Just transitions and sociotechnical innovation in the social housing sector: an assemblage analysis of residents' perspectives

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Abstract

Creating low-carbon pathways for domestic electricity and heating is a core aspect of the UK Government's housing strategy. Understanding issues of energy justice and the socio-technical dynamics of low-carbon innovation are vital for successfully implementing new technologies and retrofit measures across diverse communities and different housing types. The social housing sector is particularly important in the study of just domestic low-carbon transitions due to the challenges faced by residents concerning energy affordability and insecurity during the ongoing cost of living crisis in the UK. This qualitative study, conducted in the Northeast of England, adopts an assemblage thinking approach to examine the experiences of social housing residents. Through thematic analysis of interviewee responses, we identify themes related to cost and affordability; decision-making dynamics and energy justice; disruption, retrofit and 'fabric first'; energy autonomy and the practicalities of technology choice; and environmental values and collective climate action. We find that justice in the low-carbon home requires social housing organisations to strengthen mechanisms for resident engagement and interconnectedness before retrofit roll-out, to identify independent sources and arbiters of information on upfront and long-term energy costs, to ensure effective mechanisms for the social control of energy use, and to provide a platform to encourage nascent energy citizenship through which residents link pro-environmental behaviours in the home to broader networks of social action on climate change.

Keywords

Social housing, energy justice, domestic retrofit, assemblage thinking, sociotechnical dynamics.

1.1. Introduction – domestic decarbonisation as a sociotechnical challenge

Space and domestic hot water (DHW) heating account for around 80% of the energy consumption of households in cold-climate regions (such as those in Northern Europe) [1], yet pathways to residential net zero emissions remain challenging due to a range of technological, economic, and socio-cultural factors. In the UK, Conservative Government strategy to "build back better and build back greener", provided a broader policy framework to improve residential, retail, and industrial building fabric efficiency through insulation and other energy efficiency measures, making changes to the technologies used for both space heating and cooling within buildings, and improving the energy efficiency and performance of domestic energy services. Residential building decarbonisation was thus promised to [2]:

> "…help the economy grow, create new green jobs, and deliver greener, smarter, healthier homes and workplaces with lower bills. Delivering energy performance improvements and low-carbon heating systems will create new jobs in all parts of the UK – offering enormous potential to support our 'levelling up' agenda."

Achieving housing sector decarbonisation is made possible through improvements to the efficiency of domestic buildings, changes to UK low carbon technology supply chains, an array of alternative low-carbon heating technology options for domestic users in both new build and 'retrofitted' properties, and changes to facilitate pro-environmental social practices of energy use in the home. Domestic net zero requires action across multiple pathways of decarbonisation [3] including: energy infrastructure connections (e.g., centralised, off-grid, feed-in-tariffs, smart meters); renewable energy sources (solar photovoltaics [PV], micro-wind, heat pumps); co-adoption of related technologies (such as electric vehicles) [4]; energy-efficiency measures; changes to building standards and appliance ratings; and crucially: transformation of energy energy-saving domestic social practices and behaviours [5, 6].

At the household scale, different factors influence the uptake of new low-carbon electricity and space heating technologies (such as solar panels, air, and ground source heat pumps) and fabric changes (such as external cladding to provide insulation). These factors concern: consumer choice and decision-making autonomy; technology availability; cycles of innovation (such as the rapid obsolescence of recent to the market technologies); the relative affordability of new heating technologies; the human resources necessary for manufacture, installation, modelling, project management, maintenance and repair of novel technology solutions; and issues of energy literacy [7], social acceptance [8], behaviours, habits and social practices associated with energy services (e.g. washing, cooking, and entertainment) [6, 9-11]. As multiple studies have shown, understanding of the *sociotechnical dynamics* of low-carbon transitions [12] is essential to the successful and fair implementation of technologies within the low-carbon home. Such dynamics concern the interaction between people, materials, design, decision and marketing processes, technology uptake and use, standards, technology availability and people's engagement with the technologies in situ [13-16]. Understanding the dynamic complexity of domestic low-carbon transitions is important if the roll-out of energy efficiency measures is to be both commercially successful and achieve broader social justice objectives [17]. Residential decarbonisation plans must be suitable for different housing types, markets, user histories, domestic living patterns, and must be compatible with diverse social values related to entertainment, cooking, washing, mobilities and thermal comfort [18]. This relative sociotechnical complexity involving inter-related technological and human factors, makes the pre-defined selection of the 'best' configuration of technology options difficult to predefine in regional energy policy. However, the range of domestic net zero transition pathways through a combination of these elements also allows a degree of design flexibility and creativity: allowing choice of technology to be adaptive to local climate conditions, costs considerations, energy resource availability, infrastructure, and social justice and political governance conditions (including building regulations, tariffs, and other social factors) [19, 20]. Within this, the resident user of low carbon technologies is a key stakeholder, and so engaging with resident perspectives in the process of a just domestic decarbonisation transition is essential [21].

1.2. Theoretical framework – assemblages of the low carbon home

Contemporary approaches to assessing low carbon technology transitions have predominantly focused upon techno-economic modelling approaches that provide insight into design, implementation, and diffusion of new technologies at scale [12]. Such techno-economic approaches are invaluable for identifying optimal transition pathways for policymakers and planners. However, critics note that it is necessary to broaden the range of actors, normative frameworks and social determinants involved in the technology assessment and implementation process, including engaging end users from different demographics and cultural backgrounds [22-24]. Low carbon transitions when understood as a sociotechnical phenomenon, concern not only market diffusion of new technologies but also changes in use of practices, cultural discourses, and structural socio-economic and political constraints to action [25], including differing conceptions of technological desirability in different places, competing "imaginaries" of low carbon futures [26, 27], and the alignment of technological policies of ecological transition with others policies, including those related to energy justice and social welfare [28, 29].

To untangle the complexity of these socio-technical dynamics and relations, we draw upon *assemblage thinking* in our research design [see for example 30] – an approach used to explore how low carbon social housing is socio-materially constructed from a diverse array of technological configurations, infrastructures, human agents, value positions and social practices. The socio-technical dynamics of low carbon retrofit of social housing infrastructure and the construction of new build properties is necessarily imaginative, processual, and emergent; it is not simply a question of implementing technology and then measuring the outcomes in terms of energy units used and carbon saved. "Assemblages", drawing from the work of Deleuze and Guattari [31] stems from their use of the French term "*agencement*": to "lay out" and "fit together". Assemblage thinking captures the process of how actors arrange and organise the low carbon home as a socio-material and ethical construct. The low carbon home is not something that is built and then used, rather it is imagined and then assembled from its constituent human and non-human elements into a stable configuration or "working arrangement" [32] over time.

Assemblage thinking provides a lens for empirical observation that captures the heterogeneity and diversity of descriptive and normative relations between agents and technological systems. Assemblage thinking emphasises fluidity, relationality, and interconnected normative relations between human and non-human agents. The central tenets of this approach are that individuals engaging with (in this case) low carbon pro-environmental actions and objects are mutually embedded – a just transition within the home occurs within complex socio-material interdependencies. An assemblage is therefore a description of the purposeful action that enables different elements to be gathered together [33]. As such, assemblage thinking, as an analytical approach or orientation [30], is gaining traction in the study of the socio-technical dynamics of energy technologies and infrastructures [34, 35] because it lays bare how an individual engages not only with a new technology, but (in this case) also new practices of energy use, emergent environmental and political values, power relationships between tenants and social housing landlords, and experiences of change and disruption within the home. Something as seemingly mundane as a new air-source heat pump elicits an assemblage of socio-material discourses relating to the politics of low carbon investment [36], energy poverty and energy justice [37], electricity access [38], temporality and governance scale [39], and the evolving social practices of sustainable energy use [40, 41]. We draw therefore upon assemblage thinking to understand the configurations of these socio-technical dynamics of energy justice from the 'bottom-up' user-oriented perspective of social housing residents. In this empirical study we use qualitative interviewing techniques to explore such assemblages at a point *before* technology rollout occurs across the housing stock. We therefore use assemblage thinking approach to produce something like a critical or "discursive" technology assessment [22, 42, 43] that explores beliefs, motivating behaviours, environmental values, and socio-material and structural constraints to just domestic low carbon transitions in the social housing sector.

1.3. Case study details

This paper concerns a key group within the broader pattern of residential decarbonisation – namely residents of the *social housing sector* (hereafter SHS). Social housing organisations (hereafter SHOs) across the country are commonly leaders in domestic energy efficient retrofit of existing housing stock, in part due to their coordinated capacity to build and retrofit at scale [17, 44]. Importantly, social housing tenants make up about 18% of the UK's population and are characterised by a lower-than-average-income, relative economic inactivity, higher-than-average prevalence of fuel poverty [45], and as such, represent a vulnerable population whose perspective is often overlooked within energy economics and user behaviour research [46, 47]. Researching the experiences and needs of residents in this sector is of critical importance at a time when concerted action from national-to-local scales on residential decarbonisation takes place alongside a cost-of-living crisis exacerbated by the re-opening of the global economy after the Covid-19 pandemic, and food and fuel cost increases and price inflation exacerbated by the war in Ukraine.

This qualitative case study was co-produced with the SHO Thirteen Group (hereafter Thirteen) in the northeast of England. Thirteen manage over 35,000 homes, with more than 72,000 customers from North Tyneside to Yorkshire. Most homes are managed within the Tees Valley region [48]. The Tees Valley, situated in the North-East of England and incorporating parts of historic County Durham and the North Riding of Yorkshire, has long been at the centre of "carboniferous capitalism" [49]. Since the 1970s, waning steel employment became emblematic of the region's steep decline in manufacturing jobs including in the previously expanding chemical industry [50, 51]. This has left the region with a legacy of protracted socio-economic deprivation, especially concentrated in Middlesbrough. The 2019 English Indices of multiple deprivation demonstrate that the local authority is, on many measures, the most deprived in England [52]. Economically, Tees Valley firms remain competitive in advanced manufacturing and the chemical and process industries although these sectors are now characterised by high levels of foreign ownership which presents opportunities (the ability to import managerial and technical best practice) as well as challenges (local capacity to influence investment decisions and the development of a 'branch plant' economy). In 2016, the area formed a "combined authority" (Tees Valley Combined Authority, hereafter TVCA) which holds selected powers and responsibilities over economic development and transport in the region. The TVCA Local Industrial Strategy set out plans to support clean energy, low carbon innovation (specifically offshore wind energy, carbon capture and storage and hydrogen) as areas of growing output and employment. Action on domestic low-carbon transition therefore takes place within this broader socio-political landscape of Net Zero investment.

In terms of housing, Tees Valley private and rental markets are characterised by low densities and a dispersed spatial structure. The legacy of heavy industry means that development land has significant constraints and viability challenges, with distinct gaps between high price and low price areas; and core urban communities suffering from often poor quality housing stock and housing market underperformance relative to national and regional benchmarks [53]. Thirteen as a major social housing provider is notable in its development of a coordinated strategy for housing stock regeneration, including an embedded decarbonisation and domestic net zero emissions plan. Thirteen has embarked upon a scheme of upgrades to around 2,500 of its properties as part of a longer-term £230m retrofit programme [54]. This approach involves an energy transition to low carbon domestic technologies, with the installation of insulation, solar panels, air source heat pumps and battery energy storage systems. A key challenge for SHOs like Thirteen is understanding how to engage residents to become active stakeholders in energy transitions that affect their homes and personal wellbeing [55], such that energy and carbon reduction performance can be maximised through user social practices in the home. This study explores through qualitative interviews with residents of the Thirteen SHO, the assemblages of decarbonisation currently happening (or about to happen) within this critical case study in the SHO sector.

2. Methods

Participants were recruited voluntarily by the SHO's tenant list and through social media posts on the SHO's website. 20 SH resident participants were recruited (see Table 1): 10 men and 9 women, with an age range from 26-75. There was no demographic information available for 1 participant. All residents lived in the Tees Valley. No incentives were offered to participate. Semi-structured interviews (interview topic guide available in Supplementary Material 1) were conducted through a mix of small-group and individual face-to-face or online interviews based upon participants' access needs and challenges related to Covid-19 meeting restrictions. Before commencing the interview, participants listened to a short introduction by one of the authors on UK Climate Change goals, low carbon homes, and a short video of a model retrofit home with an explanatory live commentary, that demonstrated how a low-carbon technology home would look (Supplementary Material 2). The walkthrough video was created using Autodesk REVIT, 3D modelling software. One of the authors provided live narration to the walkthrough and still images of a low-carbon home and narration. The video was supplemented (from feedback after the first group interview) with a short testimonial from a tenant with low-carbon technology already installed. These two elements serve as an *elicitation device* [56] to stimulate participant imagination in visualising and contextualising the domestic low carbon technology in their own home.

Table 1. Participants in the interview study

Participant pseudonym	Age	Expressed gender	House type	No. of bedroom
Brenda	49	Female	Semi	3
Alice	38	Female	Semi	2
Jun	64	Male	Flat	1
Nick	73	Male	Flat	1
Sarah	68	Female	Bungalow	2
Unknown	Not supplied	Not supplied	Not supplied	Not supplied
Daniel	71	Male	Mid-Terrace	3
Lucas	74	Male	Flat	2
Carly	51	Female	Mid-Terrace	2
Andrzej	31	Male	Flat	2
Richard	75	Male	Flat	1
Harry	40	Male	Flat	1
Uchechi	26	Female	Mid-Terrace	3
Malcolm	71	Male	Flat	1
Colleen	73	Female	Flat	2
Alicja	59	Female	Flat	-
Mike	63	Male	Bungalow	2
Mina	53	Female	Bungalow	1
Adina	40	Female	Flat	2
Mohammad	56	Male	Flat	1

N.B. Pseudonyms are randomly applied based upon commonly occurring names to preserve participant anonymity.

2.2. Data analysis

A hybrid thematic analysis [57] and inductive coding framework was applied to analysis of interview transcripts. We first identified broad, 'top-level' themes, followed by iterative in-depth coding to explore relationships, comparisons, frequency, and elaborations considered as determinants of nascent assemblages of domestic low carbon transition. It is through the interpretation of these elements, first in isolation, and then together, that the assemblage of the just low carbon home is socially constructed. Each theme was developed through coordination and comparison between at least three researchers to ensure validity.

3. Results

We provide reference to *in vivo* coding of participant utterances thematically mapped across the qualitative data set. In each case we discuss the theoretical and practical implications of expressed beliefs and values to low carbon behaviours and uptake amongst SH residents in our sample, and thus "assemble" the socio-technical dynamics of just domestic low carbon transition from the resident users' perspective.

The following dominant top-level themes were identified from thematic coding of the qualitative data. These five themes are used as primary headings to structure the discussion below:

A. Cost and affordability
B. Decision-making dynamics and energy justice
C. Disruption, retrofit and 'fabric first'
D. Energy autonomy and the practicalities of technology choice
E. Environmental values and collective climate action

A. Cost and affordability

Cost is a dominant factor in participants' decision-making over low-carbon technology uptake in the home, specifically the key technologies under consideration for SH residents – air source heat pumps and solar photovoltaic (solar PV) systems. Participants commonly differentiated between upfront cost and long-term costs. Upfront cost strongly influences energy affordability for social housing residents, specifically the costs of installation for leaseholders who are concerned that the initial outlay would not be recouped quickly enough to make the investment worthwhile when compared to fossil-fuel intensive space heating alternatives:

> "I'm a low user of particularly gas…. I don't see how a heat pump can improve on that from a financial point of view, particularly considering the capital cost involved, which from what I understand is several thousand pounds." [Lucas].

Of specific note is that participant/resident age was a factor in assessing the desirability of upfront cost. Some expressed concern that older people living in social housing but experienced the upfront cost would not benefit over the long term due to the investment risk to reward over the life course of the individual:

> "Old people like me. People can't see the payback. You know, I would see anybody in their late 50s onwards would say this is not for me because it's unaffordable and you know, I wouldn't get the payback. Younger people? Yes." [Nick].

It is the temporality of cost that dominates the socio-material discourse of energy cost. Upfront cost is presented as a barrier to uptake, but the timeframe of investment cost to savings benefit is a key mediating factor. Though many were concerned about the financial capital needed to invest in heat pumps, solar panels, and installation improvements to the home, they recognised longer-term financial benefits of sustainable energy, particularly at a time when rising energy costs due to the war in Ukraine, and the opening of the global economy following the COVID-19 pandemic were stressing household budgets. Cost is social constructed in relative terms. Participants sometimes referred to solar panels producing "free" electricity. Others noted:

> "Well, it's going to be cheaper fuel, that's the big factor isn't it" [Colleen].

> "In here we have a fairly inefficient boiler, it is going flat out even to keep the house warm at the moment, at a high cost. So, I'd certainly be delighted to have anything that altered that." [Daniel].

Cost is something that is *imagined* in the context of their individual use, personal circumstances, and energy autonomy. Participants commonly discussed how they use gas and electricity frugally, that is, there is conscious control by rationing its use to save money. For them cost was often framed negatively. There was concern that for those who are low users of gas for space heating, i.e., those who manage personal finances through frugal use of gas and electricity, there was concern that an "always on" the heat pump would be less economically efficient and would have less user control over the money spent on energy services in the home.

There are two issues in understanding cost within the sociotechnical assemblage of the low SHS carbon home. The first factor concerns *relative cost* between renewable energy when compared to fossil fuel alternatives. The second concerns the social control of energy use. With respect to the first concern, cost does not refer to a fixed threshold of price versus saving, it is a relational factor embedded in networks of *trust* and *trustworthiness* – participants called for reliable information on the relative costs and what it means and a household budget scale to be disseminated by the SHO. Questions that arose about who would be best placed to provide that information, as manufacturers of heat pumps were not trusted, compared to independent analyses (academics were mentioned as independent arbiters of cost-versus-reward value). New technology is therefore an expression of economic power, that technology manufacturers may seek to lure people in to buying their products with promises of energy and cost savings, but that fossil fuel alternatives may be cheaper for some users. In absence of clear cost data over time, residents must rely upon *proxy* representations of cost value (such as projected savings), and thus trust across a network of stakeholders from the SHO to financial advice authorities. The relative "success" of low carbon transition through new technology is thus dependent upon trust-building within this broad network of heterogenous energy system actors from tech companies and their representatives, to the SHO, to other users. Participants commonly stated that the wanted to speak to other social housing residents who already had head pumps and solar panels installed in order to make an informed decision. Peer-learning and social dissemination of personal experience is therefore important within a network of stakeholder trust. The second issue mirrors findings from other studies that show that a personal sense of control over the use of energy through prepaid metres, smart metering, or the tangible purchase of fuels (e.g., oil or in rarer instances wood, charcoal or kerosene) is of primary importance to those on low incomes [58, 59]. For those without the financial resources to absorb economic "shocks" such as unforeseen bills, loss of employment or benefits, we find that domestic *autonomy* in energy decision-making is often prioritised over a low individual unit cost, even if it ironically risks greater financial hardship [as seen in studies of prepaid water metering: 60, 61]. There is an emergent assemblage that shows demonstrates desire for balance between low-cost energy services and user choice. Establishing mechanisms for vulnerable residents to have adaptive capacity to balance between cost and control is therefore a key priority for social housing organisations to establish.

B. *Decision-making dynamics and energy justice*

Decision-making factors branched from the individual technology in the home, to the communities build across different occupancy and social housing tenancy types. Those living in multi-occupancy buildings expressed concern or scepticism about the practical viability of low carbon retrofit, and the ways in which decisions over technology uptake are made. Many concerns centred on how individually owned heat pumps or solar panels could be used in a multi-occupancy site. These concerns were around how energy savings or energy production benefits could be shared equitably between residents, how costs would be shared amongst tenants for installation, maintenance, decommissioning and cover or service charges, and how decision-making over installation could be consensual amongst all residents within a specific building, or street. This is of particular concern where mixed occupancy cuts across the SH, private rented sector (PRS), and owner-occupied housing types (such as multiple flats in the same building). It is notable that in central Middlesbrough, the PRS is now the dominant tenure [62]. This leads to concerns among some participants that they wouldn't benefit from technology changes, or else wouldn't be able to share them fairly with other residents. For example, where solar photovoltaic and heating systems were discussed, those in ground floor flats were concerned they wouldn't get electricity access the only those on the top floor would benefit. In medium-to-high rise blocks of flats, the pattern and process of implementation through fair distribution and access to all residents was a key concern:

> "I live in sheltered accommodation and there are 23 flats within this complex and looking at that video I can't see how 23 heat pumps would work in this building…. I can't see how individual heat boilers would work but it would need a re-jigging inside the whole building to make it work for all the flats. Well, to live in this particular building, we need the consensus of everybody. And if somebody's going to sit on the fence, we might not be able to get things changed round. You know, we need everybody's consensus and the moment everybody seems to be feeling that way, that we've got to do something about, particularly the service charges that were being faced with yearly." [Richard].

This highlights the nature of specific challenges to low carbon retrofit within social housing organisations. Low carbon technology implementation is done "at scale" on a rolling basis across a broad geographic area, yet decision-making is inherently community based and collective. This adds an additional layer of complexity to the assemblage of low carbon retrofit. For an individual private homeowner, retrofit is negotiated between homeowners and installation firms, contractors, and suppliers, or else in the PRS between landlord and tenants. In the SHS negotiation extends to the community of residents, and this decision-making is facilitated by the SHO itself. Given varying levels of knowledge, engagement and support for low carbon technologies, the process of negotiation and consensus at a building-by-building decision-making scale is a key consideration SHOs. Better understanding of the thresholds of consensus and commitment amongst the resident population is a crucial first step to produce an equitable technology implementation process that ensures energy justice – i.e., one that is procedurally fair to all residents. Fairness and involvement in decision-making are identified as key components of a stable assemblage of low carbon transition. The SHS is significant in that the SHO must balance between the individual rights of the householder and the broader commitment that they have towards decarbonisation as a *public technology* [63, 64] in which long-term strategic investment, and the well-being of an aggregate resident population takes primacy. It behoves SHOs to engage in what is often termed "upstream dialogue and engagement" [65] with the residents about the nature of low carbon technology implementation, i.e. a process of engagement that commences before the implementation phase where technology choice is settled, otherwise, this destabilises the low carbon assemblage: elevating the risk of residents rejecting, ignoring or mis-using low carbon technologies (and thus limiting their effectiveness, cost efficiency and carbon savings).

C. Disruption, retrofit, and the "fabric first" approach

Action on low carbon retrofit in Thirteen as in other SHOs follows the logic of *fabric first approach* – in which design processes maximise the performance of building components and materials first (primarily in this instance: insulation – either wall cavity, loft or internal or external cladding), and then consider mechanical and electrical systems second (in this case heat pumps and solar PV and hot water systems). Fabric first can improve electrical and thermal efficiency and reliability of the building itself, ultimately improving long-term cost efficiency (including reduced maintenance costs), and carbon emissions reduction. The fabric first approach counters the relatively high levels of embodied fossil fuel-based emissions involved in energy technology construction, and provides other benefits, such as passive efficiency as they do not require active user control [66]. Across the interviews there was emergent consensus that the fabric first approach was the most appropriate design approach to take, and that insulation above all other measures should be implemented first:

> "Retrofitting it into a house like mine would not be cost effective because it is poorly insulated for a start off. Even the existing windows are very draughty, etc. So, there would have to be a lot of insulation to the home before the low carbon side of it would work" [Brenda].

> "I suppose that would be easier if it was a new build, you know what I mean?" [Harry].

Building residency types in the SH sector cover a range of 'periods' in architectural design and building stock – from single brick Victorian townhouses, to 1930's interwar brick semi-detached properties, 1950s former local authority owned properties, and flats built between the 1960s to early 2000s, alongside modern low-carbon designed flats, bungalows, and town houses. Participants commonly expressed that low carbon technologies for space heating would be most suitable for newbuild properties. They were generally supportive of low carbon innovation to provide general environmental benefits (i.e., collective benefit to tackling climate change) but felt that their properties with lower levels of insulation and design inefficiency – such as lack of space for hot water tanks to support heat pumps – would be less suitable. It is therefore interesting that participants commonly called for the SHO to prioritise "other" properties than their own, despite the potential personal benefits that might be gained.

Participants demonstrated practical and experiential knowledge and awareness of combining insulation with heat pumps for space heating within different housing types and wanted input to further evaluate their use in their own homes. There was considerable nuance in the ways in which low carbon retrofit was imagined and discussed depending upon the housing stock and occupancy type of the individual participants, for example:

> "Insulation, draft proofing and everything else, because obviously the low-carbon stuff tends to run at a lower temperature, so the heat output is much lower." [Daniel].

There is a tendency within energy planning to treat consumers as passive users of energy services, through which price signals or automated systems can be used to alter demand [67]. An assemblage approach challenges the social construction of residents as passive consumers. Our qualitative findings reveal an appetite for active *energy citizenship* [68], in which participants show support for active engagement with the technical dimensions of energy technology design, rather than the passive social acceptance of innovation.

When it comes to retrofit specifically, not only is active engagement with the technology a concern, but also the personal experience and expectation of domestic disruption. Disruption concerns the practicalities of managing SHO wide fabric first retrofit to meet the needs of residents' working patterns (including shift work), home life, and in many cases mental and physical health concerns which require ongoing support. Some were concerned they would be moved out of their homes, or experience long delays and inconvenience during the work to improve the building fabric internally and externally:

> "[M]y main concern is the upheaval. Because I didn't go ahead with the boiler. Not the boiler, the air heating that they [Thirteen] had done four years ago, because of the disruption to the house, I wouldn't be able to cope with the stress. […] My main concern would be the disruption because I don't work and I live at home all day with two dogs and I do have mental health and physical health problems. So that's the only thing that worries me." [Carly].

The temporality of disruption defined the stability of the low carbon transition assemblage. Participants commonly expressed worries about changes to the home occurring in a piecemeal fashion, where one element is installed such as insulation, and then later heat-pump, and then later new kitchens, carpets, or bathrooms. Because the investment in both the building fabric and the technologies implemented comes from the SHO, there was concern raised that this process would be spread out, so the disruption happened multiple times, with lack of communication or certainty over the timeframe for implementation being of utmost concern. Most participants agreed that strategic planning for fabric first and then technology solution to low carbon domestic retrofit should happen all at once, and that the timings should be linked to the building work going on at the same time such as to minimise disruption. This means that certain geographies would benefit before others and rollout would therefore need to be carefully planned service to target homes that both have the lowest thermal and carbon efficiency, balanced against the needs of the most vulnerable residents.

D. Energy autonomy and technology choice

Solar energy was a popular technology choice amongst participants. As mentioned above, solar was sometimes described as "free energy", and solar panels were desirable because of the limited disruption that they would cause (external to the property and quickly installed). For some participants on low incomes and concerned about energy affordability, solar panels gave reassurance. For others, energy intermittency (during winter months when energy demand is highest) led to concerns over a perceived shortfall in energy supply. Technological solutions (namely battery storage) were recognised as essential components of a reliable renewable energy system. For some heat pumps were desirable because they would be easy to use and would keep the home warm and comfortable all year round. As found in other studies [69] thermal comfort through constant temperature and hot water availability were seen as benefits from heat pumps specifically. One participant suggested that, with temperatures rising in the UK, air conditioning could be built into the heat pumps.

> "Well, they'd be warmer. They'd just run constantly. Don't have to mess about with the thermostat or anything like that. They'd be set with the weather." [Mina].

The issue of constant heat then also links back to the energy autonomy problem: a small number of participants expressed concern over the ability to manually regulate the temperature to have zoned heating. Gas central heating is "almost instant", but participants understood that heat pumps, running at low temperatures for a long period of time may take longer to heat the property.

> "I just don't want to have my bedroom heated or anything. Can it be switched off from there?" [Alicja].

The importance of *energy autonomy* therefore extends not just to control over energy unit use and cost, but also the control of thermal comfort within the home. Heat pumps were perceived as providing fewer opportunities to control the nature of the living space, and therefore were perceived as undesirable technologies for some participants.

Other concerns relevant to social housing related to the amount of internal space used to house water thanks, metering equipment, radiators, and piping. Social housing residents commonly live in smaller-than-average dwellings, that may not have adequate storage space for hot water tanks, particularly in flats or bungalows replaced or removed airing cupboards when combi-boilers were installed. Given the complexity of different housing types, layouts and space availability, strategic role out of retrofit is extremely difficult to plan at scale, given that it requires a house-by-house, project-by-project approach. This also raised concerns around the maintenance and reliability of novel systems for which there was little personal experience of use. Participants raised concerns about being early adopters of new heat pump designs, and some wanted heat pumps to be "bedded in" before they used them themselves:

> "But I suppose the negatives are, you know, it's new technology is often a bit, there's often a bit flawed when it first launches, you know, sometimes it takes a while." [Harry].

Low carbon transition through novel technology inevitably raises questions about upscaling sustainable technology alternatives from niche-to-mainstream. Upscaling is an essential element of sustainable societal transformation [70], yet it requires reflexivity amongst a range of stakeholder actors. Technology designers, manufacturers and implementing organisations (including potentially SHOs) will often assume that user adoption of new technologies can be planned based upon cost calculations and purported social and environmental benefits (often based upon manufacturer's descriptions). Yet research has shown that such a top-down implementation approach can lead to a sense of threat and stimulate protection behaviours amongst users [71]. The simplest of these is a 'wait and see' approach, allowing early adopters to shoulder the risks, and then to benefit later once the bugs have been removed fro the system. It is vital therefore that user involvement through an interactive framework is built into the rollout process, as this can help to enhance the acceptance of low-energy solutions [72].

E. Environmental values and collective climate action

Of note was the commonality of utterances concerning issues of environmental sustainability, the role of energy in the production of greenhouse gas emissions, and personal motivation to adopt a low carbon lifestyle. The pro-environmental impact of technology change in the home, was frequently mentioned, often spontaneously, each time with a positive semantic valence:

> "This would have a massive effect on the environment in the long run." [Jun].

> "I think I can help me to warm more ecological and reduce my carbon emission and all that." [Uchechi].

Participants spoke of environmental protection with a degree of personal pride. The idea that by accepting technology changes in the home each was 'doing their part'. This is further evidence of a nascent *energy citizenship* identity within our participant population [73, 74]. Action on climate change is perceived in terms of a normative duty, one that overrides personal inconvenience (in terms of thermal comfort or space in the home) or loss of some degree of autonomy (such as a heat pump with fewer opportunities for active user control of the system):

> "Obviously saving the planet issue, but from a personal point of view I hope it would be more comfortable all year round and it would be cheaper to run and then obviously if it's cheaper to run, it's using less energy, therefore saving planet." [Daniel].

Energy citizenship represents therefore not only active engagement in the control of energy systems and uses, but also the broader collective social action necessary to combat climate change. Many participants implicitly linked their personal pro-environmental behaviours and social practices to the broader *politics* of renewable investment, sometimes discussing the political complexity around environmental initiatives. For some there was a feeling of pressure to 'be green' and 'politically correct' and that expressing openly negative views on sustainable energy is socially undesirable. Others felt that a push for low carbon technology simply displaces more radical action that needs to be taken to stop climate change, implicitly mentioning themes related to *greenwashing*.

> "Environmental initiatives can sometimes be a bit, there's some people who know more about than I do, or sometimes will say things like. Well, you know, this is not resolving the issue really needs radical change, there needs it needs to be to economic change and all these little things don't help actually hurt, because they are distracting. I don't know, probably that's going outside my area of expertise a bit." [Harry].

Some participants argued that rather than looking at a household-by-household scale, a national plan is needed for renewables and infrastructure, a strategy that sits alongside a need for more, and better-quality social housing. Concerns were also expressed that individuals were doing their best to be involved in environmentally friendly initiatives, including low carbon housing, but the greater government funding is necessary to make this an effective Net Zero strategy. Certain participants expressed that only through democratic political action can the public make themselves heard on this issue.

> "Most green people doing their best to get these houses done. Anyone that gives a hoot about the world. You don't have to be part of an organisation to care enough to

> think I'm going to do something here. We all can help the planet and help our pockets by doing something or speaking about it. The more we yell at the government the more they will think they've got to do this." [Mohammad].

Embedded within the assemblage of the low carbon transition in the home are multiple interconnected environmental values. The range of expressed positions was diverse: from those that emphasise pro-environmental behaviour through energy saving measures in the home, towards those that link action on social housing to a broader welfare agenda for vulnerable populations, and those that see an opportunity for a greater voice in government towards environmental change at a national scale. We see therefore that action towards a domestic low carbon transition speaks to a broader network of environmental values that extends across different scales of governance and action. The participants imagined the low carbon home not only in practical and physical terms, but in implicitly symbolic terms: we interpret this here as the home representing a place in which energy citizenship *starts* rather than ends. For many of our participants, it was the connection between the home and the motivation for broader political action on climate change that was important (even to the point that low carbon technologies were a distraction from the deeper societal transformations needed to avert climate catastrophe). We find therefore that our SHS residents were keen to expand beyond the label of *energy consumer*, to one that encapsulates that of a political actor capable of stimulating environmental change on a broader scale beyond the home.

4. Conclusions

This research explores the sociotechnical dynamics and justice considerations of low carbon transition within the social housing sector (SHS) through interpretive analysis of residents' perspectives. We explore the domestic low carbon transition informed by *assemblage thinking*: drawing upon the 'material turn' in social theory [75] consonant with recent research in the social studies of science and technology, energy geographies and environmental sociology [30, 34, 37, 40, 75]. The assemblage of the low carbon home in the SHS is one that connects the practical socio-material processes of retrofit to issues of participative and distributive energy justice (in the decisions over what technologies are implemented, when, how much disruption and who gets the energy within a multi-occupancy site), and pro-environmental political action that extends from the home to broader networks of political and social values (including greenwashing, low carbon investment and collective social action on sustainable societal transformation). The environmental benefits and duties of pro-environmental behaviour change through technology uptake and use were discursively linked to nascent *energy citizenship*, in which disruption, thermal comfort, and upfront costs are willingly 'sacrificed' for the collective benefit of carbon emissions reduction. This concept of energy citizenship also extends towards community level decision-making over technology implementation. In multi-occupancy buildings, and across groups of social housing residents, there is a clear sense that decisions on technology uptake should be taken collectively rather than individually, despite difficulties of implementing this practice in mixed use communities of social housing residents living alongside private rented sector residents and homeowners. For sites that might involve shared low carbon heating or electricity systems across different housing sectors, it behoves SHOs to engage broadly across communities and housing types to maximise the low carbon benefits of rollout, thus ensuring a commitment to community procedural energy justice. Moreover, the assemblage of the low carbon home also serves as a symbolic representation of pro-social change towards greater climate action. SHOs thus can facilitate a link between domestic pro-environmental behaviours and practices with broader collective action on climate change, by providing a platform for residents to come together and share their experiences and values towards the environment, with the potential for social learning across a shared community of low carbon practice.

Implementing new technologies is neither simple nor universally accepted, the assemblage of broader social values around energy use and environmental action mesh with the practicalities of financing the upfront cost of new tech, the balance between current cost and future service charges, maintenance costs and repairs. The domestic low carbon transition assemblage is thus a product of deeper financial insecurity and inequality within this economically vulnerable group of participants. Managing current and future financial risks through prepaid systems, for example, may in turn make them more expensive than other low-carbon alternatives. The balance between *financial* and *emotional* security provided by a sense of control over energy use and expenditure, versus the hard economic cost of the more expensive fossil fuel and/or prepaid metered energy services is delicate. Negotiating and balancing the two elements of control and affordability is a vitally important consideration in the rollout of low carbon retrofit within the SHS. Aside from cost, the primary concerns raised by residents involved domestic disruption, learning how to use new technologies, and the concept of energy autonomy — in which residents on low incomes raise concerns that solar panels and heat pumps provide insufficient cushioning from economic shocks such as loss of income, or unexpected outgoings. Many of the concerns around the implementation of low carbon retrofit concern domestic disruption to the patterns of social life. The participants expressed how "joined up thinking" in which SHOs minimise disruption by engaging retrofit rollout in line with other 'fabric upgrades' (such as replacements kitchens and bathrooms) should be prioritised despite the challenges presented by (in most cases post-Covid) supply chain disruption, or difficulties in finding appropriate labour.

The sociotechnical dynamics of low-carbon transitions from the perspective of social housing residents is an important to meet the requirements of a just transition in which the collective benefit of action on climate change does not fall disproportionately on the poorest and most vulnerable in society [76]. Though in this study we find positive reception amongst residents to low carbon retrofit, the assemblage of the low carbon domestic transition is delicate, predicated on issues of trust, procedural fairness, financial vulnerability, and fear of disruption to the patterns of social life. It behoves SHOs to undergo careful processes of engagement with their tenants, to establish timeframes for rollout which reduce disruption, to communicate the cost savings in an honest way using the best available of evidence, and importantly to link together their residents to discuss the challenges and opportunities that they face. By paying explicit attention to these identified socio-technical dynamics in retrofit rollout processes, SHOs can implement a successful domestic low carbon transition that evolves within a shared sense of community.

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