A MULTIDISCIPLINARY LITERATURE REVIEW OF LOW AND ZERO CARBON TECHNOLOGIES INTO NEW HOUSING

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The UK Government is committed to all new homes being zero-carbon from 2016. The use of low and zero carbon (LZC) technologies is recognised by housing developers as being a key part of the solution to deliver against this zero-carbon target. The paper takes as its starting point that the selection of new technologies by firms is not a phenomenon which takes place within a rigid sphere of technical rationality (for example, Rip and Kemp, 1998). Rather, technology forms and diffusion trajectories are driven and shaped by myriad socio-technical structures, interests and logics. A literature review is offered to contribute to a more critical and systemic foundation for understanding the socio-technical features of the selection of LZC technologies in new housing. The problem is investigated through a multidisciplinary lens consisting of two perspectives: technological and institutional. The synthesis of the perspectives crystallises the need to understand that the selection of LZC technologies by housing developers is not solely dependent on technical or economic efficiency, but on the emergent 'fit' between the intrinsic properties of the technologies, institutional logics and the interests and beliefs of various actors in the housing development process.

Keywords: low and zero carbon (LZC) technology, multidisciplinary literature review, new-build housing, zero-carbon new housing.

INTRODUCTION

In response to robust evidence of anthropogenic causes of global warming, many governments are increasingly putting in place national targets for carbon reduction. The United Kingdom (UK), for example, is committed to a 34% reduction in carbon dioxide emissions by 2020 and 80% by 2050 compared to 1990 levels (DECC, 2011; HM Treasury, 2008). The housing sector plays a vital role in achieving this demanding target. The existing housing stock within the UK emits over 25% of total carbon emissions (EST, 2008). The UK government has encouraged the reduction of carbon emissions from new housing by implementing a number of policies and incentives. The Code for Sustainable Homes (the Code), in particular, is driving innovation in the housing development sector by stating that all new homes built in England should be zero carbon from 2016 (CLG, 2009). This challenge of achieving

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zero carbon homes is being met, in part, by the use of low and zero carbon (LZC) technologies (CLG, 2010; Boardman, 2007).

There is a growing literature on LZC technologies that traverses diverse disciplinary boundaries, but the recurring starting (and finishing) point for much of this is a technical perspective which concentrates on their performance and cost characteristics (Lees and Sexton, 2011). There are many LZC technologies on the market that can potentially be used in housing to comply with the new regulatory requirements; some of which have appeared to have been readily accepted by housing developers, while other technologies have been rejected. The selection criteria, though, are not bounded by technical performance, but encompass a range of commercial and path dependency considerations (Sexton and Lees, 2012). The reality is that the narrow technical rationality conceptualisation does not represent that actual irrationality (based purely on measures of technical efficiency) of LZC technology adoption and diffusion. The field is thus prone, we argue, to technical rationality or an assumption that the technical performance of LZC technologies will, alone, guide selection and use.

The aim of the paper, through a literature review, is to identify the sources, tensions and potential pathways out of the technical rationality distorting our understanding of the adoption and successful integration of LZC technologies into new housing. This review draws upon technological and institutional literatures to shed different, but complementary, perspectives. The review confirms the dominant technical rationality of the literature. The instrumentality of technical efficiency and cost-benefit as drivers for the selection of 'optimal' LZC technologies are privileged. There is a smaller, but now discernible counter body of literature emerging which is beginning to both contest and shape this technical rationality by bringing attention to way that companies are responding to and translating myriad regulation and market pressures into logics which inform the selection criteria and processes.

This paper is organised as follows. First, a definition of LZC technologies is given. Second, technical and institutional perspectives on the selection of certain LZC technologies into housing are discussed. In the final section, discussion and conclusions are drawn.

DEFINITION OF LOW AND ZERO CARBON TECHNOLOGIES

The definition of low and zero carbon (LZC) technologies is slippery and is dependent on different actor perspectives. The National House-Building Council (NHBC) (2010: 2), for example, defines LZC technologies as “generally applied to renewable sources of energy, and also to technologies which are significantly more efficient than traditional solutions or which emit less carbon in providing heating, cooling or power”. This term can be applied to a wide range of technologies and indicates that it is not solely renewable technologies that will be discussed, but those which may use a combination of renewables and fossil fuels.

The Energy Saving Trust (EST) (2010: 4), when put up against the NHBC Foundation definition, blurs the boundary of the term by stating LZC technologies are those “that are zero carbon in operation (powered by 100% renewable energy) and those that are considered to be low carbon in operation (powered at least in part by fossil fuels)”. The EST (2010) further suggests that LZC technologies have an output of heat (e.g. heat pumps) and electricity (e.g. solar photovoltaic), in addition stating two further energy efficient technologies within the definition: mechanical ventilation heat recovery (MVHR) and passive flue gas heat recovery. This definition is more specific than the previous, however a slight tension is created as it excludes cooling as an outcome of LZC technologies.

A broad definition is offered by Boardman *et al.* (2005) who define LZC technologies as “renewable energy generators or technologies with better fuel efficiency than conventional technologies, and which are retrofitted to or integral to the building or community” (p. 109). This more expansive definition does not specifically state that the technology must be attached to a building, nor is there a mention of any restriction on carbon emissions.

For the purpose of this review, the definition of a LZC technology is a synthesis of the definitions already detailed. The aim is to create a broad definition that accommodates the diversity of technologies discussed in the literature. The downside of producing such an inclusive definition, of course, that from any given perspective it will lack precision (or reproduce desired bias?). A LZC technology therefore is defined as ‘a technology that can provide heating, cooling or power (or a combination of outputs) and will be powered solely by renewable energy (zero carbon) or powered in part by fossil fuels (low carbon).’ Examples of LZC technologies include, but are not strictly limited to: solar photovoltaic (PV), solar thermal, wind power, hydro power, heat pumps (ground/air/water), combined heat and power, biomass boiler, MVHR and fuel cells (adapted from EST, 2010; NHBC, 2010; SBSA, 2007).

Further, it is interesting to note that there are three recurring terms for this group of technologies: LZC technologies, renewable energy technologies [1] and microgeneration technologies [2]. All three terms have different boundaries that include and exclude various systems. Due to the changing nature of this field, as new technologies are constantly being invented and improved, it is not surprising that the boundaries of each term are permeable. It is useful to recognise the flexibility and comparisons between each term. However, we argue, that microgeneration technologies and renewable energy technologies should be classified as subgroups under the overarching broader definition of LZC technologies.

Notwithstanding the hazy and shifting boundaries of the LCZ technologies, the substantial insight is that the literature overwhelmingly frames the definitional debate in terms of the energy services produced by the technology (i.e. heating, cooling, and so on). The debate is, though, weakly coupled to the technological and institutional contexts within which they are located. The following section comment on these two perspectives.

DIFFERENT PERSPECTIVES ON THE SELECTION OF LOW AND ZERO CARBON TECHNOLOGIES IN HOUSING

Technological perspective

The ‘technological perspective’ focuses on the attributes of the technology artefact itself (e.g. its scientific performance, technological potential, lifecycle) and privileges these attributes as being the crucial determinant to the uptake of LZC technologies.

The selection of LZC technologies by housing developers to date is predominantly driven by their fundamental technical and economic attributes (Lees and Sexton, 2011). Monahan and Powell (2011), for example, compare four different energy typologies within fourteen new low energy affordable homes, including ground source heat pumps (GSHPs); solar photovoltaic (PV) and solar thermal; passive solar and mechanical ventilation and heat retrieval (MVHR); and, conventional high efficiency gas boilers (the 'control' scenario). The criterion of what constituted a certain LZC technology being a 'success' was on the basis of 'low energy use', 'low carbon emissions' and 'affordability.' The results show that all the case study homes used less energy, emitted less carbon and had lower annual running costs compared to the average UK household, emphasising the benefits of LZC technology integration over the 'basic house' design (Monahan and Powell, 2011). (Though what constitutes a 'basic house' design is not clarified in detail.) They further highlight the more noticeable tension between the different technologies in terms of affordability. The investigation demonstrates that technological performance (lowest possible energy use and carbon emissions) is important, but if the technology is not affordable by society, its selection may be affected.

Similarly, at the home occupant level, Caird *et al.* (2007) conducted a study of why certain LZC technologies (solar thermal, solar PV, micro-wind turbines and wood-burning stoves) are adopted or rejected by householders in existing homes. It was found that drivers of LZC technology uptake can be identified as the ability to gain a reduction in energy use, saving money and home owners wanting to be environmentally conscious. Caird *et al.* (2007) and Element Energy (2008) concur that the financial aspect of the technology (e.g. high capital cost of the system and long payback periods) is the main factor preventing the householders from adopting the technology.

Moreover, Pan and Cooper (2011) suggest that the financial aspect of the system can create both drivers and barriers towards LZC technology adoption. They stress that direct capital cost was a high priority for the housebuilders when selecting a suitable system for the housing project, and further led to choose a certain supplier due to the initial capital cost of air source heat pump (ASHP) systems. They further emphasise the importance of both short and long term expenses of the technology and its effect on selection. In addition to the financial aspect of the technology, the research identifies non-cost influences such as LZC technological performance, along with features of the technology that may affect its integration within a residential property, for example, ease of implementation.

Element Energy (2008:10) drills further down on the financial issues when it discusses how "consumers place a very low value on on-going costs compared with up-front capital costs." Consumers find the installation of microgeneration technologies unaffordable, while there is no or scant deliberation on the potential long-term savings of the system. The perceptions and values of society are linked to behaviour within this finding, similar to the work by Caird *et al.* (2007). In disagreement with Element Energy (2008), Faiers and Neame (2006) suggest that the economics of the technical system (economics in this context refers to the long-term investment, for example, the payback period or life-cycle costs of the system), is important, if not more important, to consumers than the initial capital costs.

Boardman *et al.* (2005) reiterate the previous key message stated by Element Energy (2008), that LZC technologies are not a cost-effective method of energy generation at this present moment. This message is presented for many technologies, for example, LZC technologies (Boardman *et al.* 2005), microgeneration technologies (Element Energy, 2008), along with technologies that have been on the market in the longer-term (ten years plus) such as fuel cells (Brown *et al.* 2007). This is also appears to be the case in community-owned technologies. The potential capital gain generated by certain technologies is a driver for its uptake, whereas those systems that are not cost-effective, or unable to achieve funding, are being rejected by communities (Walker, 2008).

In summary, the technological perspective has a focus on the actual technology (material artefact) itself; how it performs, the demands of the system when integrated and the micro-economics of the system. There appears to be a great emphasis on LZC technologies in comparison to conventional forms of technologies, in many cases the latter being more desirable due to certain characteristics (cost, reliability). The influences discussed within this section, specifically the financial aspects of the technology, are interpreted as a barrier or driver to the uptake of LZC technologies.

The technological literature is characterised by a unit of analysis which does move beyond the discrete LCZ technology or the home within which it is located. There is often an acknowledgement of the broader pressures for low and zero carbon homes (for example, UK national target commitments or the Code for Sustainable Homes). However, how these broader pressures enable or constrain the selection logics of those actors actually making those decisions is rarely detailed - there is an implicit assumption that the decision is a 'given.' It is this assumption which is of interest to the literature flavoured by an institutional perspective.

Institutional perspective

The 'institutional perspective' recognises that organisational behaviour is enabled or constrained by an institutional context. In other words, this perspective states that how an organisation acts or pursues its activities is not caused solely by economic and technological factors, but also by institutions. The ‘institutional perspective’ is interpreted in this paper as the role of institutions (such as government, local authorities, trade associations) through their policy, regulations, standards or guidelines in influencing the adoption of LZC technologies.

The importance of institutional factors that contribute to the selection of LZC technologies in new homes is less emphasised in the literature, but strands are to be found and are growing in volume and influence. A number of commentators have highlighted the vital role of governments in the uptake of LZC technologies. Without government support, the uptake of a LZC technology tends to be slower in the market place. Brown *et al.* (2007), for example, suggest the Japanese success of integrating fuel cell technology within the residential combined heat and power system is the result of a partnership of government and industry intervention. Negro *et al.* (2012), for instance, indicate the need of additional attention from policy makers in seeding up the diffusion of renewable energy technologies.

More specifically, a number of government instruments (e.g. policies, regulation) have been identified that have an influence on the uptake of LZC technologies (e.g. West *et al.* 2010; Element Energy, 2008). West *et al.* (2010), for example, state that the implementation of regulations and policies has a positive effect on the uptake of renewable technology (through the understanding of public opinions and the application of this understanding to policies).

Numerous studies further indicate that financial incentives can aid the adoption and diffusion of LZC technologies within housing. Li *et al.* (2011), for example, indicate that incentives, regulations and encouragement from the government are the main reasons why the uptake of solar water heaters in Dezhou, China has been successful. Similarly, Element Energy (2008) makes a normative stance that if in the form of subsidies, policies could be a key driver and resolve the issue of finance involved with microgeneration technologies. In contrast, Faiers and Neame (2006) state that previous policies offering grants or subsidies for solar thermal and solar PV installation have not acted as an incentive for adoption.

To further complicate the role of institutions, Boardman *et al.* (2005) amplify their responsibility; not only referring to the financial incentives that governments and local authorities can execute, but also changes to the market, changes to building regulations (new and existing build) and the provision of technological information within R&D, the supply chain and those installing the technology. The importance of markets and market policies are highlighted and suggested they are of great influence to the uptake of LZC technologies (Boardman *et al.* 2005; Tsoutsos, 2002). Although the provision of finance is not deemed as the most important element of increasing LZC technologies within housing, other drivers of LZC technologies (e.g. changes to markets) are related to and revolve around the cost (Boardman *et al.* 2005).

Foxon and Pearson (2007) further point out that it is not the lack of policies that are hindering low carbon technologies, but the process in which they are implemented. They conclude that policies designed with long-term strategies and those that combine government and stakeholder interaction will prove to be successful. (There is little indication of how broadly or narrowly the concept of a 'stakeholder' is defined.) Element Energy (2008) agree with Foxon and Pearson (2007) with the focus on the importance of policy definition, design and structure regarding their success. They are not underestimating the role of policy implementation, but suggest that attention should be paid to the details of the policies, such as carefully selected combined policies (as oppose to single policies).

In summary, the institutional perspective reveals that the uptake of LZC technologies is influenced by the logics of numerous institutions (such as local authorities or governments inflicting policies, standards or regulations). Evidence demonstrates that these influences predominantly act as drivers, as oppose to barriers, of LZC technologies. There are, however, cases where barriers are created against the technology or more commonly, a specific technology becomes favoured over others.

The literature is searching for linkages with the technological literature and is posing interesting questions for future research. The literature, however, tends to feature normative assertions that policies could do this or that (drawing, often, from experiences from other sectors such as manufacturing). The supporting empirical work to test these normative assumptions is an urgent research need.

DISCUSSION AND CONCLUSION

The technological and institutional literatures focused on LZC technologies in new housing have very different loci of investigation. Table 1 provides a summary of the perspectives and issues of each set of literatures. In broad terms, the technological literature considers and weighs the efficiency of different LZC technologies and generally makes an optimising assumption that the most efficient technology will be selected and used. There is an implicit positivism where the concern is with generalisation and prediction and the need to control the selection of LCZ technologies on the single goal of technological efficiency. The institutional literature, though rarely explicitly drawing upon the institutional theory literature, tentatively argues that regulatory and commercial logics create selection routines by housing developers which are not driven by technology optimisation criteria. Indeed, research has revealed instances where regulation compliance and commercial considerations have all been displaced by technical rationality.

Table 1 A summary of contributions to the two perspectives of the selection of low and zero carbon technologies

Multidiscipline perspective		Variables	Contributions
Technological perspective	Enablers	Low energy use	Lees and Sexton (2011), Monahan and Powell (2011), Pan and Cooper (2011), Peters *et al.* (2011), Element Energy (2008), Caird *et al.* (2007), Faiers and Neame (2006), Boardman *et al.* (2005)
		Low carbon emissions	
		Affordability	
		A reduction in fuel bills	
		Financial aspect of the system (high initial cost, long payback periods)	
		Economics of the system (e.g. payback period)	
		Technological development/improvement can aid a reduction in the cost of a system	
	Barriers	Financial aspect of the system (high initial cost, long payback periods)	West *et al.* (2010), Osmani and Reilly (2009), Caird *et al.* (2007), Brown *et al.* (2007)
		Technologies not cost-effective	
		Technologies not reliable	
Institutional perspective	Enablers	Government policy / regulations (economic / financial incentives, e.g. government grant, subsidies, renewable heat incentive; information to the public: renewable energy and environment; policies providing information; and, raising public awareness through customer motivation)	Li *et al.* (2011), Peters *et al.* (2011), Pan and Cooper (2011), West *et al.* (2010), Element Energy (2008), Brown *et al.* (2007), Foxon and Pearson (2007), Boardman *et al.* (2005), Tsoutsos (2002),
		Clear regulations (user knowledge, large scale, definition)	
		Encouragement from the government	
	Barriers	Lack of government intervention and promotion	Brown *et al.* (2007)

What is apparent is that both sets of literatures is that each, at best, acknowledges each other but generally do not authentically engage each other in a theoretical or empirical sense. Rather, the prevailing literature, by adopting a single perspective, tends to reveal a sometimes detailed, but nonetheless partial, incomplete picture. Discrete pieces of the jigsaw can be assembled to present a fragile 'leap of faith' picture that suggests that the selection of LZC technologies by housing developers is not solely dependent on technical or economic efficiency, but on the emergent 'fit' between the intrinsic properties of the technologies, institutional logics and the interests and beliefs of various actors in the new housing development process. There is an urgent need, though, for theoretical and empirical research which explicitly bring together these considerations into a systemic whole.

NOTES

[1] Renewable energy technologies are defined as "on-site solutions providing heating or power which are more efficient or emit less carbon than more traditional solutions" (NHBC, 2012: iv).

[2] Microgeneration technologies are defined as "On-site or building integrated equipment that generates electricity, but could include fossil fuels" (SBSA, 2007:44).

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