and social network methods [26], offer a helpful way to visualise and document behaviour across scales and in diverse contexts, however, they do not provide the analytical lens into how needs across the socio-spatial contexts could be communicated.

Architectural and design research have offered methods for the study of space and human interaction at multiple scales, whereby emerging studies have provided exploratory findings into the effects spatial configurations have on technology use in the home [27]. However, both social and spatial studies have tended to focus on the individual or collective levels of analysis overlooking the connection between the two. There is a need to study the interaction and relationship between the individual and collective levels of dwelling to provide a helpful insight into a more holistic approach of energy use and HEM.

The merging of social science, behavioural studies, as well as biomimetics and computation modelling could offer a new lens into ways interrelatedness between individual households and wider community, energy systems, communication and ways of living can be studied. For example, whilst not applied in the context of household energy management, or in combination with other methods, biomimetics and computational design are likely to provide better sustainability outcomes [28]. Behavioural patterns found in nature offer a view into ways responsive and interconnected communication logics develop dynamically as a response to changing needs and environmental conditions [29]. There has been little recognition of what could be learnt from nature where many examples can be found of organisms that have evolved ways of communicating collective resource need in real time to individuals [30]. Study of resource management behavioural patterns found in nature drawing upon biomimetics and computation could offer an approach to analyse communication of needs that socio-spatial analysis, discussed above, does not enable.

Using biomimetic insect behavioural pattern analysis and Multi Agent based (MAB) computational methods, Lin and Hu [28] consider energy flows to minimise the consumption cost in relation to user satisfaction, reporting an optimised cost-to-energy use ratio reduction of 13.97%. Their study offers a helpful insight into the likely analytical benefits of a biomimetic and computational approach in the context of energy behaviour. Whilst not drawing on biomimetics specifically, Magnolia et al. [31] study offer, nevertheless, helpful insights into empirical use of MAB methods within the context of energy research. They argue that MAB modelling offers an optimal approach for understanding social behaviour by predicting the implication of energy policy change on the collective, expanding work carried out by Rai et al., [32] and Palmer et al., [33].

MAB systems applications are increasingly applied in a range of domains due to their ability to drive digital tools that help analysis and develop new models and theories in large-scale distributed and decentralised systems, such as computational architecture, healthcare, manufacturing, and e-commerce. At the forefront of the field, distributed structures are beginning to focus on human-centred systems due to the need for distributed use of technology allowing users without technical preparation to interact with tools in multiple ways [34]. While our position aligns with this assertion, an approach that employs MAB modelling drawing on socio spatial energy behaviour data and not only socio-technical in addition to biomimetic concepts could offer a new understanding of interrelatedness patterns between individual HEM use and collective energy demand.

A new approach that draws on socio-technical and spatial methods in combination with biomimetics and computation could offer a new methodological approach for study of HEM interrelated use and management inspired by nature. The approach also foregrounds focus on community energy networks within a broader process of decentralisation and democratisation. This entails the formation of new institutional environments, in which local energy systems are shaped by various stakeholders, as evident in the formation of the Renewable Energy Directive in the European Union [35]. Processes of decentralisation and democratisation can be understood as representing wider moves to alter how energy is consumed, as well as the socioeconomic practices that it might underpin [36].

3. Conclusion and Discussion

Energy behaviour studies have to date drawn on a range of qualitative and quantitative methods to provide rich insights into habits, routines, and attitudes towards energy at a mostly individual scale, rather than more how such behaviour might fit together at the community level. They have mostly provided an insight into the social context of energy use but have to date ignored the spatial and multidimensional context. Though there have been a growing number of studies drawing on social and socio-technical methods and wider thinking on the need for integrated approaches [37], there have been no studies to date that have applied innovative crossdisciplinary methods that examine and optimise the interrelated collective and individual behaviours. Where energy behaviour has been analysed as part of a larger system of interdependent properties, it has excluded the spatial character or relationships between different scales (the home and housing community).

There is an urgent need for exploratory experimental and brave methodological innovation, where boundaries between and across disciplinary fields are advanced and tested across multiple dimensions of analysis. Moves towards a more-democratised use of resources such as energy will require new analytical approaches, new policies and a far-wider institutionalisation of participatory governance and community ownership [38]. Whilst the deployment of social network methodologies allows for conclusions related to energy savings [26], more work needs to be done to explore how stakeholders interact with one another, and wider communities of use. In this paper, we discuss the potential for drawing together disciplinary domains and methodological multidimensional techniques to advance study of HEM. In doing so we are positioning the HEM domain, metrics, and methods as a practical foundation that could inform similar contexts where resource needs depend on collective real-time response communication mechanisms, beyond the theoretical discourse.

The proposed research agenda could advance knowledge and offer new thinking into new types of energy governance and more widely sustainable connectivity inspired by nature. Greater exploration into individual household and community energy socio-spatial HEM behaviour and simultaneous investigation into other organisms such as social insects individual and collective resource management communication patters could lead the way to a new vision of energy use. The combining of crossdisciplinary and multidimensional thinking poses some limitations, including the lack of established use of both multidimensional and cross disciplinary techniques beyond theoretical propositions as well as potential lack of establishing shared values and ethos amongst different disciplines involved [39].

The value in developing a new agenda as discussed in this paper has far reaching benefits beyond HEM. There are epistemological and ethical advantages in combining architecture to computer science, biomimetics and social science research in order to strengthen the coherence and social collective relevance of the insights gained that moves beyond the focus on the individual. The use of methods suggested in this paper could also help advance the theoretical landscape in energy research, often called upon and discussed but as yet insufficiently advanced [40]. From an empirical standpoint, as more and more connected products and systems emerge – combined with substantial infrastructure upgrades – wide-reaching opportunities are created for leveraging new types of sustainable connectivity between individual and collective energy users, facilitating real-time data transmission, analytics, and control.

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