Low carbon innovations for mobility, food, homes and energy: A synthesis of consumer attributes

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*Abstract*

Novel consumer goods and services in mobility, food, homes and energy domains are needed to help mitigate climate change. Appealing attributes of low carbon innovations accelerate their diffusion out of early-adopting segments into the mass market (1, 2). In this paper we synthesise insights on the attributes of low carbon consumer innovations across multiple domains. Using a directed literature review and content analysis, guided by Levitt's hierarchical ring model which distinguishes core from non-core attributes, we identified over 170 relevant studies across mobility, food, homes and energy domains. We extracted a set of 16 attributes generalisable to low carbon innovations across multiple domains of consumption, with the exception of energy innovations which appeal on a reduced set of attributes. Using multi-dimensional scaling techniques we found the appeal of non-core attributes varies between domains but core attributes are consistent across domains in line with Levitt's theory. As examples, low-carbon consumer innovations within mobility and food domains share non-core attributes related to improved private and public health, whereas innovations within food and home domains share non-core attributes related to technology acceptance and usability. We develop these findings to argue that many low carbon consumer innovations are currently positioned to appeal to a distinctive but limited group of early adopters who value novelty and climate benefits. To achieve mass market diffusion, product and service development, policy interventions, and communication strategies should focus on enhancing a wider set of attributes to broaden consumer appeal.

*Highlights*

Directed review distinguishes between core and non-core attributes for low carbon innovations;
Low carbon innovations across different domains share core attributes;
Innovations within mobility and homes domains cluster against distinctive non-core attributes;
Low carbon innovations in the energy domain have limited appeal across all attributes;

*Keywords:* low carbon consumer innovations; attributes; diffusion; directed review; mobility; homes; food; energy

*Word Count: 10,985 (including appendices)*

*List of abbreviations*

| AVs | autonomous vehicles | b2c | business to consumer |
|-----|---------------------|-----|----------------------|

| EVs | EVs | HEMs | home energy management system |
|-----|-----|------|-------------------------------|
| MaaS | mobility as a service | NEVs | neighbourhood EVs |
| p2p | p2p | V2G | vehicle to grid |

*1.0 Introduction*

Marketing and diffusion research emphasise the importance of product attributes to consumer adoption. Attributes are dimensions or characteristics of a product or service, perceived by consumers to satisfy a particular need or solve a particular problem (2-4). They are important because they determine rates of diffusion (1), they provide signals to consumers with respect to competing offers (2), they are the basis on which specific offers can be positioned and targeted to relevant consumer groups (2). In diffusion research differing consumer preferences for attributes are a key factor within the adoption process. In diffusion of innovations theory, Rogers (1) identifies important differences between early adopters attracted to novel attributes that highly differentiate products and services from mainstream offers and early and late majority consumers who require the reassurances that familiar and more mainstream attributes offer. In the UK there are many consumer-focussed low carbon innovations well positioned to appeal to the needs of early adopters. In his stylised model of the distribution of market share across consumers groups, Rogers (1) suggests that early adopters make up only around 16% of the potential market. For significant $CO_2$ reductions to occur in key consumer segments such as mobility and food, diffusion needs to occur beyond this niche.  One of the major challenges relates to understanding how low carbon innovations appeal to a wider range of consumers.
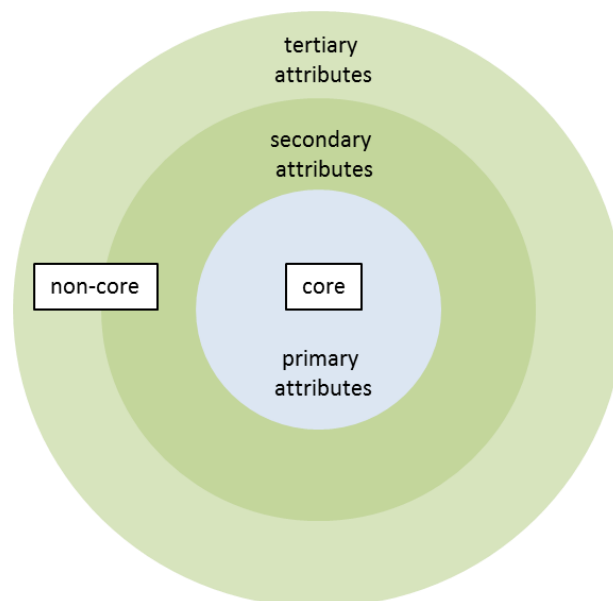


*Figure 1 - The Levitt Ring Model (1984, 1980)*

In marketing many conceptual models exist which categorise attributes, enabling deeper insights into the specific appeal of products and services to different consumer types. One of the most commonly used and adapted within marketing literature is Levitt's ring model (3) (Figure 1). This model consists of three layers or rings distinguishing between primary, secondary and tertiary attributes. The inner ring consists of primary attributes. These are core attributes that incorporate the essential and fundamental features of products and services that satisfy very generic needs (4-

7). For example hotels need to provide a safe and secure environment (4, 8, 9), public transport needs to be accessible and easy to use (5). Primary attributes generally offer nothing novel relative to competing offers yet Levitt's model shows they are core part of the offer. They are necessary but not sufficient. This emphasis is supported by many empirical studies into both high and low technology products and services (6, 9, 10).

The outer two rings in the Levitt model consist of secondary and tertiary attributes which are more distinguishable from the core primary attributes. Secondary attributes are additional, anticipated features that embellish or add value to the core (2, 4, 5, 11). In contrast with primary attributes secondary attributes are closer to luxuries or wants rather than needs (12). In addition to private mobility, private vehicles offer a range of secondary attributes such as additional design features (13). Washing machines are valued more by consumers when the value proposition includes not only primary attributes such as cost and basic functionality but secondary attributes such as improved controllability and energy efficiency (11). Tertiary attributes relate to more unique, distinguishable and unanticipated problem solving features that are novel compared to the competition. Tertiary attributes have high appeal to early adopters who value this novelty (5, 6). In their study into the valued attributes of instant messaging services, Lee, Khan (6) find a particular unexpected tertiary attribute is connectivity. This has high saliency with early adopters.

Many empirical studies use a reduced form of the Levitt ring model to concentrate on the differences between core and non-core attributes. In these studies core attributes are defined as utilitarian, functional, or instrumental. Non-core attributes are defined as hedonic, symbolic or facilitating (4, 11-14) (see Appendix A, Table 6). Since its introduction there have been many interpretations and applications of the Levitt ring model within marketing and consumer behaviour studies. Kotler and Armstrong (2) suggest the three levels clearly distinguish between layers of added value in which tertiary attributes are equivalent to an augmented product offering which is highly distinguishable from incumbents. Kano, Nobuhiku (15) develop the model to distinguish between product and service features that highly influence consumer satisfaction. Using a compatible framing between core and non-core attributes this framework determines which attributes are 'must haves' in the eyes of the consumer (8).

Although there are competing views as to whether core attributes are more important to consumers than non-core attributes (5, 6), there is strong evidence that core attributes are an essential part of the value proposition. In their empirical study of the valued attributes of high technology products Lee, Khan (6) find although early adopters place more value on tertiary level attributes, core attributes moderate adoption propensity. Other studies similarly find that whilst core attributes are not strongly related to overall satisfaction they can become dis-satisfiers if products and services perform badly against them (4, 5, 8, 9, 16). In their study into household washing machine purchases in China, Wang, Lu (11) find that a few basic, core attributes such as ease of use and convenience account for the majority of post purchase consumer satisfaction ratings.

Empirical research focussing on the attributes of low carbon innovations has historically focussed on single domain, single innovation studies. For example comparing single innovations (such as EVs), against the incumbent technologies (conventionally fuelled vehicles). They focus on comparing the core attributes of the incumbent technology (such as costs and performance) with the environmental benefit of the lower carbon alternative (such as lower emissions) (10, 17).This review

looks beyond low carbon as the sole attribute of low carbon innovations, exploring broader sources of added value across both core and non-core attributes. Applying the reduced Levitt framework to distinguish between these attribute types, this review takes a multi-domain, multi innovation approach, focussing on four key domains, all which require significant reductions in consumer based $CO_2$ emissions. These are mobility, food, homes and energy. The core contribution, apart from offering an up to date classification of the attributes of low carbon innovations, is to critically evaluate how low carbon innovations cluster within and across key consumer domains. In a final discussion this review evaluates how low carbon innovations might be positioned relative to distinctive consumer segments and identifies particular policy implications. These segments include consumers who value low carbon or other novel attributes and those that value more mainstream core attributes.

The aims of this review are twofold: to broaden understanding of the wide ranging attributes of low carbon innovations by clearly defining and identifying the core and non-core attributes; and to identify distinctive clusters of innovations across domains that share common attributes.

*2.0 Analytical Framework*

Products and services consist of a bundle of attributes which are differently valued by consumers (3). The Levitt ring model offers a simple but effective categorisation of attributes that can be easily applied across multiple consumer domains and across both high technology and low technology products and services. In basing a substantive literature review on this framework it is possible to capture attributes that are likely to appeal across multiple consumer groups and across multiple domains.

The analytical framework distinguishes between core and non-core attributes (Figure 2). Core attributes are a generic set of attributes which have broad appeal across a range of consumer domains and seen as an essential part of the overall product or service offering. Examples include safety, convenience, and low cost (18). In contrast non-core attributes include anticipated and unanticipated attributes where the latter relate to novel and unique characteristics of particular low carbon innovations or relate to an unexpected feature of low carbon innovations within a particular domain. Chitturi, Raghunathan (12) find consumers distinguish between the functional core attributes of private cars, laptop computers and mobile phones and facilitating non-core attributes of style and attractiveness. Slevitch and Oh (4), Slevitch, Mathe (8) find that 'greener attributes' are unanticipated within the hotel industry but contribute additionally to core functional and non-core facilitating attributes in terms of overall customer satisfaction.

To identify attributes the analytical framework draws on three key sources of information. Firstly empirical studies that directly apply the Levitt ring model to identify core and non-core attributes. These studies represent a wide range of consumer domains including high technology (instant messaging, mobile phones, laptops) (6, 12), household appliances (washing machines) (11), public and private mobility (public transport and private cars) (5, 12, 13) and public and private services (tourist destinations, food and hotels) (4, 8, 18). Secondly studies which although do not directly apply the Levitt model use a similar framing to distinguish between core and non-core attributes (10, 14, 19). For example Axsen and Kurani (14) identity a 2 x 2 attribute matrix that applies to mobility innovations. Although this matrix distinguishes clearly between private and public attributes it also clearly distinguishes between functional core attributes and more symbolic non-core attributes.

Thirdly studies that identify potential sources of consumer novelty from alternative models of product and service provision. This includes the sharing economy and service-based economy (20-22). These are important for low carbon innovations offering distinctive value propositions compared to mainstream incumbent technologies which mainly focus on the business to consumer retail model.
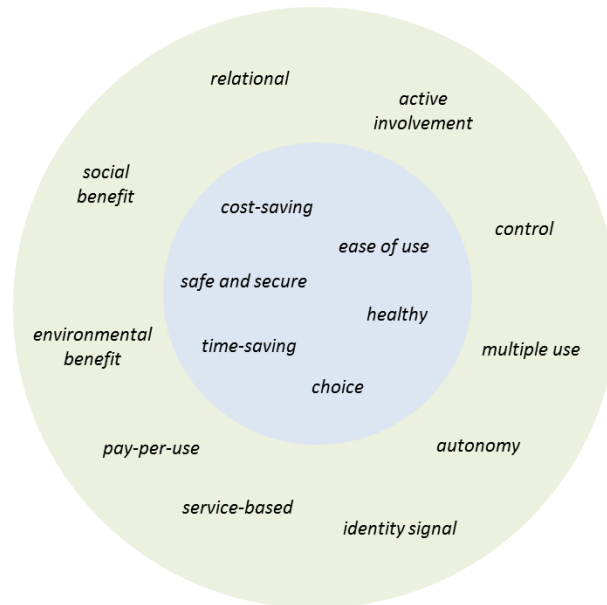


Figure 2 – The core and non-core attributes of low carbon innovations

At the centre of the analytical framework are 6 core attributes (Figure 2, blue circle). They relate to the functional, utilitarian needs of consumers. The outer ring of the framework consists of 10 non-core attributes (Figure 2 green circle). They relate to the hedonic, symbolic or facilitating needs of consumers. Attributes are defined as follows:

- *'cost-saving'*, cost efficient, low or no cost, or enables money to be used productively
- *'time-saving'*, time efficient, saves time, or enables time to be used productively
- *'healthy'*, supports healthy living or positive health outcomes
- '*safe and secure'*, provides security or is safe to use, low risk
- *'ease of use'*, low hassle, easy to use, convenient, or easy to access
- *'choice variety'*, allows users to choose alternative forms of the good or service to suit different needs or contexts
- *'environmental benefit'*, low or no emissions (or other pollution) associated with the use of a product or service
- *'social benefit'*, provides social or collective benefits shared by non-users
- *'relational'*, involves direct or indirect interactions with others who either use or provide the product or service
- *'active involvement'*, enables an active role or contribution by users to how a product is produced or a service is provided
- '*pay-per-use'*, has a usage-based or subscription-based cost structure without the need for upfront capital or other one-off investments
- '*service-based'*, useful service provided by a third-party without needing to own and maintain a product or technology
- *'multiple use'*, provides a range of different functions or forms of use, economies of scope
- *'control'*, provides control or gives users the ability to influence or manage how a product or service is used
- *'autonomy'*, independent of other service providers, people or infrastructures of provision
- *'identity signal'*, supports desirable aspects of users' individual or social identity and how this is communicated

This analytical framework (Figure 2) is used to address the following research questions:

1. Do low carbon innovations across four consumer domains share similar attributes?
2. *Do low carbon innovations cluster against specific core or non-core attributes?*

*3.0 Material and methods*

To answer these questions a category development approach described by Michelini, Principato (23) is used. This involves a form of directed review and content analysis of the literature, guided by a theory or as in this case a conceptual framing (24). The process consists of three clear stages (1) directed literature review and data collection (2) qualitative synthesis of attributes across domains and innovations (3) quantitative coding of attributes and testing for clustering across low carbon innovations.

The directed review process is driven by a set of keywords related to each individual low carbon innovation (see Table 1) plus each attribute identified in the analytical framework (see Figure 2). Keywords for low carbon innovations consist of a combination of alternative names or labels for specific low carbon innovations and specific examples. Attribute keywords are drawn from the detailed definitions of attributes, drawn from empirical studies (see Section 2). Boolean phrases are formed from these keywords to identify potential studies for synthesis. Phrasing follows the basic formula of 'attribute *OR benefit* AND (attribute-[specific]) AND (innovation-[specific]) OR [innovation-[specific-example])' (See Appendix B Tables 7(a) to 7(c)).

A wide range of search engines are used to access both grey and published studies. These include Science Direct, Scopus, Business Source Complete, Google Scholar, government, industry and trade association websites, national and local press and other media websites, marketing trade and research websites including Mintel, Euromonitor, and Statista.

Selection criteria allows studies and articles which fall into one of four key types: (i) empirical studies in which attributes are derived from users, (ii) theoretical studies in which attributes are assumed, argued or conceptualised, (iii) policy, consultancy, or other reports in which attributes are identified, and (iv) industry marketing or other reports by industry actors (including media) in which attributes are debated or discussed.

For each study selected the following information is recorded: type of article/study, specific low carbon innovation(s) analysed or discussed, content related to specific attribute(s) including examples, applications, or critiques, their relevance to specific innovation(s) and indications of importance or strength of attribute in terms of its appeal to consumers and specific consumer segments.

*3.1 Data generation*

A total of 38 low carbon innovations are identified (see Table 1). These are selected based on earlier work by the authors, in which 99 potentially disruptive low carbon innovations were identified from a wide range of literatures (25, 26). The identification of 38 low carbon innovations used in this study is drawn based on the following criteria: they are consumer facing alternatives to major incumbents

or incumbent behaviours in one of the four key domains; they have some (included limited) presence in the marketplace. They include low carbon innovations based on the digital economy (online or app-based) and alternative models of provision. This includes the ownership versus service economy and centralised retailing versus the sharing economy. The selection includes at least one low carbon innovation in each domain based on the sharing economy. Across all domains different forms of the sharing economy are represented including the on-demand economy (e.g., car clubs), the second hand economy (e.g., p2p exchange of goods and services) and the exchange of under-utilised assets (e.g., ride sharing and food sharing) (27, 28) ( See Appendix C, Tables 8(a) to 8(d)).

Table 1 – Low carbon innovations included in this study

| domain | ref | Low carbon innovation | domain | ref | Low carbon innovation |
|---|---|---|---|---|---|
| mobility | T1 | car clubs (US car sharing) | food | F1 | digital hubs for local food |
| | T2 | p2p (p2p) car sharing | | F2 | meal kits |
| | T3 | ride sharing | | F3 | 11th hour apps |
| | T4 | shared taxi (or taxibus) | | F4 | food pairing apps |
| | T5 | mobility as a service (MaaS) | | F5 | food sharing |
| | T6 | EVs (EVs) | | F6 | dietary change gamification |
| | T7 | e-bikes | | F7 | food waste reduction nudges |
| | T8 | autonomous vehicles (AVs) | | F8 | urban farming |
| | T9 | neighbourhood EVs (NEVs) | | F9 | cultured meat |
| | T10 | bike-sharing | | | |
| | T11 | telecommuting | | | |
| | T12 | videoconferencing and virtual meetings | | | |
| | T13 | telepresence and virtual reality | | | |
| homes | H1 | smart heating systems | energy | E1 | domestic electricity generation with storage |
| | H2 | smart lighting | | E2 | p2p electricity trading |
| | H3 | smart appliances | | E3 | electric vehicle to grid |
| | H4 | home energy management systems (HEMs) | | E4 | time of use pricing |
| | H5 | heat pumps | | E5 | demand response |
| | H6 | prefab retrofits | | E6 | energy service companies |
| | H7 | p2p (p2p) products and services | | E7 | third-party financing |
| | H8 | real-time feedback on disaggregated loads | | E8 | community energy |

In the mobility domain low carbon innovations selected (n=13) all have the potential to compete with private vehicle use including commuting between work and home or between workplaces or offices (e.g., e-bikes can be substituted for short distance commutes). They include those that offer service-based alternatives to vehicle ownership and those that replace or substitute the need for driving a privately owned vehicle to work or for business related travel (e.g., car clubs can replace the need for car ownership). In the food sector low carbon innovations chosen all compete with food shopping from large scale food retailers (n=9). These food innovations also have the potential to reduce food miles and food waste as well as lowering dietary related $CO_2$ emissions (e.g., digital hubs for local food provide a source of locally frown fruit and vegetables, grown on rooftops and sold in the supermarket below). In the homes sector innovations selected (n=8) help consumers to manage their energy demand (e.g., smart heating systems enable consumers to better manage the temperature and duration of heating schedules), improve home energy efficiency (e.g., HEMs) and reduce demand for new goods (e.g., p2p products and services). In the energy sector innovations relate to household energy generation, storage and use (n=8) and have the potential to improve

home energy efficiency, provide service-based alternatives to energy management, and enable households that generate their own electricity to trade with energy providers or other households.

*3.2 Data analysis*

The first research question asks "do low carbon innovations across four consumer domains share similar attributes?" To answer this question content data is extracted from articles and studies. In a first step each attribute's relevance for each low carbon innovation is recorded using a simple coding scheme (where 1=evidence attribute is relevant and 0=no evidence attribute is relevant). In a second step the richness of the content data is used to identify cross cutting themes within each attribute that apply either across domains or across similar types of low carbon innovation. Identification of these themes draws on earlier work by the authors (29) (see Appendix D, Table 9). The second research question asks "do low carbon innovations cluster against specific core or non-core attributes? Building on steps 1 and 2 above, in a third step for each low carbon innovation the appeal of relevant attributes is estimated using a scale of 1 to 3 (where 1=low appeal, 2=modest appeal and 3=high appeal). This quantification is a subjective scoring based on evidence in the literature. A final fourth step uses multi-dimensional scaling (MDS). MDS is a mathematical technique which seeks to identify the underlying structure of data (30, 31). It is commonly used for understanding relationships between 'objects' (low carbon innovations) and 'perceptions or attitudes' (appeal of attributes) (32).The output of MDS models is typically in the form of a perceptual map. This plots the geometric distance between objects in a two dimensional space (31). The two dimensions of an MDS model are open to be interpreted and are not predefined (32).

Using statistical software (33), the relative appeal of the 38 low carbon innovations against 16 attributes is transformed into a proximity matrix. Proximities are the Euclidean or straight line distance between low carbon innovations based on their appeal within this reduced 'attribute space' (30, 31). Where MDS is performed subsequent to qualitative analysis, meaningful interpretation of the axes draws on the qualitative data to account for clustering within the same attribute space or those that sit in opposing quadrants of the perceptual map (32).

*4.0 Results*

A total of 274 studies were identified from the directed review. A final total of 171 articles and papers met at least one of the four inclusion criteria. Just under half were empirical studies (n=85), the remaining were either (theoretical) studies (n=29), government or policy related reports (n=4) or industry, marketing or other reports (n=53).

*4.1 Qualitative evaluation of attributes*

Table 2 – Relevance of core attributes and cross cutting themes for 38 low carbon innovations in 4 domains of consumption

| te go | attribute | evidence in domain | st | cross cutting themes within studies/articles | References |
|---|---|---|---|---|---|

| core | | mobility | food | homes | energy | | | |
|---|---|---|---|---|---|---|---|---|
| core | *cost-saving* | x | x | x | x | 44 | 'financial savings and lower costs', 'value for money' | (34-78) |
| | *ease of use* | x | x | x | | 43 | 'convenience', 'accessibility', 'low hassle', 'flexibility', 'on demand', 'simplicity', 'easy to understand' | (35, 38, 39, 43, 49, 51, 53-55, 57, 58, 66, 75-77, 79-106) |
| | *safe and secure* | x | x | x | | 21 | 'increased food security', 'safer food', 'personal and family security' 'avoid energy blackouts' | (34, 43, 48, 57, 63, 74, 75, 87, 91, 98, 103, 107-116) |
| | *healthy* | x | x | x | | 31 | 'improved emotional and physical fitness', 'improved quality of life', 'healthier living and working environments', 'improved diet and nutrition' | (44, 48, 53, 57, 68, 69, 82, 86, 90, 98, 100, 111, 117-135) |
| | *time-saving* | x | x | x | | 25 | 'reduces time', 'frees up time', 'more productive use of time' | (34, 37, 43, 53, 57, 66, 69, 71, 74, 76, 86, 90, 98, 101, 126, 136-145) |
| | *choice variety* | x | x | x | | 30 | 'choice of use', 'choice of products', 'choice of suppliers' | (34, 35, 38, 39, 45, 51, 53, 61, 62, 79, 80, 86, 87, 89, 92, 94-96, 101, 103, 117, 121, 133, 137, 140, 146-150) |

Tables 2 and 3 summarise the results from the thematic analysis. Table 2 identifies the relevance of each core attribute across the four domains. It also identifies cross cutting themes. '*Cost- saving'* is the only core attribute common to all four domains. Across all other core attributes low carbon innovations within mobility, food and homes are widely perceived in the literature as having a similar core offering to consumers. '*Ease of use'* incorporates a number of consistent themes across domains including improved accessibility, reduced hassle, simplicity of use, and ease of understanding (76, 83). Improved accessibility is a particular cross cutting theme within this attribute relating largely to app-based innovations (81, 86, 88, 92). Other core attributes incorporate themes that demonstrate subtle differences between domains. '*Safe and secure'* varies between the public context in which mobility is consumed and the private context in which food and homes related innovations are used. AVs improve private security (34) but more localised food production secures public interest (food security) (112). Real-time feedback on disaggregated loads improves the management of peak energy and reduces the threat of energy blackouts (75). This distinction between private and public attributes is consistent with Axsen and Kurani (14) who suggest both core and non-core attributes for mobility innovations should be further categorised between private and public domains. '*Healthy*' has many interpretations across domains. Mobility innovations de-stress travel and working environments (69), and improve emotional and physical fitness (57, 98, 130, 151). Food innovations improve diet and nutrition (121, 152). Home innovations maintain healthy living environments particularly for vulnerable people (128). '*Time-saving'* is all about fulfilling a functional need to use time more productively on work or leisure. Mobility innovations reduce travel time, save time (reduce congestion) and reduce waiting times (particularly if app-based) (21, 138-140). Food and homes innovations reduce shopping time (74, 86), cooking time(90), and increase leisure time(153). '*Choice variety*' relates to both alternative forms of consumption and alternative forms of behaviour. MaaS offers choice between modes of travel (92) and digital hubs for local foods enhance choices between local foods (121). Videoconferencing and telepresence in contrast offer choice and flexibility in commuting behaviour (40, 148) and food pairing apps offer choice between using food for different recipes and wasting it (147).

Table 3 – Relevance of non-core attributes and cross cutting themes for 38 low carbon innovations in 4 domains of consumption

| Category | attribute | evidence in domain | | | | studies found (n) | cross cutting themes within studies/articles | References |
|---|---|---|---|---|---|---|---|---|
| | | mobility | food | homes | energy | | | |
| non-core | *environmental benefit* | x | x | x | x | 39 | 'lowers $CO_2$ emissions and avoids pollution', 'avoids waste', 'builds more sustainable marketplaces and greener cities', 'reduces consumption' | (27, 34-36, 46, 50, 54, 57-59, 80-82, 86, 94, 106, 108, 125, 128, 137, 140, 142, 148, 150, 154-159) |
| | *social benefit* | x | x | x | x | 34 | 'inclusive', 'help and support others', 'educate', 'enhanced local biodiversity and utilisation of space', 'builds communities', 'widespread common good', 'provides benefits to others' | (27, 34, 46, 49, 50, 66, 69, 76), Boxall (81), (86, 90, 91, 102, 103, 106, 117-119, 123, 126, 128, 145, 147, 148, 160-169) |
| | *relational* | x | x | x | x | 27 | 'integration into a community', 'strengthens relationships', 'enhances or creates social networks' | (27, 37, 38, 50, 58, 67, 69, 74, 75, 87, 91, 100, 109, 114, 138, 148, 150, 170-172), La Trobe (173), (174-179 |
| | *active involvement* | x | x | x | x | 23 | 'co-creation', 'sharing with others', 'self-reward framework', 'proactive management' | (38, 42, 43, 49, 53, 67, 70, 75, 79, 82, 88, 98, 106, 126, 128, 133, 150, 158, 169, 178-181) |
| | *pay-per-use* | x | | x | x | 20 | 'usage-based consumption', 'removal of upfront costs', 'access without ownership' | (34, 38, 57, 67, 74-76, 78, 80, 92, 94-96, 127, 160, 182-187) |
| | *service-based* | x | | x | x | 26 | 'third-party management', 'flexible usage' | (34, 35, 39, 50, 51, 53, 69, 74-76, 78, 80, 86, 90, 92, 94-96, 127, 147, 170, 183-185, 187, 188) |
| | *multiple use* | x | x | x | x | 21 | 'additional services', 'access to multiple services' | (35, 37, 39, 42, 43, 46, 49, 58, 62, 69), The Energy Saving Trust (77), (80, 89, 91, 98, 103, 104, 126, 185, 189, 190) |
| | *control* | | x | x | x | 13 | 'improved monitoring', 'improved management', 'automation' | (39, 42, 69, 75, 100, 103, 128, 150, 181, 185, 191-193) |
| | *autonomy* | x | x | x | x | 12 | 'independence', 'alternatives to major systems of centralised provision' | (36, 38, 86, 119, 125, 147, 174, 180, 185, 189, 192, 194) |
| | *identity signal* | x | x | x | x | 26 | 'collective identity', 'environmental symbolism' | (10, 38, 43, 61, 69, 86, 90, 95, 113, 117, 119, 149, 150, 174, 176, 177, 180, 189, 195-202) |

Table 3 identifies the relevance of each non-core attribute across the four domains, and related themes that emerge from studies. '*Environmental benefit*' is a common non-core attribute across all four domains, and this is entirely consistent with the framing of low carbon. Importantly other environmental benefits are common beyond lower $CO_2$ emissions, including pollution, waste, sustainability and lowered consumption (58, 81, 86, 115, 140, 177). '*Social benefit*' distinguishes between domains in which low carbon innovations offer greater public benefit. Mobility and food innovations contribute widely to public good, with themes related to social inclusivity (160, 163), improved public food education and local diversity (90, 161, 165). '*Relational*' and '*active involvement*' bring together low carbon innovations based on the p2p model with themes relating to improved physical integration within communities (170), formation of supportive online communities(67), friendships and cooperative consumption between family members, co-workers,

and within other close social networks (67, 138), and the creation of prosumers particularly in the context of ridesharing and p2p car clubs (38). '*Pay-per-use*' and '*service-based*' bring together low carbon innovations that offer an alternative to private ownership. This is reflected in themes related to usage-based and more flexible consumption (38, 76, 127, 160), access without ownership (95), and third-party management (188). Qualitative analysis confirms that there are few low carbon innovations that are '*multiple use*'. Some energy innovations provide additional grid services including distributed production as well as own consumption (192). Low carbon innovations across all four domains however, offer multiple benefits. E-bikes combine personal mobility over longer distances with the potential for improving health (126) and fully autonomous vehicles combine personal transport with the potential for a mobile office (189). NEVs provide additional mobility within parks, college campuses, and golf courses (37). Some food innovations combine dietary management with gaming and health tracking (53). '*Control*' and better management applies across food, homes and energy but is viewed as a key benefit of a small number of low carbon innovations within the homes domain which improve management and monitoring of energy use, and provide enhanced, real-time automation of household tasks such as switching on heating and lighting (39). '*Autonomy*' is also common to all four domains where it relates strongly to freeing consumers from providers. These include petroleum companies (14, 180), animal agriculture (125), food waste (147). Themes also relate to increased agency in terms of living more independently (128). '*Identity signal*' is a complex, symbolic attribute which varies between self-identification through private consumption and a social, collective identity from membership of a particular group or sub-group. Self-identities relate to low carbon innovations that help consumers to cultivate a positive self-image(177), symbolise ideas such as environmental preservation (180), inspire others to consume (14), or being seen by others to be an early adopter (93, 153, 180). Social, collective identities relate to alignment or membership of particular social groups. Car clubs for example are social organisations which offer a collective identity which has positive consequences for the consumer, including feelings of engagement and reduced normative pressure (195). Similarly many low carbon innovations in the food domain confer strong social identities for consumers who engage in more socially acceptable practices such as buying local food (86), cooking from scratch (90), wasting less food (149), and eating low meat diets (119, 174).

*4.2 Quantitative evaluation of the appeal of attributes to potential consumers*

Qualitative analysis identifies the extent to which attributes are relevant to low carbon innovations across four main consumer domains. In general the low carbon innovations across domains appeal right across the set of 6 core and 10 non-core attributes, although with differing emphasis. Low carbon innovations in the energy domain appeal on a narrower set of attributes. By scoring the extent to which each innovation appeals to consumers across attributes, the qualitative data is built upon to identify how low carbon innovations cluster according to their specific value proposition to consumers. Subjective, scorings are derived from qualitative findings within the literature. All scorings are double blind with differences between coders then resolved through discussion.

To examine the clustering of low carbon innovations against attributes two MDS models are run. The first model compares the relative positioning of all 38 low carbon innovations against the 16 core and non-core attributes. This models tests the hypothesis that low carbon innovations in the outer four quadrants of the perceptual map cluster against unique, non-core attributes. The second and subsequent model draws on the findings from model 1. Low carbon innovations proximal to the

centre of the two axes (x, y=0) in model 1 are more likely to appeal similarly against attributes shared by the 16 low carbon innovations. Model 2 tests this hypothesis using a subset of low carbon innovations and a subset of shared attributes identified in model 1.

The output from each MDS model is a perceptual map (Figures 3 and 4). The identification and explanation of clusters draws the quantified scorings of low carbon innovations against the attributes (see Appendix E, Tables 10(a) to 10(b)) and the qualitative findings (Section 4.1).
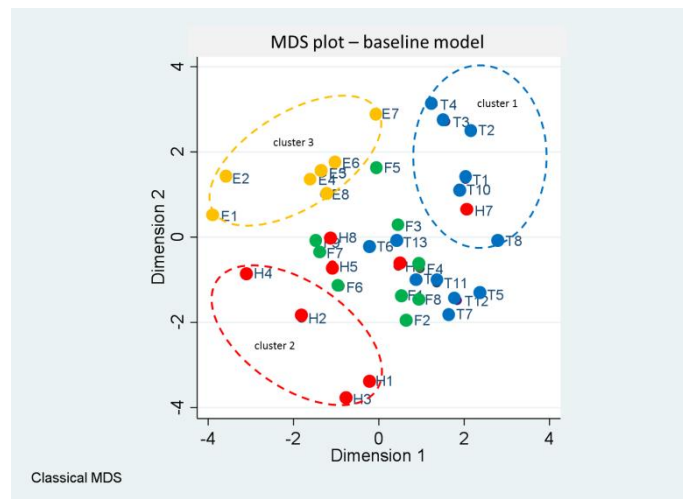


Figure 3 –Perceptual map 1 (model 1)
Outer quadrant clustering of low carbon innovations appealing against distinctive non-core attributes

Table 4 Low carbon innovations within clusters 1 to 3

|  | cluster 1 |  | cluster 2 |  | cluster 3 |
|---|---|---|---|---|---|
| T1 | car clubs | H1 | smart heating systems | E1 | domestic electricity + storage |
| T2 | p2p car share | H2 | smart lighting | E2 | p2p electricity trading |
| T3 | ride share | H3 | smart appliances | E3 | V2G |
| T4 | shared taxi | H4 | HEMs | E4 | time of use pricing |
| T8 | AVs |  |  | E5 | demand response |
| T10 | bike-share |  |  | E6 | energy service companies |
| H7 | p2p products & services |  |  | E7 | third-party financing |
|  |  |  |  | E8 | community energy |

note (blue=mobility, green=food, red=homes, yellow=energy)

Figure 3 is a perceptual map of the clustering of low carbon innovations within the full two dimensional attribute space. It shows the relative positioning of all 38 low carbon innovations, colour coded according to domain. Three clusters of low carbon innovations sit in the outer quadrants of the perceptual map. The top right corner cluster 1 (circled in blue) is dominated by low carbon innovations from the mobility domain. These are T1 (car clubs), T2 (p2p car share), T3 (ride share), T4 (shared taxi), T8 (AVs), and T10 (bike-share). Only H7 (p2p products) is included from the homes domain (see Table 4). F5 (food sharing) sits just outside this cluster. These low carbon innovations share many core attributes including '*cost-saving*', '*healthy*' and '*time-saving*' and have high to moderate appeal against non-core attributes '*environmental benefit*' and '*social benefit*'.

Unique to this cluster, however, is high to moderate appeal against non-core attributes '*pay-per-use', 'service-based', 'relational' and 'active involvement'*. These low carbon innovations are all based on the sharing economy model, strongly associated with these non-core novel attributes (21, 22). Findings also suggest these more novel attributes are supported by a relatively strong core offering. Core attributes are an essential part of the value proposition to consumers and can become dis-satisfiers if they are not adequately met (4, 7).

Diametrically opposite cluster 1, a smaller cluster 2 (circled in red) is dominated by homes innovations. These are H1 (smart heating), H2 (smart lighting), H3 (smart appliances) and H4 (HEMs). They also share many core attributes, including *'cost-saving', 'ease of use' and 'safe and secure'*. These are important core attributes that are highly valued by mainstream consumers who value familiarity, trust and fit within current social practices (203). This cluster almost exclusively offers two non-core attributes *'control'* and '*multiple use*'. As with cluster 1, this is clearly linked to 'smart', technology-mediated control of domestic functions.

In the top left corner cluster 3 (circled in yellow) consists entirely of energy innovations. These low carbon innovations have a weak core offering and only appeal against 'cost-saving'. This is indicative that these energy innovations fail to offer a compelling challenge to the mainstream model of passive energy consumers and centralised utilities. Solar PV, and EVs are expensive and subject to enabling infrastructure and regulation. Energy innovations in this cluster have distinctive non-core appeal particularly against '*autonomy*' where this relates strongly to providing consumers with alternatives to centralised utility supplied energy (185, 192).

In the centre of the perceptual map there are 19 low carbon innovations dominated by food innovations. These are all highly to modestly appealing against public, non-core attributes '*environmental benefit*' and '*social benefit*' but have low appeal against the other 8 non-core attributes relative to clusters 1 to 3. The second MDS model tests the hypothesis that these 19 low carbon innovations cluster on the shared attributes which include the 6 core attributes plus the two non-core attributes '*environmental benefit*' and '*social benefit*'. Core attributes such as 'low cost', 'ease of use', 'time-saving' are essential to mainstream consumers and are also attributes against which low carbon innovations can compete directly with incumbent technologies (3, 6, 7, 203).
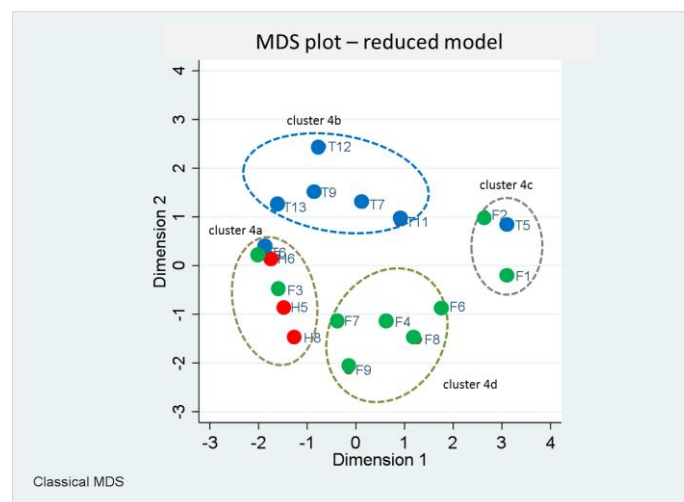
Figure 4 – Perceptual map 2 (model 2)

Outer quadrant clustering of low carbon innovations appealing against distinctive core attributes

Table 5 Low carbon innovations within clusters 4(a) to 4(d)

| Cluster 4(a) | | Cluster 4(b) | | Cluster 4(c) | | Cluster 4(d) | |
|---|---|---|---|---|---|---|---|
| T6 | EVs | T7 | e-bikes | F1 | digital hubs food | F4 | food pairing apps |
| F3 | 11th hour apps | T9 | NEVs | F2 | meal kits | F6 | dietary change gamification |
| F5 | food sharing | T11 | telecommuting | T5 | MaaS | F7 | food waste nudges |
| H5 | heat pumps | T12 | video-conferencing | | | F8 | urban farming |
| H6 | prefab retrofits | T13 | telepresence | | | F9 | cultured meat |
| H8 | real-time feedback | | | | | | |

Note (blue=mobility, green=food, red=homes, yellow=energy)

Figure 4 is a perceptual map showing the clustering of the reduced set of low carbon innovations (n=19) within a new two dimensional space. Clusters are identified based on their positioning within the outer quadrants of the perceptual map. Figure 4 shows four clusters, 4(a) to 4(d). Cluster 4(a) (circled in brown) is a cross domain cluster of six low carbon innovations. These are T6 (EVs), F3 (11th hour apps), F5 (food sharing), H5 (heat pumps), H6 (prefab retrofits) and H8 (real-time feedback). These all have very limited core appeal, appealing only against '*cost-saving'*. In this cluster there is a clear cross cutting theme of improved efficiency and reduced waste. For the homes innovations this relates to better use of energy and lower fuel bills, (46, 77). For mobility this relates to more efficient private mobility and lower running costs (36, 61). For food this relates to lowered food waste and lower food costs (65, 149).

In the top left corner cluster 4(b) (circled in blue) is a cluster of five alternative forms of mobility. These are T7 (e-bikes), T9 (NEVs), T11 (telecommuting), T12 (videoconferencing) and T13 (telepresence). These low carbon innovations have wider appeal across the core attributes (relative to cluster 4(a)) with moderate to high appeal against '*cost-saving'* and '*time-saving*' and some appeal against '*healthy*'. Particular cross cutting themes relate to reduced costs of travel (84), more productive use of time(70, 144) and reduced social costs where this relates directly to the health and social wellbeing of individuals and or employees (69)

Diametrically opposite cluster 4(a), cluster 4(c) (circled in grey) is a cluster of 3 low carbon innovations. In contrast to cluster 4(a) and 4(b), low carbon innovations in this cluster have low to no appeal against '*cost-saving'.* These low carbon innovations are F1 (digital hubs food), F2 (meal kits), and T5 (MaaS). Cluster 4(c), however, has the strongest core offering against non-monetary core attributes with strong appeal against attributes valued by consumers of technology based products and services including '*ease of use,* '*time-saving'* and *'choice variety'*. These three low carbon innovations use technology or apps to improve access to food and private and public forms of mobility (86, 90, 92).

In the bottom centre of the perceptual map cluster 4(d) (circled in green) is a domain specific cluster of food innovations. These are F4 (food pairing apps), F6 (dietary change gamification), F7 (food waste nudges), F8 (urban farming), and F9 (cultured meat). These low carbon innovations have low to moderate appeal against '*ease of use*' and '*choice*' but high appeal against '*healthy*'. Here health relates to a range of both private and public benefits including improved diet (53), improved food

security, and improved public health (48, 112, 131).

*5.0 Discussion*

*5.1 Key findings*

*<u>Low-carbon innovations appeal to consumers in many different ways beyond their contribution to emission reductions.</u>* This review provides novel insights on the wide ranging attributes of low carbon innovations across multiple domains of consumption from mobility and food to homes and energy. It shows that a set of 16 core and non-core attributes are robust and generalisable across consumption domains and the wide variation in context that this implies. This finding in itself is important for it challenges the view that low carbon innovations appeal against a small set of environmental and social benefits which are largely domain specific (203). Although core attributes are fairly homogenous across consumption domains, low carbon innovations within specific domains cluster against a reduced set of non-core attributes. These attributes relate to unique sources of added value over and above incumbent goods and services (5, 8).

*<u>Low-carbon innovations are differentiated by non-core attributes but need to perform well on core attributes in order to diffuse more widely.</u>* Models from marketing theory including those by Levitt (3) and Kotler and Armstrong (2) emphasise the importance of core attributes in competing effectively with incumbent technologies and practices such as private car use, shopping from supermarkets, and passively using energy without regard to system performance. Accelerating market growth of low carbon innovations requires complementary development and marketing strategies from industry and government. This includes building greater public awareness on the private and public benefits of low carbon innovations.

*<u>Low-carbon innovations with strong appeal on core attributes are more compatible with current consumption practices and have stronger potential to move rapidly into the mass market.</u>* The transition from car ownership to sharing modes of transport presents a significant challenge not least because it challenges socially acceptable norms of behaviour. In contrast, low carbon innovations such as smart home technologies require only incremental change to current familiar practices such as cooking, or controlling heating and lighting. They also build on the significant developments in the digital economy that enable controllability and manageability of owned assets. In the UK over 90% of adults under the age of 50 have access to the digital economy (they own a smartphone), nearly 100% of all households own a washing machine of some sort (204, 205). This review finds a cluster of smart home innovations which are highly appealing because they offer controllability, and enhanced, real-time automation of household tasks such as heating, lighting, and clothes washing (39). They also have a very strong core offering to consumers. This strong core positioning, combined with their compatibility and familiarity with existing practices suggests homes innovations should have more mass market appeal (1). Although a Mintel survey in 2017 of 2,000 UK consumers found 47% were willing to pay extra for smart home devices (62) currently only between 1-6% of UK households have invested in more energy efficient smart home appliances (46) while the market for low-energy-related smart products like TVs and voice-controlled home assistants has grown rapidly. In the short term governments and industry could offer financial incentives or product leasing and rental agreements to encourage greater adoption. In the longer term a more disruptive strategy would be to shift consumer demand away from buying products towards buying

functionality. This could help overcome the high upfront costs of creating smarter, more energy efficient homes (206).

*Novel non-core attributes can drive disruptive change which challenges incumbent firms and mainstream consumer practices.* Disruptive innovation is a field of business and management scholarship interested in the transformative potential of novel goods and services for consumers. Its outcome is the dislodging of incumbent firms and interests from entrenched market positions. It builds on the seminal work of Christensen (208) who theorises that incumbents fail to see disruptive threats from innovations which offer a wholly new set of attributes while performing poorly on the core attributes currently valued by mainstream consumers. Low carbon innovations based on the sharing economy model could effectively stimulate disruptive growth in new market segments based on these new set of demands and preferences from consumers (25). To support emission reduction objectives, government, industry and marketing practitioners need to build and support new value propositions around these novel attributes driving innovation towards improved performance on the new dominant adoption criteria.

*Sharing-economy innovations in different domains of consumption offer non-core attributes related to social interaction, connectedness, and activity.* The appeal of mobility innovations clusters around a reduced set of non-core attributes strongly associated with the sharing economy business models. The sharing economy has experienced significant growth over the last decade, attributed to the fact that it harnesses, and in most cases capitalises on, currently under-utilised physical assets such as private vehicles (207). This review suggests the appeal of low carbon mobility innovations based on the sharing economy model relates not only to their ability to replace the need for car ownership but also to the direct network externalities that accrue as others become connected via the same service (171). This offers potential consumers wider opportunities for social interaction, the ability to connect with like-minded people, and the possibility of becoming more actively involved in 'co-creation' of consumption activity (174).

*Digitally-enabled on-demand services have strong potential to outcompete incumbents both in younger consumer segments but increasingly in the mass market as they focus innovation development on continual improvements on core attributes.* The digital economy offers opportunity for alternative forms of products and services that challenge incumbent providers who currently maximise on low cost and convenience. There is an emerging cohort of younger consumers referred to as 'Generation Z' who are the first generation to have grown up alongside wide scale access to the digital economy (215). Their rapid socialisation around video gaming, mobile phone apps and web-based technology means they are receptive to web and app-based innovations within the digital and sharing economy. This review identifies a unique cluster of innovations which offer consumers on-demand access to mobility, food and domestic services through smart phones and web-based technology. In addition to having strong potential appeal to this emerging cohort of consumers, these digital innovations are also uniquely positioned to adapt rapidly and competitively within the marketplace. For example, 11th hour food apps such as 'Too Good To Go' (216) use technology platforms that enable them to rapidly improve against core attributes such as ease of use through software improvements in ordering and payment systems, and as technology platforms and digital skills become more widespread.

*Low-carbon innovations for managing the supply and use of energy in homes have weak consumer appeal on core attributes and without stronger policy interventions are likely to remain stuck in early-adopting market segments.* The way that energy is used and managed in the home is integral to the deep and pervasive changes required within the energy system to mitigate climate change (25). This review included energy innovations that offer consumers a range of technology solutions to managing energy use in their homes. A major finding is that these low carbon innovations have a weak core offering, limited to their potential for saving money. They also have low appeal against other core attributes essential to wider technology acceptance and diffusion (209, 210). Energy innovations are currently positioned to appeal to a specific niche of energy conscious 'prosumers' who wish to be more actively involved in managing, generating and trading their household energy. To support growth in this segment, the government needs to re-introduce policy to encourage more active household participation in the energy market. The successful feed in tariff (FIT) scheme introduced by the UK Government in April 2010 offered UK homeowners strong incentives to invest in rooftop solar PV. Resulting adoption contributed towards a new generation of prosumers who were moderately more engaged with their home energy use and needs, along with a more aware and involved relationship with the energy supply system. The FIT scheme closed in March 2019 resulting in a downturn in new solar PV installations (77). Clear signals and actions are now required by the government that continue to challenge the incumbent model of passively using energy whenever and however it is needed in the home. Strategies are required that establish new social norms of behaviour around household energy management.

*Clusters of innovations across consumption domains appeal on similar attributes, and are readily linked to specific types of lifestyles*. Lifestyles play an important role in shaping consumer behaviour regarding novel low-carbon goods and services (211). Lifestyle not only leads to patterns of behaviour (204), intentions and choices such as where to live and what to eat (212), but also to expressions of self-identity. In marketing lifestyle is used to profile and segment consumers according to their likely purchasing decisions (213, 214). Marketing researchers typically identify constituents of lifestyle in a particular consumption domain such as food or tourism in order to help target relevant goods and services. This review identifies clusters of innovations across consumption domains that similarly appeal against core attributes. For example, a single cluster of mobility and homes innovations support lifestyle change related to health and diet. Government and industry should maximise the benefits from adopting market-segmentation based strategies to target specific lifestyle groups.

*5.2 Implications for Government (and policy)*

This final section draws on key findings in Section 5.1 to make three additional recommendations for government action.

*Recommendation 1 - Support growth of low carbon innovations in the digital and sharing economies by ensuring digital skills are more widespread.* The digital economy is growing rapidly in the UK (217). Incentives and educational support are required to bridge the digital divide between more affluent, educated consumers and those with lower skills and motivation. This latter group includes low income rural communities, and employees who have not acquired digital skills through the workplace (218). Interventions could include public skill centres positioned in high footfall public

spaces (such as shopping centres), and providing skills grants for employers, particularly where employees could replace their daily commute with a low carbon alternative.

*Recommendation 2 – Support low carbon lifestyle change through funding national and local social marketing campaigns.* Social marketing applies the commercial marketing model to products, services and initiatives with public benefits (219). This approach has proved successful in public health where campaigns have targeted behaviour change in smokers, diabetics, and clinically obesity (220). As well as improving outcomes in individuals these campaigns have a wider public benefit. Social marketing interventions have been used by local councils to effect behaviour change. This includes using menu labelling to influence food choices in council run canteens. Integrated national and local campaigns could aid the diffusion of low carbon innovations by building a broad low carbon consumer consciousness throughout the population. This would raise the saliency of low carbon innovations. Priority and provocative topics could include 'the emissions impact of food' and 'the true costs of car ownership'.

*Recommendation 3 - Support research and data collection in the early adopter market to identify and understand early adopters, their characteristics and their motivations*. Early adopters play a critical role in seeding market growth yet research and practice remains disconnected between private market research and public academic research. Funding streams should be dedicated to aligning professional market research organisations and the academic and non-governmental research communities. Government sponsored social surveys which collect annual data from households should also be directed towards collecting data on low carbon innovations. For example, Understanding Society in the UK is a national, longitudinal survey which interviews over 40,000 households on a repeated annual basis. These surveys need to track low carbon consumption behaviour across a wider range of consumer domains.

*6.0 Conclusion*

This review addressed the following research questions (1) Do low carbon innovations across four consumer domains share similar attributes? (2) Do low carbon innovations cluster against specific core or non-core attributes?

A directed review of over 170 articles and studies followed by qualitative and quantitative synthesis identified 16 cross cutting attributes that variously appeal within and across four different consumer domains: mobility, food, homes and energy. These domains are important because they all require significant reductions in consumer based $CO_2$ emissions (221). Seven clusters of low carbon innovations were identified based on their appeal against similar attributes. Three domain specific clusters offered unique added value against non-core attributes. Three cross domain clusters offered added value against core attributes.

Contrary to traditional segmentation approaches focussing on single innovations in single domains, the framing proposed and tested in this review is a  segmented approach. It is uniquely based on the shared characteristics and attributes of low carbon innovations. By concentrating on attributes there is an opportunity for government interventions, marketing and communications campaigns to more proactively target specific groups of consumers with low carbon innovations that are also relevant to their needs and expectations.

Appendix A – Empirical studies based on the Levitt ring model (Table 6)

Table 6 – Core and non-core attributes identified in studies based on the Levitt framing

| study | core attributes identified | non-core attributes identified | product/service type (high/ low technology) | product/service |
|---|---|---|---|---|
| (222) | cleanliness and health | relationship with service providers | low | hotels |
| (11) | functionality | control, energy efficiency, brand identity | low | washing machines |
| (6) | ease of use, choice, time-saving | connecting with others | high | instant messaging services |
| (8) | cleanliness, safety, security, comfort, | environment, societal benefits, sustainability | low | hotels |
| (4) | cleanliness, safety, security, comfort, | personalisation | low | hotels |
| (12) | functionality | style, attractiveness | high | mobile phones, laptops |
| | functionality | style, attractiveness | low | cars |
| (18) | safety, convenience, cost, infrastructure and services | local environment, entertainment | low | tourist destination |
| (5) | ease of use, value for money, information | travel experience | low | public transport |
| (13) | performance | design features | low | cars |

Appendix B - Full list of keywords used within the search terms (Tables 7(a) to 7(c))

Table 7(a) - Innovation keywords used in directed review search terms

| ref | Innovation keywords | ref | Innovation keywords |
|---|---|---|---|
| T1 | car club, car share | F8 | urban OR green OR pod AND community AND farm |
| T2 | peer AND  to AND peer AND car OR vehicle AND share / p2p AND vehicle OR car AND share | F9 | cultured OR lab AND meat |
| T3 | ride AND share | H1 | smart AND heat |
| T4 | taxi AND share | H2 | smart AND light |
| T5 | mobility AND  service OR MaaS | H3 | smart AND appliance OR wash OR fridge |
| T6 | electric AND vehicle OR car OR EV | H4 | home AND energy AND man OR HEM |
| T7 | electric AND bike OR bicycle OR e-bike | H5 | heat AND pumps |
| T8 | autonomous AND vehicle OR car / Self AND driving AND vehicle OR car | H6 | prefab AND retrofit |
| T9 | neighbourhood  AND vehicle OR car NEV OR ZEV / zero AND emission AND vehicle OR car community AND EV | H7 | peer AND to AND peer AND product OR service / p2p AND service OR product |
| T10 | bike  AND share | H8 | real AND  time AND feedback AND energy |
| T11, T12, T13 | telecommuting OR video-conferencing OR telepresence  / home AND working / virtual AND meeting | E1 | domestic AND electricity AND storage |
| F1 | digital AND hub AND local AND food / online AND  farm AND shop  / online AND food AND app | E2 | peer AND to AND peer AND electricity/p2p AND electricity |
| F2 | meal AND kit OR box | E3 | electric AND vehicle OR car AND grid |
| F3 | 11th AND hour AND app | E4 | time AND use AND price AND elec |
| F4 | food AND pairing OR matching | E5 | demand AND response AND elec |
| F5 | food OR community AND share | E6 | energy AND service AND Co / ESC |
| F6 | gamification AND diet OR food | E7 | third AND party AND finance AND elec |
| F7 | nudge AND food OR waste | | |

Table 7(b) - Attribute keywords used in directed review search terms

| main keyword | attribute keywords |
|---|---|
| cost-saving | cost OR price OR cheap |
| time-saving | time OR convenient |
| healthy | health OR wellbeing OR comfort |
| safe and secure | safe OR secure |
| ease of use | easy OR accessible  OR convenient OR hassle |
| choice variety | choice OR select OR flexibility |
| environmental benefit | environment AND OR $CO_2$ emissions AND OR pollution AND OR low carbon AND OR waste AND OR efficient |
| social benefit | community AND OR local AND OR society |
| relational | relationship AND OR interaction AND OR share AND OR friendship AND OR sociable |
| active involvement | involvement AND provision |
| pay-per-use | pay AND use AND OR subscription |
| service-based | service OR own AND OR third-party AND OR maintain |
| multiple use | use AND range AND OR function |
| control | control OR influence OR manage |
| autonomy | autonomy OR independent OR agency |
| identity signal | identity OR image OR esteem |

Table 7(c) - Innovation examples used in directed review search terms

| ref | examples | | |
|-----|----------|-----|---|
| | | F7 | - |
| T1 | Zipcar, City Car Club, Co-Wheels | F8 | Food from the Sky (UK), Gotham Greens (US) |
| T2 | Liftshare | F9 | Mosa Meat, Meatable |
| T3 | Bla Bla Car, Liftshare | H1 | Samsung Smart Fridge, |
| T4 | Lyft Line, UberPool | H2 | Philips Hue |
| T5 | Whim (Helsinki) | H3 | Samsung Smart Fridge, Bosch Washing Machine with Home Connect |
| T6 | Tesla (top range), Nissan Leaf (mid range), Renault Zoe (bottom range) | H4 | CarbonTRACK |
| T7 | Raleigh Redux, GenZe 200 | H5 | - |
| T8 | Waymo, Uber, Tesla Model S Autopilot | H6 | Energiesrong |
| T9 | Renault Twizy, BugE | H7 | Streetbank, Freecycle, eBay, Gumtree |
| T10 | Santader Cycles (London), Ofo (Beijing) | H8 | - |
| T11 | | E1 | Tesla PowerWall |
| T12 | Cisco, Polycom | E2 | Piclo, Vandenbron, Power Ledger |
| T13 | | E3 | Nissan Leaf - Ovo |
| F1 | Heartier, Farmdrop, Open Food Network UK | E4 | - |
| F2 | Hello Fresh, Gousto | E5 | - |
| F3 | FoodCloud, NoFoodWasted | E6 | Vital Energi |
| F4 | - | E7 | - |
| F5 | Olio, Hubub, Share your Meal, TooGoodToGo | E8 | Solarplicity |
| F6 | FIT game (US) | | |

Appendix C Full description of low carbon innovations (Tables 8(a) to 8(d))

The 38 low carbon innovations included in this study are more fully explained in Tables 8(a) to 8(d) below.  These tables describe each low carbon innovation in detail. Column (a) highlights the incumbent technology or behaviour which needs to be displaced for significant $CO_2$ reductions to occur within this domain. In mobility the dominant consumer behaviour is private car use which accounts for over 75% of UK private vehicle kms (223). In the food sector the dominant consumer behaviour is big food shopping from large scale food retailers (and associated waste) which accounts for 95% of grocery expenditure (224).  In the homes sector and energy sector the dominant consumer behaviour is inefficient and passive energy use and waste.  Columns (b) and (c) distinguish between low carbon innovations according to alternative models of provision. These are ownership (own) versus service economy (se) and the centralised retailing model (cr) versus and sharing economy (se) (see also Section 3.1).  Where low carbon innovations offer multiple modes of provision this is indicated.

Table 8(a) - mobility innovations used in this study

| ref | Low carbon innovation | description | (a) | (b) | (c) |
|-----|----------------------|-------------|-----|-----|-----|
| T1 | car clubs or car sharing | allow members to book, pay for, and use vehicles belonging to the club which may be parked in specific places or be locatable through an app or website. | | sb | se |
| T2 | p2p car sharing | enable users who are car owners to lend their cars on a temporary basis to other users in exchange for payment. | | sb | se |
| T3 | ride sharing | connect passengers wanting to make a specific journey with drivers making the same journey who are willing to give them a lift in exchange for payment or for free. | | sb | se |
| T4 | shared taxi (or taxibus) | can be called and used by multiple passengers with similar routes who each specify their start point and destination using an app. | | sb | se |
| T5 | mobility as a service (MaaS) | an app or website which integrates planning, booking and paying for journeys on a range of public, shared and private transport modes. | | sb | cr |
| T6 | EVs (EVs) | powered by on-board batteries which are recharged by plugging the car in at designated charging points. Can be owned or shared as part of car club or car sharing | | own /sb | cr/ se |
| T7 | e-bikes | electric motor and battery for assisting with pedalling or for powering the bicycle up to limited speeds. Can be owned or shared as part of MaaS | | own /sb | cr/ se |
| T8 | autonomous vehicles (AVs) | fully autonomous vehicles in which no driver or back-up driver required. AVs can be owned or shared as part of MaaS. | | own /sb | cr/ se |
| T9 | neighbourhood EVs (NEVs) | low speed battery EVs (similar to a golf buggy) | | own /sb | cr/ se |
| T10 | bike-sharing | a service in which bicycles are made available for shared use to individuals on a short term basis for a price | | sb | se |
| T11 | telecommuting | the elimination or partial elimination of a commute trip by working from home | | own | cr |
| T12 | videoconference-ing and virtual meetings | a conference or meeting between two or more participants at different sites by using computer networks to transmit audio and video data | | sb | cr |
| T13 | telepresence and virtual reality | systems which present interactive video and audio between locations with near life like audio quality and with near life size video images. | | sb | cr |

Note: Column (a) spans rows T1–T13 with the text "owning or using a private car, commuting or travelling for work".

note (a) main incumbent/ behaviour change; (b) service-based provision (sb) or ownership (own); (c) centralised retail (cr) or sharing economy (se)

Table 8(b) - food innovations used in this study

| ref | Low carbon innovation | description | (a) | (b) | (c) |
|---|---|---|---|---|---|
| F1 | digital hubs for local food | online versions of farmers markets in the form of a website or app through which people can buy a range of food products for delivery from different local producers. | buying from large food retailers, wasting food (farm to plate) | own | cr |
| F2 | meal kits | boxes of pre-portioned ingredients for specific recipes delivered to households for preparing freshly cooked meals at home. | | own | cr |
| F3 | 11th hour apps | enable cafes, restaurants or supermarkets to advertise unsold meals or surplus fresh food to consumers at significantly reduced prices | | sb | se |
| F4 | food pairing apps | provide recipe suggestions for making use of ingredients left in fridges or cupboards, with particular emphasis on vegetarian food. | | sb | cr |
| F5 | food sharing | connects users to excess home-grown vegetables, food nearing its sell by date in local shops and any unwanted food in households | | own | se |
| F6 | dietary change gamification | behaviour change games that encourage a transition from high meat diets | | sb | cr |
| F7 | food waste reduction nudges | providing a choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentive | | sb | cr |
| F8 | urban farming | using greenhouse technology (stacking greenhouses on top of each other) which situates the growing of food within buildings (homes and workplaces) | | own | cr |
| F9 | cultured meat | animal meat that is grown using a bioreactor instead of an animal | | own | cr |

note (a) main incumbent/ behaviour change; (b) service-based provision (sb) or ownership (own); (c) centralised retail (cr) or sharing economy (se)

Table 8(c) - homes innovations used in this study

| ref | Low carbon innovation | description | (a) | (b) | (c) |
|---|---|---|---|---|---|
| H1 | smart heating systems | can learn and automate heating schedules while also enabling household members to control the heating through an app or website even when they are not at home | | own | cr |
| H2 | smart lighting | enable household members to control the brightness and hues of bulbs using an app or voice commands. | | own | cr |
| H3 | smart appliances | include washing machines and fridges are connected to the internet and can be controlled by household members through an app or website. | | own | cr |
| H4 | home energy management systems (HEMs) | technology platform which relays multiple information on home energy use and occupancy which allows the user to monitor energy usage, production and manually control or automate energy use | not actively managing energy (resources) | own | cr |
| H5 | heat pumps | storage solutions to match energy supply to heating and cooling demand, efficient transfer of heat from point of production / storage to point of use. | | own | cr |
| H6 | prefab retrofits | non-intrusive retrofit fitted externally, completed within one week without residents having to move out, off-site fabrication with quality control and standardised volume production | | own | cr |
| H7 | p2p products and services | individuals or households exchanging products or other material goods through an online marketplace | | own | se |
| H8 | real-time feedback on aggregated loads | interactive smart meters in every household and small business site improve grid responsive and interactivity + disaggregation algorithms to appliance level (or activities) help inform domestic energy management | | sb | cr |

note (a) main incumbent/ behaviour change; (b) service-based provision (sb) or ownership (own); (c) centralised retail (cr) or sharing economy (se)

Table 8(d) - energy innovations used in this study

| ref | Low carbon innovation | description | (a) | (b) | (c) |
|---|---|---|---|---|---|
| E1 | domestic electricity generation with storage | households can store surplus electricity they generate for later consumption using a battery system. | | own | cr |
| E2 | p2p electricity trading | households can buy and sell electricity they've generated at home directly with other households through an online platform. | | own | se |
| E3 | electric vehicle to grid | energy companies can control when to recharge or discharge batteries in EVs which are plugged in, subject to pre-agreed terms with the vehicle owners. | buying energy from centralised utilities or not actively managing energy | own | cr |
| E4 | time of use pricing | exposing retail consumers to (highly variable) marginal costs of supply (especially very high peak prices) as a financial incentive for load shifting | | own | cr |
| E5 | demand response | remote (utility) or automated (software) management of loads (typically large users) in response to price signals or supply shortages | | own | cr |
| E6 | energy service companies | third-party management of energy consumption on a service- or performance-contract basis to incentivise energy-saving investments | | sb | cr |
| E7 | third-party financing | third-party financing of generation assets (esp. rooftop PV) - e.g., roof leasing, property tax adjustments (PACE), mortgages (esp. if building integrated) | | sb | cr |
| E8 | community energy | a community-led project or process to meet its own energy requirements through decentralized generation (electricity, heating) and/or demand-side efficiency | | sb | se |

note (a) main incumbent/ behaviour change; (b) service-based provision (sb) or ownership (own); (c) centralised retail (cr) or sharing economy

Appendix D – Identification of cross domain over-lapping attribute themes (Tables 9(a) to 9(b))

The synthesis of qualitative data draws on a thematic analysis in Pettifor, Wilson (29). This study used structured elicitation methods, interviewing over 60 people living in a representative city. In these interviews respondents were encouraged to discuss what they considered was the widespread appeal of low carbon innovations. Similar to this review, innovations represented four key domains of mobility, food, homes and energy. Table 9 illustrates how the main themes elicited from these interviews (Table 9 columns (a) and (b)) have informed the identification of over-lapping themes in this review (Table 9 columns (c) and (d).

Table 9(a) – Source of overlapping themes identified in this review (core attributes)

| Ref | Pettifor, Wilson (29) | | This review | |
| --- | --- | --- | --- | --- |
| | main themes identified from interviews (c) | sub-themes identified from interviews (b) | attributes identified from directed review (c) | main themes from qualitative findings (d) |
| C1 | offers clear monetary benefits | 'cost-saving', 'low price' 'low running costs', 'money saving' | cost-saving | 'financial savings and lower costs', 'value for money' |
| C4 | is easy to use, reduces hassle or is more convenient | 'inclusive', 'accessible', 'low complexity', 'low difficulty', 'familiar and accessible platform' (smart app on a phone) | ease of use | 'convenience', 'accessibility', 'low hassle', 'flexibility', 'on demand', 'simplicity', 'easy to understand' |
| C6 | is easy to use, reduces hassle or is more convenient | | | |
| C6 | is widely accessible | | | |
| C17 | requires no prior knowledge | | | |
| C19 | improves accessibility through use of smartphone | | | |
| C22 | positively supports healthy living | 'safe and secure', 'builds safer communities' | safe and secure | 'increased food security', 'safer food', 'personal and family security' 'avoid energy blackouts' |
| | | 'reduced stress', 'improved personal health & wellbeing', 'increased personal comfort' | healthy | 'improved emotional and physical fitness', 'improved quality of life', 'healthier living and working environments', 'improved diet and nutrition' |
| C5 | is more time efficient | 'not time consuming', 'saves time', 'efficient use of time' | time-saving | 'reduces time', 'frees up time', 'more productive use of time' |
| C18 | allows users to choose alternative forms of good | 'flexible choice', 'personalised choice', 'more choice' | choice variety | 'choice of use', 'choice of products', 'choice of suppliers' |

Table 9(b) – Source of overlapping themes identified in this review (non-core attributes)

| | | Pettifor, Wilson (29) | | This review |
|---|---|---|---|---|
| C2 | reduces impact on the environment | 'good for the environment', 'reduces waste', 'reduces $CO_2$ emissions', 'maximises use of resources' (stuff space), 'more energy efficient' | environmental benefit | 'lowers $CO_2$ emissions and avoids pollution', 'avoids waste', 'builds more sustainable marketplaces and greener cities', 'reduces consumption' |
| C15 | maximises use of resources | | | |
| C7 | directly benefits local economy or community | 'supports local economy' 'improves/supports local business (profit margins)', 'keep things local', 'creates local jobs', 'source local goods and services', 'collective benefits' | social benefit | 'inclusive', 'help and support others', 'educate', 'enhanced local biodiversity and utilisation of space', 'builds communities', 'widespread common good', 'provides benefits to others' |
| C23 | benefits a collective, wider population | | | |
| C27 | actively builds relationships with other users | 'sociable', 'shareable', 'friendships', 'links family and friends', | relational | 'integration into a community, 'strengthens relationships, 'enhances or creates social networks' |
| C14 | encourages mutual interactions or builds friendships | 'mutual exchange is encouraged', 'mutual benefits' | | 'co-creation', 'sharing with others', 'self-reward framework', 'proactive management' |
| C20 | involves or strengthens interactions within a community | 'promotes community', 'enhances interactions with community', | active involvement | 'co-creation', 'sharing with others', 'self-reward framework', 'proactive management' |
| C25 | connects people with producers | 'connects people with local services' | | |
| C32 | involves users in creating or providing good or service | 'involves users in creating or providing good or service' | | |
| C1 | offers clear monetary benefits | 'low upfront costs', 'no upfront costs' | pay-per-use | 'usage-based consumption', 'removal of upfront costs', 'access without ownership' |
| C16 | reduces dependence on others | 'reduces or negates the need for owning a good', 'hands over responsibility to third-party' | service-based | 'third-party management', 'flexible usage' |
| C18 | allows users to choose alternative forms of good | 'allows users to choose alternative forms of the good or service to suit different needs or contexts' | multiple use | 'additional services', 'access to multiple services' |
| C9 | enables or improves controllability | 'improved personal control', 'improved technology control', 'control of the service', 'of the resource', 'of the cost, 'improved organisation of day to day life', 'improved clarity' | control | improved monitoring', 'improved management', 'automation' |
| C16 | reduces dependence on others | 'increased independence', 'increased agency' | autonomy | 'independence', 'alternatives to major systems of centralised provision' |
| C26 | enhances separation from others | | | |
| C11 | enhances personal image and self-identity | 'supports or enhances desirable aspects of end-user's individual or social identity' | identity signal | 'collective identity', 'environmental symbolism' |

Appendix E – Detailed scorings of clusters against attributes (Tables 10(a) to 10(b))

Table 10(a) – the appeal of clusters 1 to 3 against non-core attributes

| type | attribute | cluster 1 | | | | | | | cluster 2 | | | | cluster 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T1 | T2 | T3 | T4 | T8 | T10 | H7 | H1 | H2 | H3 | H4 | E1 | E2 | E3 | E4 | E5 | E6 | E7 | E8 |
| core | cost-saving | | | | | | | | | | | | | | | | | | | |
| | ease of use | | | | | | | | | | | | | | | | | | | |
| | safe and secure | | | | | | | | | | | | | | | | | | | |
| | healthy | | | | | | | | | | | | | | | | | | | |
| | time-saving | | | | | | | | | | | | | | | | | | | |
| | choice | | | | | | | | | | | | | | | | | | | |
| non-core | env. benefits | | | | | | | | | | | | | | | | | | | |
| | social benefit | | | | | | | | | | | | | | | | | | | |
| | relational | | | | | | | | | | | | | | | | | | | |
| | active involvement | | | | | | | | | | | | | | | | | | | |
| | multiple use | | | | | | | | | | | | | | | | | | | |
| | control | | | | | | | | | | | | | | | | | | | |
| | pay-per-use | | | | | | | | | | | | | | | | | | | |
| | service-based | | | | | | | | | | | | | | | | | | | |
| | autonomy | | | | | | | | | | | | | | | | | | | |
| | identity signal | | | | | | | | | | | | | | | | | | | |

Key to attribute strength

| | |
|---|---|
| | non-relevant/no appeal |
| | low appeal |
| | modest appeal |
| | high appeal |

Key to innovations in each cluster

| | cluster 1 | | cluster 2 | | cluster 3 |
|---|---|---|---|---|---|
| T1 | car clubs | H1 | smart heating systems | E1 | domestic electricity + storage |
| T2 | p2p car share | H2 | smart lighting | E2 | p2p electricity trading |
| T3 | ride share | H3 | smart appliances | E3 | V2G |
| T4 | shared taxi | H4 | HEMs | E4 | time of use pricing |
| T8 | AVs | | | E5 | demand response |
| T10 | bike-share | | | E6 | energy service companies |
| H7 | p2p products | | | E7 | third-party financing |

note (blue=mobility, green=food, red=homes, blue=energy)

Table 10(b) – The appeal of clusters 4(a) to 4(d) against core attributes

| type | attribute | cluster 4(a) | | | | | | cluster 4(b) | | | | | cluster 4(c) | | | cluster 4(d) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | T6 | F3 | F5 | H5 | H6 | H8 | T7 | T9 | T11 | T12 | T13 | F1 | F2 | T5 | F3 | F4 | F6 | F7 | F8 | F9 |
| core | cost-saving | modest | high | high | high | high | high | modest | modest | | high | high | | | modest | high | high | low | low | low | low |
| core | ease of use | | | | modest | | low | low | | low | | | low | high | high | | | low | | | |
| core | safe and secure | | | | | | low | | | | | | low | | | | | | | modest | low |
| core | healthy | | low | | | | low | modest | | low | | low | modest | modest | modest | low | high | high | low | high | modest |
| core | time-saving | | | | | | | modest | | modest | high | high | high | high | high | | low | | low | | |
| core | choice | | | | | | | | | modest | | modest | high | | high | | low | low | low | | |
| non-core | env. benefits | high | modest | modest | modest | high | modest | high | high | modest | high | high | low | low | modest | modest | low | modest | low | modest | modest |
| non-core | social benefit | high | modest | high | | modest | modest | high | modest | modest | high | low | modest | modest | low | modest | modest | modest | low | high | |

Key to attribute strength

| | |
|---|---|
| (grey) | non-relevant/no appeal |
| (light pink) | low appeal |
| (pink) | modest appeal |
| (dark red) | high appeal |

Key to innovations in each cluster

| Cluster 4a | | Cluster 4b | | Cluster 4c | | Cluster 4d | |
|---|---|---|---|---|---|---|---|
| T6 | EVs | T7 | e-bikes | F1 | digital hubs food | F4 | food pairing apps |
| F3 | 11th hour apps | T9 | NEVs | F2 | meal kits | F6 | dietary change gamification |
| F5 | food sharing | T11 | telecommuting | T5 | MaaS | F7 | food waste nudges |
| H5 | heat pumps | T12 | video-conferencing | | | F8 | urban farming |
| H6 | prefab retrofits | T13 | telepresence | | | F9 | cultured meat |
| H8 | real-time feedback | | | | | | |

note (blue=mobility, green=food, red=homes, blue=energy)

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