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A framework for measuring and modelling low-carbon lifestyles

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ABSTRACT

Lifestyle is an integral and inevitable feature of transformation pathways consistent with the Paris Climate Agreement and United Nations Sustainable Development Goals. Studies differentiating lifestyle types, clusters, or segments vary in their focus, purpose, reach, generalizability and availability. Universal frameworks are largely proprietary in nature, developed and used by market research companies for targeted communication and behaviour change strategies. There is a need for a more accessible lifestyle typology to promote understanding of lifestyle and its main drivers.

In this paper we present a lifestyle typology for application to low-carbon research based on publicly available data from national statistical agencies. Drawing on substantive, inter-disciplinary literature, we define lifestyles as the interplay between cognitions and behaviours in specific material and social contexts. Using this definition, we develop a generalisable analytical framework for measuring and classifying lifestyles empirically, based on perspectives from public health, marketing, and pro-environmental research.

We apply our framework using hierarchical cluster analysis of nationally representative household social survey data. We select four countries with contrasting contexts and lifestyles: UK (n = 5000 respondents), USA (n = 900 respondents), Australia (n = 5000 respondents) and China (n = 5000 respondents). We identify four low-carbon lifestyle types – 'Resourceful', 'Active', 'Constrained' and 'Cautious' – that are consistent across countries and robust to variation in analytical approach. Each lifestyle type is characterised by its low-carbon cognitions, by its propensity for low-carbon behaviours, and by its contextual markers. We use this differentiated lifestyle typology to identify major sources of heterogeneity in the opportunities, capacities, and constraints to leading a low-carbon lifestyle.

Our approach is transparent and replicable, and our lifestyle framework is empirical-based and generalisable to different country contexts. Our findings can guide policy interventions for enabling low-carbon lifestyles, and enhance research efforts to model lifestyle. An improved understanding of lifestyle and its contribution in achieving the Paris Agreement climate targets, could also enhance efforts to visualise and plan for the low-carbon transition.

1. Introduction

Low-carbon lifestyles are an important area of research. A global transition towards sustainable living requires long-term changes to how people lead their lives, and the products and services they consume (Lubowiecki-Vikuk et al., 2021). Global energy modelling studies show that lowering the carbon footprint of lifestyle related demand can provide an essential contribution to achieving the Paris Agreement targets (van den Berg et al., 2019; van Sluisveld et al., 2016).

Exactly what constitutes a lifestyle is not consistently defined in the literature. There are contrasting perspectives. These reflect in the wide range of empirical studies and associated lifestyle typologies. Studies emphasising routine patterns of behaviour observe these in different contexts, such as home, work, and leisure (Barr and Gilg, 2006; Mowen and Minor, 1998). Lifestyle typologies distinguish heterogeneity across consumption, expenditure and activities explained by socio-demographic characteristics. More cognitively driven studies associate cognitive drivers with behavioural outcomes. These studies view lifestyle as intentional but responsive to context (Office for National Statistics, 2017). Typologies emphasise the influence of value systems and world views on choices, related to social character. Contrasting perspectives, in health and pro-environmental behaviour relate lifestyle to expressions of self-identity (Axsen and Kurani, 2011).

There are also contrasting measurement approaches. These vary

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between quantitative and qualitative disciplines and include surveys, national databases, and individual diaries. Sampling approaches are typically national and lack wider generalisability. Universal typologies do exist. The Roper Consumer Styles, for example, distinguish between 8 lifestyle groups measured across 25 core countries measured across over 35,000 individuals (GFK). The proprietary nature of these surveys means they lack transparency and access. There are many similar proprietary frameworks, particularly in marketing and consumption research including Sinus Milieu, Euro Socio-Styles, and MOSAIC (SINUS, 2019; GFK, 2021; Experian, 2022; GFK, 2020).

A universal definition and framework for conceptualising, measuring, and segmenting low-carbon lifestyles has theoretical and practical application:

- It brings together key elements of lifestyle incorporating multiple perspectives, applicable across domains and situations.
- It harmonises perspectives across communities engaged in similar research goals e.g., global energy system modelling.
- It extends current perspectives in low-carbon research to encapsulate wider motivations and intentions, capturing for example, synergies between healthy and sustainable lifestyles.
- It frames key elements of lifestyle, and through their relationships and interactions, provides insight into potential drivers. These can be tested to inform government and policy aimed at widespread engagement in low-carbon behaviour.
- It is generalisable across domains and geographies; it lends itself to intra and inter-country operationalisation using for example national large-scale social survey data. These surveys draw on large sample sizes and robust methodologies.

There are also advantages to exploring mitigation strategies related to lifestyle at many levels. For example, a segmentation of lifestyle groups could be used as a basis for designing and targeting interventions which act on a range of lifestyle factors in a concerted manner. A lifestyle typology could also encapsulate behavioural interventions, such as the A-S-I ('avoid', 'shift', 'improve') framework. This is increasingly being used to frame policy interventions for different behaviour types (Creutzig et al., 2022). In this respect a robust, reliable and valid empirically-based framework could support modelling and simulation analysis, such as those used to model the energy system. These models are becoming increasingly important and influential in informing climate policy debate (Krey et al., 2019).

Our study has three main aims:

1. To develop and test a universal framework for measuring low-carbon lifestyles
2. To measure heterogeneous lifestyle types across countries and cultures
3. To understand behavioural, cognitive and contextual variation across lifestyle types.

The relationship between lifestyles and low-carbon behaviour is an emerging area of research. We contribute a robust social science approach to framing, identifying and measuring low-carbon lifestyle. Our analysis also provides key insights into potential barriers and enablers to leading a low-carbon lifestyle.

2. Literature review

2.1. Contrasting perspectives and research traditions on lifestyles

Perspectives on lifestyle date back to the mid-19th century when lifestyles were shaped by the structures, and traditions of that period. This includes compliance with systems of rule, individual morality, social status, and wealth (Reynolds et al., 1974). In 1922 Weber, a notable sociologist defined lifestyle as 'a response to our social world which illustrates place in the system of social prestige' (Jansen, 2011). This early perspective lacks an appreciation of the material world which features heavily in modern living.

Recent definitions of lifestyle highlight a lack of agreement and harmonisation. They vary within and between research disciplines in terms of complexity and emphasis. Simple definitions of lifestyle, for example in marketing emphasise 'ways of living', 'spending time and money' (Dernini et al., 2017; Hur et al., 2010; Viana et al., 2016). More complex definitions acknowledge the role of cognitive systems which influence behaviour and spending patterns. These include values, attitudes, opinions, ethics, ideology, and morality (Grunert, 1993, Thøgersen, 2017a, Jansen, 2011).

The complexities of lifestyle are emphasised in public health literature. The World Health Organisation, for example suggests "there is no optimal lifestyle to be prescribed for all people. Culture, income, family structure, age, physical ability, home and work environment will make certain ways and conditions of living more attractive, feasible and appropriate" (World Health Organisation, 1998).

Perspectives in pro-environmental, sustainable, green (termed low-carbon) lifestyles are narrowly defined. They are concerned with the adverse impacts of lifestyles on environmental conditions, and on how and why different groups seek to reduce these. Howell (2013) defines low-carbon lifestyle as "making changes to one's lifestyle to reduce one's carbon footprint through intentionally adopting new technologies and/or behaviour". This reflects the importance of intentional actions. More complex definitions acknowledge the shaping influences of the wider social and physical environment. As in public health, social institutions, conditions and infrastructures lock-in undesirable behaviours and habits (Vita et al., 2019). Binder and Blankenberg (2017) distinguish between perceived lifestyle and actual lifestyle. This definition reflects the inconsistencies between ways of thinking and ways of behaving. Peoples' good intentions toward a low-carbon lifestyle are often inconsistent with the emissions impact of their actual consumption (Longo et al., 2008: Middlemiss, 2011, Binder and Blankenberg, 2017).

Contrasting research perspectives contribute worthwhile insights for a universal framing of low-carbon lifestyle. These include: the influence of cognitive systems which drive behaviour (Jain, 2019); the reflexive nature of lifestyle in that it communicates self-image, social standing and morality to others (SINUS, 2018); synergies between cognitions in health and low-carbon research related to ethical and sustainable consumption (Cengiz and Torlak, 2018; Rich et al., 2019; Leonard-Barton, 1981); the shaping role of the social and material environment which locks people into certain patterns of behaviours (Office for National Statistics, 2017); the importance of contextual and cognitive factors in shaping lifestyle. In this respect context includes greater structural flexibility in working and private lives, erosion of family structure, digitalisation of day-to-day living, and growing polarisation of wealth (SINUS, 2018). Cognitive factors include shifts in attitudes and values, beliefs or ideology which challenge the dominant consumer culture (Kuanr et al., 2019; Cengiz and Torlak, 2018).

2.2. Frameworks for measuring lifestyles

A fundamental issue in empirical study is the choice or development of an analytical framework. An analytical framework defines the dimensions of analysis. It is an instrument for classifying and categorising key elements. In lifestyle research there is no universal framing of lifestyle. There are a wide variety of frameworks used across disciplines that emphasise important elements of lifestyle, yet there is considerable potential academic and practical value in exploring synergies across domains and between different research fields (Quam et al., 2017). A universal framing could pool resources for understanding the complex interplay between related lifestyle elements, identify mutual benefits, and facilitate collaboration on strategies to engage, motivate, and empower individuals and groups to adopt and sustain low-carbon lifestyles.

The 'Health Promoting Lifestyle Profile' (HPLP) (Walker and Hill-Polerecky, 1996) and the 'total health framework' (Bodai et al., 2017) are substantiated frameworks in health that draw the three elements of lifestyle together. Patterns of behaviour are the observable actions of cognitive processes (Jamal et al., 2016; Faiola et al., 2019). Lifestyles are then shaped by contextual factors such as socio-economic settings (including education, income, and social norms), demographic factors (such as gender and life stage) and grounded in cultural identities and traditions. Lifestyle frameworks are applied through coordinated practitioner action on cognitive, behavioural, and contextual pathways (Bodai et al., 2017). Interventions target emotional resilience (stress management, membership of a support group, social connections, mindfulness); specific practices (diet and nutrition, physical inactivity, smoking, excess alcohol consumption); and contextual factors (support groups, access to facilitating infrastructure, availability of healthy food choices) to reduce the risk of chronic diseases such as type II diabetes. These frameworks provide important tools for understanding interrelations between lifestyle elements and specific health outcomes, and for devising, implementing, and evaluating health strategies with social and economic value.

The 'Actions, Interests, Opinions' (AIO) framework and the 'Value Systems' approach are cognitively driven, frameworks. The AIO framework combines manifest 'actions' (work, leisure, consumption) with 'interests' related to objects, events and 'opinions' related to family, home, and achievement (Lazer, 1963; Srihadi et al., 2016; Jain, 2019). In the Value Systems approach, values are defined as guiding principles in people's lives (Vyncke, 2002). It is based around a set of predetermined value statements adapted from independent sources including the Rokeach Value Survey (Rokeach, 1973), and Schwartz value framework (Schwartz, 1992). There are a range of other frameworks that align variously with these two approaches. For example, the food-related lifestyle model sees lifestyle as a mix of habits, conventional ways of doing things, and reasoned behaviour (Nie and Zepeda, 2011). It is based on the simple attitude, behaviour, context (ABC) model (Guagnano et al., 1995) which is a specific representation of the three lifestyle elements: behaviours, cognitions, and context. These models are highly generalisable, and serve a common economic purpose, to identify consumer lifestyle segments used for understanding buyer profiles, product positioning and predicting consumer behaviour (Jansen, 2011). For example, the AIO-based model has been used to identify food-related lifestyles and explain purchase and usage patterns for kitchen appliances in the US (Hur et al., 2010). In the Global South, the AIO framework has been used for lifestyle segmentation to better understand consumer purchase behaviour in India (Jain, 2019), and the tourism market in Indonesia (Srihadi et al., 2016). The 'Values System' model has been used, for example, to understand the motives behind non-material low-consumption lifestyles (Rich et al., 2019). These frameworks are adapted to measure specific lifestyles such as 'voluntary simplicity' and as an instrument to assess the effectiveness of behaviour-change initiatives. In general, marketing research is focused not on promoting change but evolving and adapting lifestyle measurements to wider societal trends and shifts in normative values.

In low-carbon research, there are no dominant frameworks. Lifestyle is measured based on behavioural commitment (Barr and Gilg, 2006; Barr et al., 2011; Binder and Blankenberg, 2017), basic orientations (Axsen et al., 2016; Markvica et al., 2020), Thøgersen, 2017a), perceptions of self and world (Hayles and Dean, 2015; Hagbert and Bradley, 2017), consistency across domains (le Gallic et al., 2018; Millot et al., 2018; Katz-Gerro et al., 2017), or contextual influences (George-Ufot et al., 2017; Chen et al., 2019). Integrative frameworks exist which recognise the entwined challenges of public health and environmental protection. The Lifestyle of Health and Sustainability (LOHAS) framework for example, identifies five dimensions of sustainable economy, health, personal development, alternative health care, and ecological lifestyles. In low-carbon research cognitive frameworks emphasise the role of altruistic values, and awareness of environmental problems associated with climate change. From this perspective lifestyles are purposeful but also responsive to contextual factors, ranging from living and consumption situations (Thøgersen, 2018), socio-economic factors such as education and income (Valeri et al., 2016) and physical and social structures (Axon, 2017). Low-carbon lifestyle frameworks are applied according to these differing emphasis to study relationships between sustainable behaviours, cognitions (such as beliefs, attitudes, self-identity, and wellbeing) and contextual factors, and evaluate the suitability of environmental policy instruments (Valeri et al., 2016) to direct lifestyle choices towards 'improved' societal and environmental outcomes.

2.3. *Analytical approaches for measuring lifestyles*

Lifestyle research employs a wide variety of measurement approaches, drawing on primary and secondary methodologies, and combinations of these. Quantitative methods emphasise the use of surveys to collect data on lifestyle elements (le Gallic et al., 2018) or other secondary datasets (Defra, 2011). Secondary data lends itself to systematic review (Quam et al., 2017; Minich and Bland, 2013), narrative review (Dernini et al., 2017) and systematic review and meta-analysis (Loef and Walach, 2012).

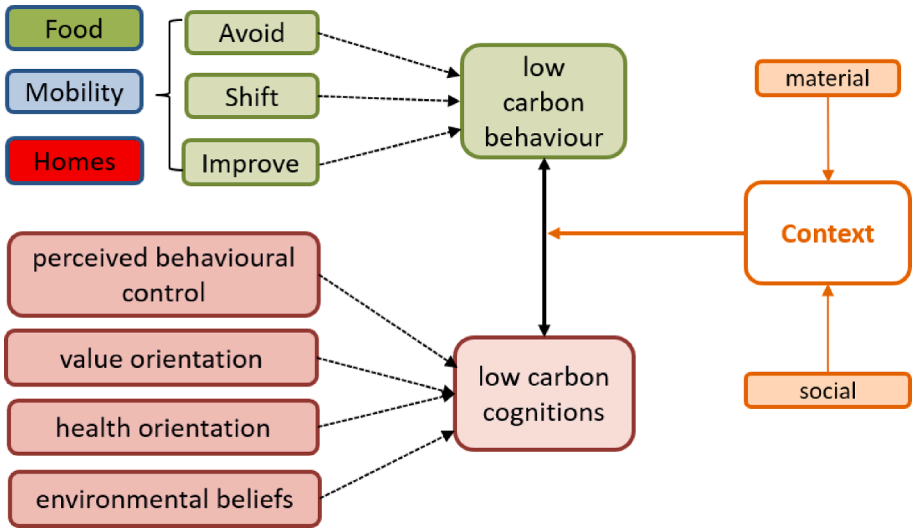


Fig. 1. Analytical Framework for Low-carbon Lifestyle.

In quantitative approaches, data is typically reduced for validity and parsimony (Barr and Gilg, 2006; Etminani-Ghasrodashti et al., 2018). Euro-Socio-Styles, for example reduce survey data from 24,000 respondents across multiple variables, to measure lifestyle heterogeneity across two main dimensions of lifestyle. Reduction methods typically use factor analysis (Tudor et al., 2016), principal component analysis (Thøgersen, 2017a, Thøgersen, 2017b) or multiple correspondence analysis (Katz-Gerro et al., 2017).

Qualitative approaches are also used in lifestyle research. Marchand and Walker (2008) for example, explore the narratives attached to sustainable lifestyles with 11 people practising voluntary simplicity. This study identifies useful insights into the narratives of lower carbon lifestyle, but in taking a more grounded approach lacks universality and generalisability. Mixed methods approach overcomes this limitation by combining qualitative focus groups and in-depth interviews, with quantitative surveys (Markvica et al., 2020; George-Ufot et al., 2017).

A wide variety of public data sources also measure aspects of lifestyle. In health studies for example, the UK Biobank is a large prospective health resource documenting the health and wellbeing of around 500,000 participants (https://www.ukbiobank.ac.uk). This resource has been mined to identify lifestyles associated with cardiovascular disease mortality, all-cause mortality (Foster et al., 2018) and with the incidence of dementia (Lourida et al., 2019). The Office for National Statistics compiles information that enables a contextualising of health outcomes in the UK, according to differences in lifestyles (Office for National Statistics, 2017).

3. Materials and methods

3.1. Analytical approach, method and data for measuring lifestyles

We define lifestyle as '*the interplay between cognitions and behaviour in specific material and social contexts*'. Lifestyle is a unifying concept, that directs behaviour across multiple domains. It consists of three interacting elements: cognitions, behaviour and contexts. Cognitions direct and motivate behaviour. Context shapes how the interplay between behaviours and cognitions constitutes lifestyle.

Our universal and generalisable framework for low-carbon lifestyles draws on this general definition and consists of three main 'elements': low-carbon cognitions, low-carbon behaviour, and social and material context (Fig. 1).

People who live a lower carbon lifestyle are characterised by stronger low-carbon cognitions and a higher propensity to engage in low-carbon behaviour (e.g., own electric vehicles, use active modes of transport, eat a vegetarian diet, and use low-energy household appliances). Context is material (e.g., access to enabling infrastructure) and social (e.g., family capital and social cohesion). It shapes the relationship between cognitions and behaviour and creates an enabling or constraining environment for a lower carbon lifestyle (Howell, 2013, Jensen, 2009, (Pícha and Navrátil, 2019; Millot et al., 2018).

Fig. 1 illustrates our analytical framework for low-carbon lifestyle. This framework combines constructs which are both substantiated in the literature on lifestyle and broadly generalisable to publicly available, large scale national social survey data (Agnew et al., 2023). Low-carbon cognitions incorporate four different constructs. These are distinctive but complimentary pathways to low-carbon behaviour. They are: 'perceived behavioural control' (PBC), 'value orientation', 'health orientation', and 'environmental beliefs'. They are all theoretically substantiated or empirically proven to motivate or direct behaviour associated with reduced environmental impact.

PBC: We define this as *'beliefs that personal actions will lead to desired goals'*. It breaks down into two main themes 'agency', defined as 'the capacity to act independently and to make free choices' (Hagbert and Bradley, 2017) and 'efficacy', defined as 'the belief in one's ability to succeed in specific situations' (Longo et al., 2019). Health and low-carbon research emphasise the importance of agency and efficacy in the achievement of personal goals. In environmental research these more specifically relate to longer term goal setting. People who are guided by longer terms goals are more willing to invest in a lower carbon future (Thøgersen, 2017b, Verplanken, 2018).

Value orientation: We define this as *'guiding principles which reflect how individuals live their lives (in relation to self and others)'*. Values and worldviews shape how individuals perceive particular (ecological) issues, their potential solutions, and willingness to engage in solutions (Hedlund-de Witt, 2012). These include 'inner versus outer directedness' (Rokeach, 1973); 'long term versus short term orientation' (Hofstede and Minkov, 2010); openness to change versus conservatism and altruism versus self enhancement (Schwartz, 2008; Schultz et al., 2007).

Health orientation: We define this *as 'cognitive evaluation of current lifestyle that relates to personal well-being, life-satisfaction, and feelings and activities related to mental and physical health'*. People who engage with low-carbon initiatives evaluate their lifestyles more positively (Vita et al., 2020). Responsible, sustainable consumption relates to personal metrics including quality of life, mental and physical health outcomes (Pícha and Navrátil, 2019). These influence choice of diet, and active modes of transport that promote physical exercise (Atzendorf et al., 2018).

Environmental beliefs: We define this as *'saliency of the need to act towards environmental, or sustainable outcome'*. It incorporates attitudes, beliefs and concerns towards the need for environmental and societal change. Beliefs are primary considerations in lifestyle. They relate to what individuals think or know; they combine with desires to drive intentions (Jensen, 2009). The extent to which people value the environment is influenced by their belief systems, people who value ecological aspects exhibit a higher ecological behaviour (Chen, 2014).

Our analytical framework incorporates behaviour within three domains: mobility, food, and homes (household energy and use). Consumption activity related to travel, food and diet and energy use in homes are principal components of daily life and key opportunities for emissions reductions (Wilson et al., 2020). These three domains all require significant reductions in consumer-based emissions (Cherry et al., 2018). They are all central in modelling of energy consumption and the influence of lifestyle (van den Berg et al., 2019; van Sluisveld et al., 2016).

Behaviour in each domain is categorised into three types: (1) those that 'avoid' high emission behaviour e.g., 'avoiding' the need to travel, by teleworking; (2) those that 'shift' to a lower carbon alternative e.g., 'shifting' to a low-meat diet; and (3) those that improve (or adopt) more energy efficient alternatives. This typology is drawn from the avoid–shift–improve (A-S-I) framework which has been used historically to align policy measures with behaviours that reduce the environmental impact of transport. Although there is some ambiguity in how these classifications are applied, this framework is increasingly being used in energy modelling and related scenario development (Creutzig et al., 2022; van den Berg et al., 2019).

In our analytical framework, context is exogenous to lifestyle; but shapes the interactions between behaviour and cognitions. Context enables or constrains intentions towards low-carbon behaviour. It consists of material and social factors. Material factors are physical. They include affordability and wealth where this relates to income, home ownership, type of housing and access to enabling infrastructure (Etminani-Ghasrodashti and Ardeshiri, 2015; Etminani-Ghasrodashti et al., 2018; Gray et al., 2019). This includes access to digital networks (broadband access, cellular networks) and related skills in using these (Da and Bug, 2015; SINUS, 2018). Other infrastructures include transportation networks, food distribution, and access to lower carbon forms of energy (Thøgersen, 2017b, Thøgersen, 2018). Social factors include family and educational capital, where this relates to levels of education, household size and membership. It also includes social connectedness, related to cultural and community cohesion and supportive networks (Barr and Gilg, 2006; Katz-Gerro et al., 2017; Buckner, 1988).

Table 1
Representation of Analytical Framework.

Construct	Valid items (N)			
	UK	China	US	Australia
Low-carbon Cognitions				
perceived behavioural control	12	2	2	12
value orientation	10	25	3	6
health orientation	10	11	8	13
environmental beliefs	15	1	5	4
total (n)	**42**	**39**	**18**	**35**
Low-carbon Behaviour				
mobility	5	9	1	2
food	7	6	3	5
homes	7	1	1	1
total (n)	**19**	**16**	**4**	**8**
Material Context				
affordability and wealth	2	2	2	2
living conditions	10	4	3	5
access to infrastructure	11	11	3	7
Social Context				
family and educational capital	5	5	5	5
social connectedness	1	5	1	1
Total (n)	**29**	**27**	**14**	**20**
Total (N)	**90**	**82**	**36**	**63**

3.2. Data requirements

Operationalisation of our analytical framework requires nationally representative, robust and reliable data which contains comparative measures of all elements and constructs within our framework, measured for individuals in that country. We review sources of large-scale social survey data for relevant quantitative data. Studies are chosen using five criteria: public availability; national representation; random sampling (individuals and/or households); valid measures of elements (and constructs) within our framework; variables are measured within the same time frame.

With respect to criteria validity, valid items are determined as those that 'adequately' measure and can be used to quantify constructs within our framework. In each country data-set we compare item wordings with a pre-determined set of keywords, derived from our definitions and descriptions of all elements and constructs. See Appendix 1(a) – Selection of Valid Items (Tables 6, 7 and 8). We require at least one valid measure of low-carbon behaviour within the three domains (mobility, food, homes). We use a 10-year time frame which widens the search criteria to include rotating panel designs. These rotate the inclusion of survey items over different years. Four datasets met these criteria: UK Understanding Society (2014–2018) (Understanding Society, 2021); China Family Panel Study (2012–2016) (Institute of Social Science. Peking University http://www.isss.pku.edu.cn/cfps/docs/, 2015); US General Social Survey (2006–2014) (Smith et al., 2015); Australian Household, Income and Labour Dynamics Survey (2012–2019) (Summerfield et al., 2011). See Appendix 1(b) – Overview of Secondary Data Sources.

All four datasets provide multiple measures of elements and constructs within our framework (see Table 1). There is a generally lower representation of low-carbon behavioural items within USA (n = 4) and Australia (n = 8).

3.3. Data sampling and preparation

We apply a five-step procedure to prepare the datasets, applying statistical methods using Stata IC/17.0 (Statacorp, 2021). To preserve within country heterogeneity each dataset is prepared separately (steps 1–4) before merging to form a multi-country dataset (step 5). Fig. 2 illustrates these five steps.

Step one: data-reduction. In each country data-set multiple items (for each construct, see Table 1) are reduced to operationalise constructs using a data-reduction approach. Items within our datasets vary between scaled items, categorical and ordinal items which means we need to apply a range of data reduction approaches. Where items measure the same construct, using the same scaling we create a single scale (where Cronbach's alpha >= 0.7 (Bonett and Wright, 2015). For items which measure diametrically opposite constructs (e.g., opposing value orientations), using the same scaling we use factor analysis to create key dimensions (Tudor et al., 2016). Where items are measured on different scales, we use poly-choric factor analysis (Holgado-Tello et al., 2008). Where categorical items all measure the same construct we follow the broad approach in (Hergesell, 2022), to create weighted scales which reflect carbon emissions or energy use, with low emissions items given a higher weighting. Operationalised constructs are robust, single measures of the constructs within our analytical framework.

Step two: standardisation. In each country dataset, for each composite variable we convert the original metrics to standardised measurement scales. This enhances comparability and harmonisation of data prior to statistical modelling and helps to reduce bias. We re-scale all items as unidirectional, and range standardised (Milligan and Cooper, 1988). Scales measure 1 = high and 0 = low in low-carbon cognitions and low-carbon behaviour.

Step three: non-response. For each country we create a balanced dataset in which heterogeneity across all operationalised constructs is fully captured for all respondents in the dataset. This involves removing cases with a missing response for any composite variable. We assume non-responses are 'missing at random' i.e., not correlated with the

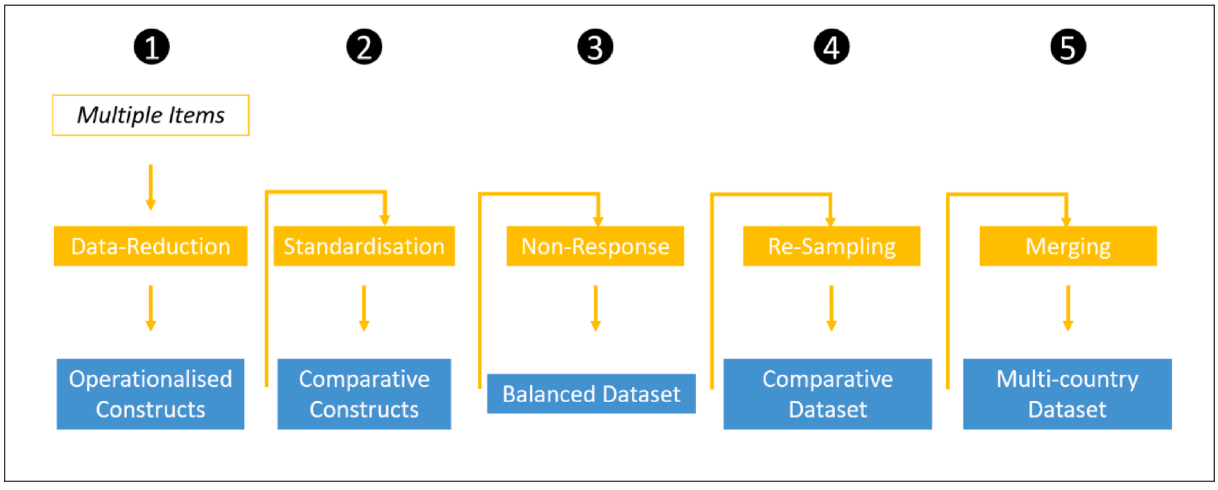


Fig. 2. Steps to Data Preparation.

Table 2
Results of Sensitivity Testing for each Country.

Country	UK			China		
Test	Duda Hart	Calinski/ Harabasz		Duda Hart	Calinski/ Harabasz	
Measure	Je(2)/Je(1)	Pseudo T^2	Pseudo F^2	Je(2)/Je(1)	Pseudo T^2	Pseudo F^2
n-clusters	maximise	minimise	maximise	maximise	minimise	maximise
1	0.9347	334.98		0.9073	510.85	510.85
2	0.9418	237.3	334.98	0.9136	283.13	415.12
3	0.8378	184.48	289.32	0.9091	174.19	337.96
4	**0.9443**	**184.19**	**262.55**	**0.9066**	**128.91**	**294.65**
5	0.9367	164.27	248.54	0.9360	136.76	268.88
Country	USA			Australia		
Test	Duda Hart	Calinski/ Harabasz		Duda Hart	Calinski/ Harabasz	
Measure	Je(2)/Je(1)	Pseudo T^2	Pseudo F^2	Je(2)/Je(1)	Pseudo T^2	Pseudo F^2
n-clusters	maximise	minimise	maximise	maximise	minimise	maximise
1	0.9118	86.86	86.86	0.9118	483.55	483.55
2	0.8922	54.03	75.46	0.8955	432.18	474.32
3	0.8892	41.61	64.53	0.8894	218.86	403.75
4	**0.9161**	**41.12**	**59.74**	0.8568	215.02	362.24
5	0.9065	35.57	55.6	0.9196	169.64	329.61

outcomes of our analysis (Raghunathan et al., 2001).

Step four: re-sampling. We reduce the sample size of each country dataset for comparability purposes. Following Step 3, sample sizes remain large for the UK (n = 12,500 respondents), China (n = 16,076 respondents) and Australia (n = 7,932 respondents). These large samples are likely to result in diminishing returns on the accuracy of cluster analysis methods (Dolnicar et al., 2016; Mooi et al., 2017). To reduce samples, we 're-sample' each dataset. For the UK, China and Australia we take random samples of 5,000 individuals. We apply the same random sampling algorithm for each dataset. We apply no ex-ante criteria in terms of stratification of these samples. We check for representation across important demographic variables including age and income ex post. The USA has a sample size of N = 900 which is appropriate for cluster analysis. See Appendix 2 – demographic representation (Tables 9(a), 9(b) and 10).

In a final Step five we merge the four country datasets to form a single multi-country dataset.

Synthesising data from multiple sources, contextualised in four different countries could generate biased results (Kaminska and Lynn, 2017). To account for this our data preparation, analysis and results are performed at the country level as well as multi-country level. For each dataset, we apply the same analytical framework to develop standardised items and constructs, and all results are sensitivity tested and validated for representativeness, reasonableness and meaning.

3.4. Data analysis

We combine multivariate statistical methods in Stata IC/17.0 (Statacorp, 2021). We use hierarchical cluster analysis to partition individuals into clusters or groups. We use the Ward criterion as a measure of similarity to aggregate respondents with similar characteristics into the same cluster (Mooi et al., 2017; Dolnicar et al., 2016). We analyse each country dataset in turn, beginning with China and the UK which are both very robust datasets; highly representative of our analytical framework (see Table 1). We follow with USA and Australia. We examine each cluster solution, looking for consistency across all countries. Each country dataset is subjected to the same series of sensitivity tests (see Table 2). Initially a dendrogram is used to visually examine the hierarchy of clusters and potential partitioning points. Caliński and Harabasz (Caliński and Harabasz, 1974) variance ratio criterion and Duda-Hart index (Duda et al., 2001) are used to deduce the most appropriate number of clusters in each country (see Table 2). The defined partition is then consolidated using a K-means method (Caliński and Harabasz, 1974; Duda et al., 2001; Mooi et al., 2017; Vuik et al., 2016).

Bold orange denotes optimum cluster solution in each country (UK, China, USA), pale orange denotes variation in the optimum solution (Australia).

To confirm the four-cluster solution in each country we compare two sensitivity tests; Duda-Hart index and the Caliński and Harabasz variance ratio criterion. We identify the optimum cluster solution in each country by balancing three criteria;

1. Large values of the Duda–Hart Je(2)/Je(1) index (Mooi et al., 2017; Duda et al., 2001).
2. Accompanying small value of the corresponding pseudo-T_2 (Mooi et al., 2017; Duda et al., 2001).
3. Large values of the Caliński and Harabasz variance ratio criterion (Caliński and Harabasz, 1974).

In Table 2 we highlight in orange bold, the optimum cluster solution in each country. We find the four-cluster solution to be a good fit for UK, China and USA. In Australia there is evidence to support either a four or five cluster solution. In final 'sense- testing' of the cluster profiles, and in the interests of parsimony we seek to empirically substantiate the four-cluster as a multi-country solution. We find four empirically heterogenous lifestyle types within and across the four countries. See Appendix 3 – Empirical consistency of the four-cluster solution in each country (Table 11).

We measure lifestyle heterogeneity across the two main elements: low-carbon behaviour and low-carbon cognitions. The clustering equation can very broadly be described as:

$N_{Cluster}$ = Low-carbon behaviour (mobility + homes + food) + low-carbon cognitions (perceived behavioural control + value orientation + health orientation + environmental beliefs)

In China and the UK (based on no priors) we identify a four-cluster solution. This four-cluster solution is confirmed for both Australia and the USA.

We use further multivariate statistical methods to characterise the four lifestyle types including T-Test and Scheffé multi comparison of means, Chi-squared testing and multinomial logistic regression (Savin, 1980, (Mooi et al., 2017). We measure mean differences, bivariate relationships, and probabilities related to the size and strength of relationships between the three elements of lifestyle.

To enrich our profiling of the low-carbon behaviour for lifestyle types, in a final step we extend our multi-country analysis across different behaviour types, applying ex-post the A-S-I framework. In the multi-country dataset, we disaggregate behavioural measures into one of three types in each domain. Table 3 shows the measurement and distribution of equivalent behaviours. In mobility 'Avoid' behaviour, for example, all four countries measure valid items. In homes 'Improve' only UK includes valid items. To preserve multi-country representation, we apply multiple imputation methods to extrapolate missing items. Multiple imputation is a principled statistical method for handling missing data (Raghunathan et al., 2001). To predict missing values, we use the modelled relationship with low-carbon cognitions and contextual variables (income (i), age (a) and digital skills (d)). All predictor variables are range standardised (within country data). The general form of the equation is:

$$\text{A-S-I behaviour}_{\text{domain}} = \beta_0 + \beta_1 x_c + \beta_2 x_a + \beta_3 x_i + \beta_4 x_d$$

4. Results

We identify four universal low-carbon lifestyle types that we label 'Resourceful'; 'Active'; 'Constrained'; and 'Cautious'. Each lifestyle type has varying propensities towards low-carbon behaviour which is consistent with the strength of low-carbon cognitions. Each lifestyle type is similarly enabled or constrained by material and social context.

In Table 4 we report universal lifestyle heterogeneity across the three key elements of low-carbon cognitions, low-carbon behaviour, and context. For constructs which are statistically different ($|p|<=0.05$) across the four lifestyle types, we highlight in dark orange text the highest value. Values reported for cognitive and behavioural heterogeneity are mean centroid values. They measure 'strength', scaled from 0 (weak) to 1 (strong). For example, a high mean score indicates stronger low-carbon cognitions or stronger low-carbon behaviour. Statistically significant differences relate to comparison with the universal mean for each element. Values reported for context are percentages, apart from income which is an absolute mean value. We focus on items that are statistically significant.

Results reported for low-carbon behaviours are average behavioural propensities across a range of self-reported low-carbon behaviours. We do not have data on related CO_2 emissions or resource use in absolute terms.

4.1. Key findings 1: Four lifestyle types are clearly distinguished by their low-carbon cognitions, behaviours and contexts

'Resourceful' types are highly enabled by their social and material contexts. They act on their strong beliefs in climate change and fully engage in a lower carbon lifestyle across all behaviours. 'Resourceful' types are stronger in low-carbon cognitions (mean = 0.606) and low-carbon behaviour (mean = 0.465) relative to other lifestyle types. Cognitively they hold the strongest environmental beliefs (mean = 0.505). Their propensity towards low-carbon behaviour is consistent across all three domains (mobility, food and homes) and across all behaviour types (avoid, shift, improve). They are highly contextually enabled. A higher percentage of 'Resourceful' types are above average in technology savvy (56%), live in urban environments (74%) and have supportive social networks (65%). They have the highest average income (US$37,889). 'Resourceful' types account for on average 23% of the population.

'Active' types are goal driven and seek healthier outcomes in life. They are strong in low-carbon cognitions (mean = 0.608) where this relates to higher-than-average levels of PBC. They have the highest assessment of their overall health (mean = 0.713). This relates to being more goal driven, physically more active, and more satisfied with their lives. Behaviourally they are stronger in avoidance behaviours, in mobility and food and equally likely as the 'Resourceful' type to shift to a vegetarian diet. They tend to be younger. The highest percentage (16%) of this group tend to be under 35 years of age. They have on average a

Table 3
Representation of A-S-I Behaviours in Mobility, Food and Homes Domains.

	Mobility	Food	Homes
Avoid	***Reduce / avoid use of carbon intensive modes of transport*** *Fewer flights; Drive less* *(UK, CHN, USA, AUS)*	***Avoid unsustainable goods*** *Avoid excess packaging* *Avoid products for environmental reasons* *(UK, USA)*	***Reduce home energy consumption*** *Reduce heating controls; use less lighting* *(UK, USA, AUS)*
Shift	***Shift from car to public transport / cycling / walking*** *Shift to public transport from car* *Walk short journeys* *(UK, CHN, AUS)*	***Shift to a more sustainable healthy diet*** *Low meat diet* *(UK, CHN, USA, AUS)*	***Shift to lower carbon source of fuel*** *cook using low-carbon fuel (electricity, biogas* *(CHN))*
Improve	***Fuel-efficient vehicles / Electric vehicles*** *Car share; Own EV; Own E-bike* *(UK, CHN)*	***Efficient use of food products / reduce waste*** *Recycled packaging; Take owns bags shopping (UK, USA)*	***Micro-generation*** *Home has solar panels for water; heating; wind turbine* *(UK)*

Based on the A-S-I framework (evaluated in Creutzig et al. (Creutzig et al., 2022) and van den Berg et al. (van den Berg et al., 2019).

Table 4
Cognitive, Behavioural and Contextual Heterogeneity Across Lifestyle Types (bold orange colour denotes that a value is statistically significantly higher than the universal mean).

	Universal	Resourceful	Active	Constrained	Cautious
Sample size (n) [%]	*15,900*	3,592 [23%]	4,795 [30%]	4,259 [27%]	3,254 [20%]
Element 1*					
Low-carbon Cognitions	*.564*	**0.606**	**0.608**	0.474	0.567
Constructs					
PBC	*.653*	0.691	0.708	0.501	**0.728**
Value orientation	*.557*	**0.602**	0.562	0.515	0.555
Health orientation	*.617*	0.643	**0.713**	0.504	0.595
Environmental beliefs	*.440*	**0.505**	0.425	0.371	0.483
Element 2*					
Low-carbon Behaviour	*.396*	**0.465**	0.416	0.359	0.339
Constructs					
Avoid Mobility	*.548*	**0.576**	**0.575**	0.515	0.522
Avoid Food	*.364*	**0.410**	0.389	0.315	0.341
Avoid Homes	*.548*	**0.588**	**0.583**	0.574	0.421
Shift Mobility	*.489*	**0.594**	0.409	0.492	0.487
Shift Food	*.469*	**0.484**	**0.490**	0.450	0.449
Shift Homes	*.506*	**0.540**	0.512	0.473	0.510
Improve Mobility	*.157*	**0.184**	0.162	0.129	0.156
Improve Food	*.641*	**0.682**	0.658	0.598	0.627
Improve Homes	*.338*	**0.345**	0.339	0.333	0.337
Element 3					
Context					
Income (US$)	*31,116*	**37,889**	29,565	27,703	30,432
Educated (% high education)	*51*	41	34	39	**43**
Technology Savvy (% high)	*44*	**56**	45	38	39
Urban environment (%)	*63*	**74**	63	64	67
Supportive social networks (%)	*57*	**65**	63	56	60
Smaller households (<=2)	*45*	48	34	46	**58**
Age (means years) [%<35 yrs]	*52 [14]*	52 [14]	51 **[16]**	**55** [9]	54 [13]
Own home (%)	*83*	82	**85**	81	83

*measured on a scale 0 to 1, where 1 = high and 0 = low.

moderate income (US$29,565). A higher percentage of this group own their homes (85%). 'Active' types are the biggest group. They account for on average 30% of the total population.

'Constrained' types face strong barriers to low-carbon lifestyle. They have the lowest levels of low-carbon cognitions (mean = 0.474) where this relates to low motivation and low PBC. Their value orientation is towards self and they are inner directed. They have low environmental beliefs (mean = 0.371). Generally, they have a low propensity towards low-carbon behaviour (mean = 0.359). They have above universal average engagement in 'avoidance' behaviours related to homes (mean = 0.574) where this relates to saving energy (switching off lights and lowering heating controls). They have above universal average engagement in 'shift' behaviour related to mobility (mean = 0.492) where this relates to shifting towards public transport use from a car.

Table 5
Contextual Variation Between Lifestyle Types by Country (bold orange text denotes that the value is statistically significantly different when compared across the four lifestyle types).

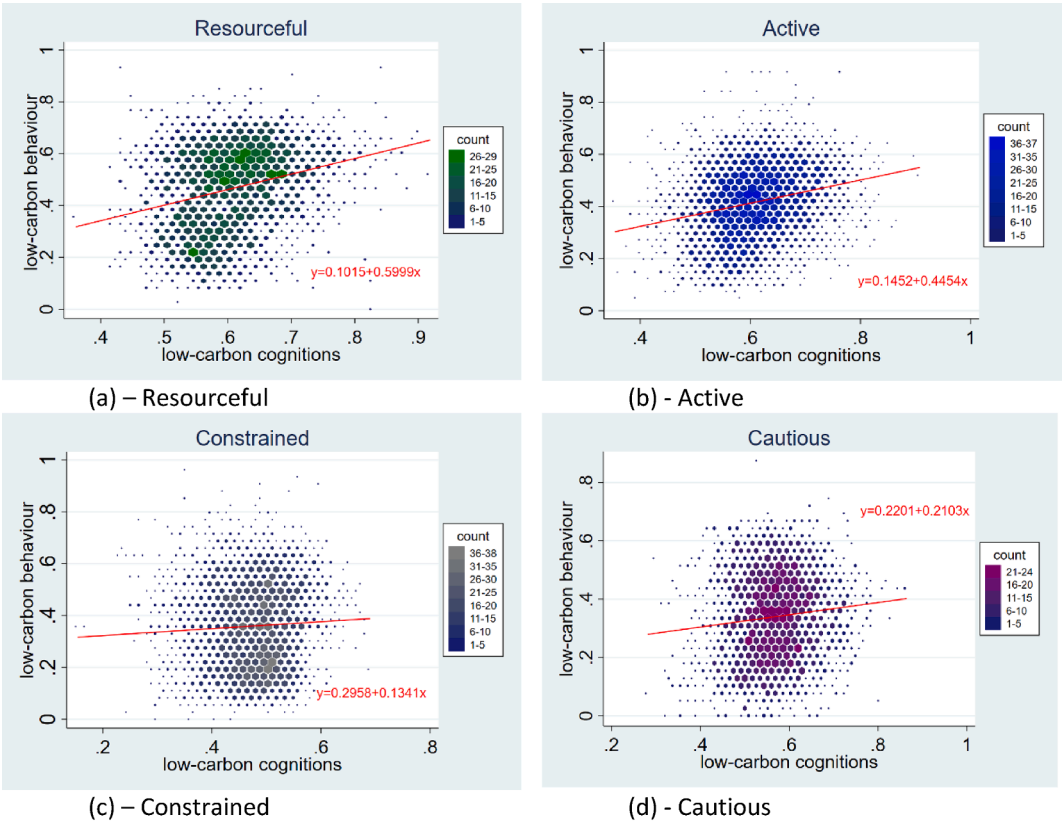
	UK	China	US	Australia
Resourceful (sample size)	25%	15%	21%	28%
Technology savvy (% high)	**60%**	**42%**	**31%**	**63%**
Supportive social networks (%)	**79%**	67%	**47%**	54%
Own home (%)	**91%**	86%	65%	75%
Active (sample size)	17%	40%	28%	34%
Technology savvy (% high)	59%	26%	**31%**	64%
Supportive social networks (%)	71%	**70%**	45%	53%
Own home (%)	88%	88%	68%	**82%**
Constrained (sample size)	37%	25%	18%	20%
Technology savvy (% high)	51%	12%	21%	51%
Supportive social networks (%)	68%	55%	32%	40%
Own home (%)	85%	88%	52%	68%
Cautious (sample size)	21%	21%	33%	18%
Technology savvy (% high)	38%	30%	28%	56%
Supportive social networks (%)	67%	58%	39%	**60%**
Own home (%)	82%	88%	**73%**	81%

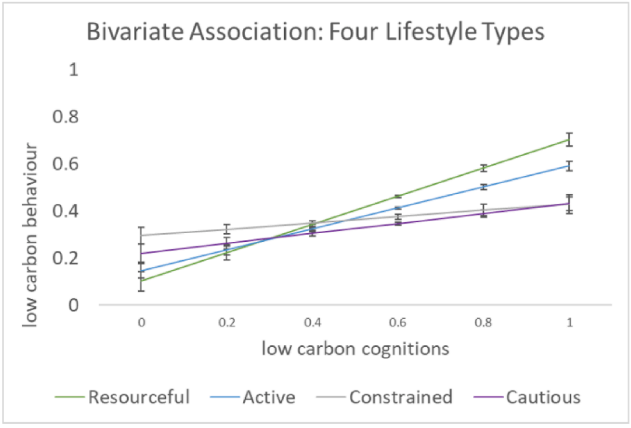
They are highly contextually constrained. They have the lowest average income (US$27,703). A low percentage of this group are technology savvy (38%). Just over half have average levels of support from social networks (56%). They tend to be older (mean age = 55 years). Approximately 9% of 'constrained' types are age 18–35 age. This is the lowest percentage across all lifestyle types. 'Constrained' types account for on average 27% of the population.

'Cautious' types have the means but not the motivation. Cautious types are not distinguished by their cognitions which are close to the universal average. The exception is PBC which are the highest across all lifestyle types (mean = 0.728) where this relates to strong efficacy and agency. Behaviourally they are the most 'disengaged'. They are above the universal average in 'shift' behaviour related to homes. This relates to propensity to use alternative forms of energy such as electricity or biomass. Contextually they are the most educated lifestyle type (43% are highly educated) and the type most likely to live in a smaller household (58%, 2 or less people). 'Cautious' types account for on average 20% of the population.

4.2. *Key findings 2: Each lifestyle type is associated with different identifiers that vary across countries*

Material and social context is an important source of lifestyle heterogeneity. It shapes the relationship between low-carbon cognitions and low-carbon behaviour. Across UK, China, USA, and Australia we find small differences in the profiling of lifestyle types. These emphasise differences in social and material structures and related inequalities between countries. Table 5 summarises the most notable differences;





(e) – Sensitivity Plot

Fig. 3. Bivariate Association Between Low-carbon Cognitions and Low-carbon Behaviour.

these relate to technology savvy, supportive social networks and home ownership. In line with Table 4, for constructs which are statistically different (Chi2 |p|= 0.000) across the four lifestyle types, we highlight in dark orange text the highest value.

Technology savvy describes greater access to enabling digital infrastructure (including high digital skills). It is also likely to be a general proxy for wider skills and competences linked to educational attainment. The general pattern identified across lifestyle clusters has structural features in parallel with the digital divide (Cullen, 2001). The more technology savvy 'Resourceful' types in all countries are wealthier and more urban. 'Constrained' types, particularly in China, are more rural and lack access to infrastructure and resources. China has high digital inequality, in part a representation of a divide that highlights social inequality, social disadvantage and exclusion (Liu et al., 2017). In the USA we find evidence of greater equality between lifestyle types which is contrary to the digital divide discourse in US society (Cohron, 2015).

Supportive social networks increase social cohesion or connectivity and reinforce behaviour change. Strong social cohesion is related to physical health and wellbeing and is characteristic of 'Active' types. In materially enabled 'Resourceful' types, the share of supportive social networks is consistently moderate to high across countries (highest for the UK and the USA). For 'Active' types, the proportions are also generally high, and are highest for China (70%) relative to other types. Of note, is the lower-than-average share for 'Constrained' (lowest for China, the USA, and Australia) and 'Cautious' (lowest for the UK) types. Australia shows divergence to this pattern, with the more affluent 'Cautious' group, assuming the highest share.

These findings reflect structural Influences on social cohesion known to vary between Western and Asian societies (Delhey et al., 2018). These cross-societal differences are reflected in lifestyle heterogeneity in our study. In western societies, social cohesion is reduced by income inequality, religiosity and materialist values. In Asian regions the most cohesive countries are those with moderate levels of income inequality (not the lowest), and authoritarian countries are slightly more socially cohesive than democratic ones.

Rates of home ownership in different lifestyle types are homogeneous across countries in the 'Constrained' types but heterogeneous between 'Active' and 'Resourceful' types, with notable differences in the UK. In the UK outright home-owners are older (mean age = 57 years). They are less likely to have children and live in under-occupied dwellings (Ministry of Housing Communities & Local Government, 2019). China has a homogenous pattern of homeownership across the four lifestyle types. It has transitioned from a 'socialist welfare-oriented housing system' to one of the countries with the highest proportion of home-owners, 87% in urban areas and 96% in rural China (Huang et al., 2021). Tenure decisions in China are also shaped by housing subsidies and political status rather than just socio-economic and market forces.

Slight variations in the lifestyle clusters reveal an interplay between demography, education, social connectedness and digital skills. The motivation to learn new skills / adopt new technology is partly related to generational differences (Volkom et al., 2014). In the UK, 'Cautious' types are the most educated, they are the oldest and have the lowest proportion of 'technology savvy'. In contrast, the 'Cautious' in China have the highest proportion of younger people, and high share of digital skills despite economic constraints. The more technology savvy 'Resourceful' cluster also have more supportive social networks. The evolution of digital access, acceptance and use is not just related to individual characteristics but to social support relationships and networks. Unequal digital access leads to unequal participation in society (Van Dijk, 2005).

4.3. *Key findings 3: Low-carbon cognitions direct low-carbon behaviour, if context is 'enabling'*

The consistency between strength and direction of association of low-carbon cognitions and low-carbon behaviour in more enabled lifestyle types is a major finding in this study. In Fig. 3 we report the linear

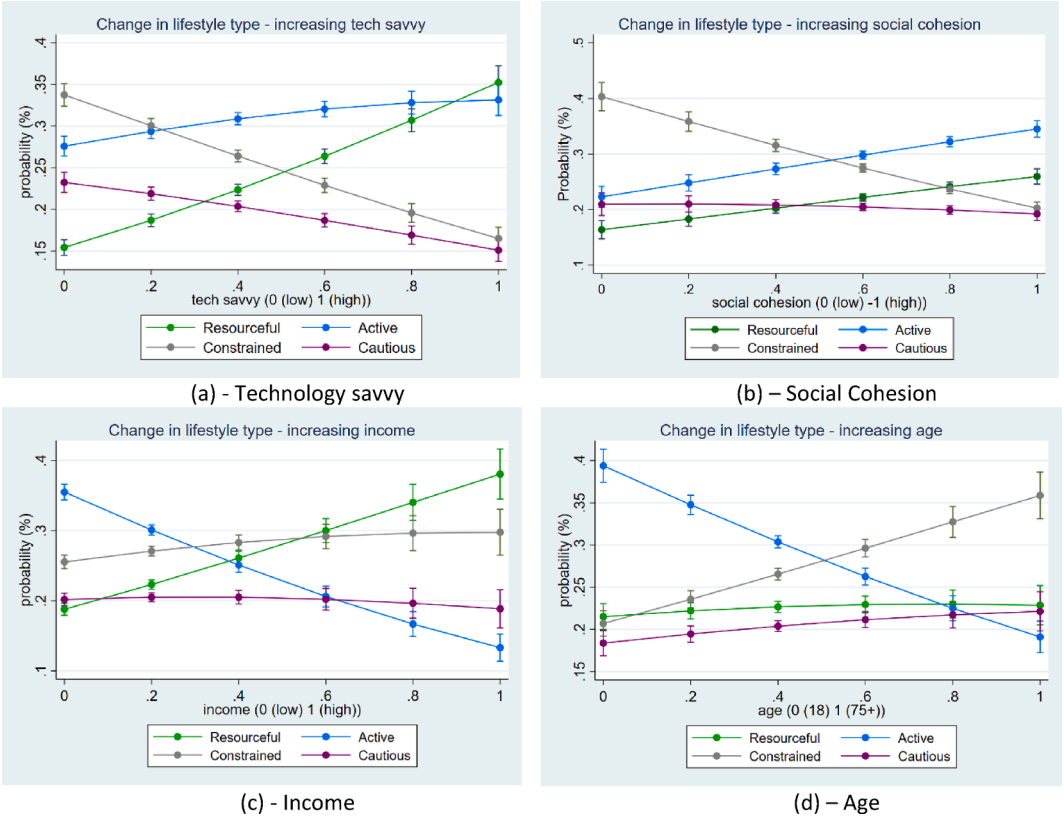


Fig. 4. Marginal Probabilities of Lifestyle Type with Changing Context.

relationship between low-carbon behaviour and low-carbon cognitions. The first four graphs (Fig. 3(a) to 3(d)) are bivariate histograms, with a regression line of best fit. Fig. 3(e) is a sensitivity plot. It examines values at which this bivariate relationship is significantly different between the four lifestyle types.

'Resourceful' and 'Active' types are contextually 'enabled'. For them low-carbon behaviour is more strongly directed by low-carbon cognitions ('Resourceful' $\beta = 0.271$, 'Active' $\beta = 0.244$). Our results show a significant, positive association between low-carbon cognitions and low-carbon behaviour in both these types (Fig. 3(a), 3(b)). Cognitive pathways for these two types are different. 'Resourceful' types are directed more by long-term, altruistic values and beliefs in climate change. 'Active' types are driven by health-related goals and improved life satisfaction. These findings are consistent with the wider literature that informed this study. In health studies sustainable behaviour is directed by personal assessment of health and motivations to improve health (Pícha and Navrátil, 2019). In pro-environmental literature, low-carbon behaviour is directed by complementary pathways including strength of environmental values and beliefs, efficacy and agency to act (Hedlund-de Witt, 2012; Hagbert and Bradley, 2017; Longo et al., 2019).

'Constrained' types face many barriers to engagement: low-carbon behaviour is weakly directed by low-carbon cognitions ($\beta = 0.0534$). Our results show a positive but weak association between low-carbon cognitions and low-carbon behaviour in this type (Fig. 3(c)). 'Constrained' types have low affordability and access to supportive infrastructure. This is reflected in their weak levels of PBC. Their above average engagement in 'avoidance' behaviours in the home (saving energy by turning off heating, lighting) suggests behaviour is motivated by a need to save money.

'Cautious' types are 'enabled' but 'passive': low-carbon behaviour is weakly directed by low-carbon cognitions ($\beta = 0.1076$). In comparison with the other lifestyle types, 'Cautious' types, have a moderately enabling context, reflected in their highest levels of PBC. Our results suggest that despite this enabled context, cognitively they are likely to be the most conflicted. They have low environmental beliefs, more likely to hold conservative values (happy with the status quo), and self-orientated. Hayles and Dean (Hayles and Dean, 2015) distinguish 'active' from 'passive' lifestyle types as those willing to take individual responsibility versus those that believe environmental action is others' responsibility.

Fig. 3(e) compares change in low-carbon behaviours for each 1unit change in low-carbon cognitions for each lifestyle type. Error bars measure differences at 95% confidence. At the 'universal' mean low-carbon cognitions (0.564), there are small, but significant differences in low-carbon behaviours across the four lifestyle types (error bars do not overlap). These differences are notably much smaller between 'Constrained' and 'Cautious' types. As low-carbon cognitions strengthen (0.564 to 1) these two groups converge. The opposite effect is observed between the 'Resourceful' and 'Active' types, for whom the association between low-carbon cognitions and low-carbon behaviours is much stronger. They diverge as low-carbon cognitions increase.

4.4. Key finding 4: The opportunity to change lifestyle is shaped by context

Five key contextual predictors influence membership of lifestyle type and change towards a lower carbon lifestyle: technology savvy; income; urban/rural living; age; and social cohesion.

Fig. 4 illustrates the change in marginal probabilities across the four lifestyle types under the four most significant contextual shifts (Fig. 4(a) to 4(d). Marginal probabilities and change in marginal probabilities are calculated from sequential multinomial logistic regression models which predict cluster membership (and size) as a function of context: technology savvy, age, income and social cohesion.

As material and social context changes, we find evidence that inequalities of access, affordability and social inclusion significantly influence low-carbon lifestyle choices. When socio-technical contexts become more enabling, there are large shifts towards 'Resourceful' and 'Active' lifestyle types; most noticeable when more people have access to digital skills and related technology. Fig. 4(a) shows that almost 70% of the population move into these types as technology savvy is increased. Fleming (2017) suggests that digital technology is a potentially critical component in the pathways to a low-carbon lifestyle, society and future.

The shift towards 'Resourceful' and 'Active' types is not as large for levels of social cohesion (Fig. 4(b)), we see a larger increase in 'Active' types compared to 'Resourceful'. This reflects a younger age profile of 'Active' types (see also Figure (4(d)). There are inevitable interactions between technology and related social systems and these are both necessary to accelerate the transformation towards low-carbon lifestyle (Rosenbloom, 2017). Geels et al. (Geels et al., 2017) propose that this interaction between technologies and social groups will fast track low-carbon transitions.

Higher levels of income create a strong divergence between the 'Resourceful' and 'Active' lifestyle types (Fig. 4(c)). At higher levels of income, 'Active' and 'Cautious' types shift towards 'Resourceful' types, with a small increase in 'Constrained' types. This is illustrative of the close synergies that exist between low-carbon and healthier lifestyles, as 'Active' types become more enabled by income they engage more widely in low-carbon behaviour, beyond food. There is likely to be some interaction between income and age, where this reflects experience, education and employment potential. In contrast 'Constrained' types remain constant as income increases, illustrative of the importance of both cognitions, and context in this type.

Our findings are consistent with studies observing and measuring the antecedents to lifestyle which emphasise the importance of both material and social structures that effect lifestyle choices (SINUS, 2018).

5. Discussion

Our lifestyle framework offers a novel framing and construction of lifestyle typologies which encapsulates both cognitions and behaviours. It includes a contextual interpretation, and identification of heterogeneity within and across countries, cultures and traditions. Whilst we rely on only four countries, we present a strong and robust basis for further testing of this framing as relevant data becomes available. In this final discussion we highlight key insights from our work in terms of understanding lifestyle and its overall contribution to imagining and planning a low-carbon future.

5.1. A generalisable multi-country lifestyle framework is an important tool for understanding lifestyle contributions to climate change mitigation

In this study we have provided a transparent, replicable approach using publicly available data to identify four heterogeneous lifestyle types. In each of the four countries sampled, these lifestyle archetypes are representative and could form the basis of segmented strategies by government and industry towards lower carbon lifestyles. In this respect, our lifestyle framework could be used more generally to align heterogeneous lifestyle types who have varying propensities towards low-carbon behaviours. For example, in the food domain our findings clearly distinguish between four types with varying propensities towards eating a low-meat diet. Our framework could also be used ex-ante to position products and services in a way that appeals to these four like-minded lifestyle types.

Our lifestyle framework and typology measure multi-country lifestyle types but is restricted in its generalisability to specific countries and regions, we measure single countries representing Europe, South East Asia, North America and Australasia.

Communities in the Global South are disproportionately threatened by the most serious consequences of climate change yet there is a lack of relevant research and data to inform scientific enquiry (Adekoya et al., 2021; Blicharska et al., 2017; Karlsson et al., 2007). This North-South divide in research relevant to climate change is well documented and believed in part to be due to country wealth, but also government factors

and scientific traditions (Arora, 2016). A major disadvantage to the research community is it can limit approaches to a narrow set of cultures and perspectives (Karlsson et al., 2007). Despite this limitation, lifestyle researchers have made novel use of public domain survey data (e.g., energy consumption and general health) for countries including Malaysia, India, and Nigeria. These studies largely conclude that people across these countries face particular challenges in their every-day life. Challenges relate to limited health and welfare systems (Jamal et al., 2016), poverty (Katz-Gerro et al., 2017), access to education, technology and clean fuels(Hubacek et al., 2007), and corrupt systems of political governance (George-Ufot et al., 2017). Measuring and tracking these key inequalities, help to account for the limited research agenda identified in our search for data across the Global South. For example, the India National Sample Survey, a long-standing survey of households, tracks inequalities across systems of wealth, health, education and access to basic goods and services (India National Sample Survey Office, 2023). The Afro-Barometer, a not-for-profit network of volunteer organisations, tracks basic human rights and freedoms across seventeen African countries (The Pan African Research Network., 2023). Although a 'datafication' process is claimed to be underway within Global South countries, this has been largely driven by private sector companies (Taylor and Broeders, 2015; Mahrenbach et al., 2018). Adekoya et al. (Adekoya et al., 2021) call for a re-think of the north–south divide so as to enable and enhance scientific enquiry, climate action and the achievement of sustainable consumption goals.

Although by design our multi-country framework is not representative of the Global South our independent profiling of lifestyles in China (see Section 5.1) shows a degree of divergence across the social and material context, characteristic of countries in the Global South. This includes higher levels of social cohesion - where this relates to support from family and community (Kuanr et al., 2019), lower levels of digitalisation, and limited access to clean fuels for cooking and low-carbon technology (Etminani-Ghasrodashti et al., 2018; Katz-Gerro et al., 2017; Hubacek et al., 2007).

To overcome difficulties in accessing further comparative data in the Global South, our model framework can also be used as a measurement model to extrapolate the four lifestyle types across other countries and regions. This approach can utilize other globally representative datasets which measure the main elements and constructs within our analytical framework. For example, the World Values Survey (Inglehart et al., 2014), measures cognitive items including PBC, value orientation, life satisfaction, and beliefs in climate change across more than 90 countries worldwide. The National Geographic Survey (Globescan and Greendex, 2014), measures low-carbon behaviour across 18 different countries covering all four domains (mobility, food and homes) and the avoid-shift-improve behavioural types. The World Bank (World Bank, 2020), measures a wide range of contextual indicators including income (GDP), population characteristics, and digitalisation across more than 60 countries. This approach is particularly relevant in informing and improving the representation of lifestyle in global energy system models. These models lack adequate representation of the social processes that drive lifestyle (van den Berg et al., 2019).

5.2. Transition towards low-carbon living involves an interplay between lifestyle elements

Across often disparate literatures, lifestyle change is commonly framed from a single, cognitive perspective as being motivated and intentional, either with respect to specific behaviours, or more broadly to construct a consistent self-identity or standing within the world (Haq et al., 2008; Hagbert and Bradley, 2017). Our findings challenge this conception by suggesting that transitions towards low-carbon living involves an interplay between multiple elements of lifestyle. It involves cognitive elements which strengthen the pathways to low-carbon behaviour; it involves contextual elements which enable individuals to act on their cognitions; it involves behavioural elements, which widen experiences within and across domains and different types of low-carbon behaviour and so enhances self-consistency. The three elements of lifestyle are in this respect recursive.

Many studies portray multiple, distinctive, complimentary cognitive pathways to low-carbon behaviour (Longo et al., 2019; Thøgersen, 2017a; Graham and White, 2016). We differentiate and define these two pathways and their unique influence on multi-country lifestyle types. The first cognitive pathway, is driven by low-carbon values and beliefs and emphasises outward-looking, altruistic values, concern for the welfare of others, and saliency of climate change ('Resourceful' types). This cognitive orientation aligns with policy interventions and related narratives that emphasise 'green identity' and 'social benefit' (Jansen, 2011; SINUS, 2018; Starr, 2008). 'Resourceful' types demonstrate greater 'consistency' across all domains of behaviour and all behaviour types, consistent with their emphasis on self-identity, described by Whitmarsh and O'Neill (Whitmarsh and O'Neill, 2010) as 'I am therefore I do'. The second cognitive pathway is driven by personal goals related to health and life satisfaction and emphasises physical and mental wellbeing, and personal happiness ('Active' types). This orientation aligns with interventions and narratives that emphasise the 'private benefit' of a healthier lifestyle including reduced risk of disease, improved self-esteem, fitness and wellbeing (Middleton et al., 2013; Jamal et al., 2016; Walker and Hill-Polerecky, 1996).

5.3. Digital and related social inequality present major barriers to large-scale transitions to a low-carbon future

The enabling and constraining effect of social and material context is confirmed in our study. We find overlapping barriers to engagement in low-carbon lifestyle that emphasise the relevance of infrastructure which supports low-carbon living, contributes towards inequalities of access to low-carbon living which reflect in the motivations, agency and efficacy for people to act on their low-carbon cognitions. They significantly influence what Sinus (SINUS, 2018) refers to as the 'landscape for lifestyle change'.

The digital divide relates to a gap between those with ready access to the tools of information, communication and the knowledge they provide access to, and those without (Cullen, 2001). It exists in most countries and is clearly evidenced in our findings. Many institutions and academics are actively engaged in exploring the implications of this for climate change and a transition towards low-carbon living. Internet access and use are spreading rapidly around the globe but there is a stark digital divide that reflects wider social inequalities underlying barriers to change (World Bank, 2020). These were apparent during the Covid-19 pandemic which accelerated the rate of digital transformation as a larger proportion of the population lived and worked virtually (Kudyba, 2020), but also highlighted digital inequalities among the more vulnerable in society (Watts, 2020; OECD, 2020). This diversification in digital opportunities reflects in a diversification of attitudes, opinions, values, and behaviours embodied in lifestyle within our findings.

Digital advancement requires improvement in related infrastructure in and around cities and urban environments. It also requires higher levels of educational attainment, which moderate ability to exploit digital innovation (International Telecommunication Union Digital Skills Insights, 2020). Information and communications technology provides access to environmental information and opens doors to wider community resources, empowering individuals towards low-carbon behaviour (Gong et al., 2020). Systemic digital inequality is evidenced through our findings for China, where 'Constrained' types tend to be more rural and in material resources and infrastructure. This inequality creates unequal opportunities to exchange knowledge and ideas and engage more widely with society. This digital exclusion highlights wider societal inequality, disadvantage, and exclusion (Liu et al., 2017). Social inequalities also raise formidable contextual barriers to low-carbon transformation.

We face significant challenges in foreseeing how digital drivers of lifestyle will impact the transition to a net zero carbon future. There is deep uncertainty in lifestyle dynamics in the context of technological

change (Lyons et al., 2018; Sorrell, 2020). There are very divergent potential futures associated with technologically driven individual and collaborative consumption of energy and materials. Digital technology is widely seen as a potentially critical component in the pathways to a low-carbon lifestyle, society and future (Fleming, 2017). It provides opportunity for low-carbon transformation of daily activities (Zhang et al., 2021). Increased consumption of digital technologies and related innovations links consumers with information and social networks, providing opportunities to share resources across many aspects of daily life with potential emission-reducing benefits (Wilson et al., 2020). However, there are potential rebound effects from an upsurge in energy consumption due to increasing use of information and communication technologies (Lange et al., 2020). The success of a low-carbon project in large part, relies on effective communication of the advantages of distribution technologies (Peters et al., 2013). A useful first step is to deepen our understanding of lifestyle orientations (cost, environment, family, social interaction) and expressions in the advancement of digital technology, and the premise by which politically steered equitable digital access could create an enabling context for low-carbon lifestyle change.

Resource inequality limits individual agency such that environmental choices are the reserve of the more privileged in society (Ronald, 2019).

5.4. Identifying and measuring lifestyle types enables industry and government to design effective policy interventions

Widespread, rapid, and intensifying climate change presents an evident and pressing need to create focused avenues for transitioning to low-carbon ways of living (Allan et al., 2021). A prerequisite to developing effective policies and practices, is a perspective that moves beyond a narrow understanding of behaviour change to one that appreciates the full breadth of the cognitive influences on behaviour change and the positive influence of enabling contexts (Peters et al., 2013).

5.5. Understanding lifestyle typologies allow targeted, differentiated interventions matched to lifestyle types

Fundamental to this are strategies to invest in improved digital infrastructure and access in rural and disadvantaged communities, the removal of contextual barriers, and provision of opportunities and lifestyle choices for marginal or excluded disengaged individuals. In our findings, these types accounted for nearly half of all respondents sampled across the four countries. Digital parity could provide a springboard for transitioning to low-carbon ways of living through information networks that facilitate shared resources. Digital technologies can be utilised to form learning communities to raise low-carbon awareness in developing economies (Nawi et al., 2019).

5.6. It is important to retain aspects of culture and tradition that translate to low-carbon ways of living in countries of the Global South and can enrich perspectives in the Global North

In the Global South many communities lack access to resources, knowledge and functioning institutions which is a major obstacle to more sustainable living. However, it is argued that many aspects of adaptive capacity reside in these strong social networks (Rockenbauch and Sakdapolrak, 2017; Berkes and Ross, 2013). An approach is required that preserves and emphasises the importance of established communities and social networks in the Global South, builds lifestyle choices around connected societies, collective living, strong cultural ties, and traditions (Kuanr et al., 2020).

These interpretations can enrich understandings of low-carbon living in the Global North (Hayward and Roy, 2019). Strong social cohesion links individuals with neighbours, friends and family, and wider communities. These can initiate low-carbon opportunity (Barr and Gilg, 2006; Peters et al., 2013; Peters et al., 2010) and shape lifestyle, providing 'entry points' to lower carbon living (Evans and Abrahamse, 2009; Kurz et al., 2015). Social networks create shared visions of societal actions that empower people to live a low-impact lifestyle (Alexander et al., 2007; Parkhill et al., 2015), promote community resilience (He et al., 2020), and have potential spill-over effects to influence others (Thøgersen, 2013).

Encouraging low-carbon transition through socially orientated interventions could motivate and incentivise disengaged lifestyle types. Investing in community-based sustainability programs (Middlemiss, 2011; Forrest and Wiek, 2014; Axon, 2017) can provide a platform for sharing low-carbon ideas and practices, working collectively on sustainability challenges, assisting with technical issues, and delivering long-term supportive social networks. The challenge remains to meaningfully draw in the wider public as a means of mainstreaming low-carbon lifestyles (Shirani et al., 2015), Axon, 2017, Axon, 2020). Participatory strategies for tapping into existing grass-roots organisations (Seyfang and Smith, 2007; Celata et al., 2019; Vita et al., 2020) and social networks (Seegebarth et al., 2016) can be developed to further identify opportunities that act as a catalyst for transforming lifestyle (Axon, 2016) and through 'scaling deep' (Gilby, et al., 2019) create new low-carbon norms and values in society.

Creating policy aimed at specific archetypes will better align with the diverse motivations and contexts of different lifestyle types. In our research we use the Avoid-Shift-Improve framework to distinguish behavioural heterogeneity across three domains of low-carbon behaviour. We find clear evidence that the four lifestyle types engage very differently across these domains and are likely to be responsive to very different types of incentives. 'Resourceful' types are more innovative, they are more likely to be adopters of innovations in all three domains. They are motivated by low-carbon goals. 'Active' types engage in food and mobility behaviours where they align with personal goals towards healthy lifestyle. 'Constrained' types engage in some behaviours where these are likely to be driven by cost and income constraints. 'Cautious' types are passive and disconnected.

We have presented a robust social science approach to framing and operationalising low-carbon lifestyles, however, there are some study limitations that could be addressed by future research. The operationalisation of our framework using large-scale social survey data captures a single cross-section of time. Further research would benefit from a longitudinal approach which tests the temporal resilience of our framework and enhance understanding of the mechanisms of lifestyle change. To enable this extension of our work, governments need to continue to invest in the collection of robust, un-biased, large-scale, nationally representative longitudinal survey data which supports the low-carbon research agenda. Our universal operationalisation of low-carbon lifestyle types draws on data, predominantly from the Global North. In our work we identify and acknowledge the inherent cultural, economic, and political differences between the four countries, particularly in China. Future research should seek to expand application of our lifestyle framework into other countries within the Global South. By creating North-South partnerships between research institutions, the limitations of access and language barriers inherent in using secondary data collected in other cultures and countries, could be overcome, and our understanding of low-carbon lifestyle enriched.

6. Conclusion

In this study we developed and tested a framework for measuring low-carbon lifestyles in multiple countries. Our framework is transparent and generalisable. We identified four heterogeneous lifestyle types, robust across countries and cultures. These lifestyle types varied in propensity towards leading a low-carbon lifestyle. We examined behavioural, cognitive, and contextual variation across these lifestyle types and identified important contributions towards imagining and planning a transition towards change. Our findings emphasise the dynamic relationship between low-carbon cognitions, low-carbon behaviour and social and material contexts which promote understanding of lifestyle and

the conditions under which lifestyles may transform. These insights could be used, for example, in global integrated assessment models (IAMs) to improve representations of lifestyle, which are currently simplified, rely on scenario narratives, and fail to fully capture all three elements (and potential drivers) of lifestyle (Mundaca et al., 2010; van den Berg et al., 2019; van Sluisveld et al., 2016). In this respect our generalisable lifestyle typology could be applied to a global IAM ex-post to explore the impact of climate change mitigation on lifestyle under various shared socio-economic pathways. It could be applied ex-ante by endogenizing certain parameterisations drawn from our statistical modelling. This would enable models to fully capture both the outcomes and processes of lifestyle, providing insights and mechanisms for modelling change under different mitigation scenarios. Our lifestyle typology could be used in a broader context by government and industry as a segmentation tool that tailors incentives to lifestyle types or to target policy towards particular behaviour using the ASI framework but with further differentiation according to lifestyle types.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix 1a

See Tables 6 to 8

Table 6
Thematic summary of cognitive lifestyle items identified from each dataset.

Theme	Sub-theme	Key terms	Country code	n items
Perceived Behaviour Control (PBC)	Self-efficacy: belief in ability to succeed in specific situations	Solve or overcome problems / solutions, find ways, stick to aims/goals, deal/ handle the unexpected / unforeseen, invest effort, remain calm, self-confidence, as good as others, opportunities to improve, aspirations, work hard to be the best	UK US CH AU	10 2 2 3
	Agency: capacity to act independently and to make free choices	Make household / family / big decisions, control, change things, helpless[1], pushed around[1]	UK AU	2 9
Value orientation - values and attitudes towards self and others	Long-term gratification / orientation	Delayed gratification / long-term reward / goals, spend money wisely, trust* with money, give* up comfort, consider others, motivate self, pays off in the long run, put off[1], short-term focus[1], impulsive[1], live for today[1], future will take care of itself[1], thought /think through	UK AU	10 6
	Individual identity	Importance of fun, relationships, success, lonely, family, children, money, legacy; popularity	CH	11
	Openness to change / outward looking	Traditional attitudes[1], role of children / men / women / mothers / fathers, working mothers, willing to help, trust* in others, assist*, foreign aid, fair / just / equitable	CH US	14 3
Health orientation	Personal wellbeing	Subjective wellbeing, enjoy life	UK CH	1 2
	Life satisfaction	Life satisfaction; satisfaction with health, leisure time, income, family, conditions / circumstances are excellent / ideal / perfect	UK CH AU US	4 2 1 3
	Physical health	Physical health / condition / state / status, illness[1] / ill-health[1] / sickness[1] / infirmity[1]	UK CH AU US	1 1 1 2
	Mental health	Mental health, depressed[1], nervous[1], restless[1], hopeless[1], an effort[1], meaningless[1], down[1], worn out[1], tired[1], full of life, cheer, calm, peaceful, energy, happy	UK CH AU US	1 6 9 2
	Exercise intensity	Vigorous / strenuous / moderate / physical activity* / exercise, walking, cycling	UK AU US	3 2 1
Environmental beliefs	Willingness to change	Environment* / climate AND, willing* to help, changes needed / required, willing* to accept higher prices / taxes / cut, reduction, lower living standards or conditions	UK US	2 3
	Low-carbon efficacy	Environment* / climate change beyond our control[1]; not worth[1]; too difficult[1]	UK US	3 1
	Climate / environmental beliefs	Environment* / climate AND major disaster / impacts, dangerous, crisis / problem*, too far in future[1], warming, temperature / sea level rise	UK US CH	3 1 1
	Engagement with change agencies	Environment* / climate AND, membership, group, organisation, community participation / involvement, volunteer* / donation*, car sharing, car club, donate money / financial support, charity, social donations / gifts	UK CH AU	7 9 4

[1] Scale reversed (i.e., scale directionally consistent with low-carbon lifestyle; country abbreviations: CH (China), UK (United Kingdom), AU (Australia), US (United States of America).

Table 7
Thematic summary of key terms used to identify low-carbon behaviour.

Theme	Key terms	Country code	n items
Mobility low-carbon behaviour: ownership and use (transport modes)	Own* / use AND Hybrid, EV, plug-in, public transport, use car / drive less, walk*; car share / club, fewer flights, frequency of cycle / bike / bicycle, e-bike /subway / bus / motorbike / motorcycle / scooter / e-scooter, taxi, expenditure on car fuel[1], expenditure on public transport	UK	5
		CH	9
		AU	2
		US	1
Food low-carbon behaviour: consumption, source, diet	Frequency of eating: meat[1] / processed meat[1] / fish[1] / poultry[1] / dairy / beans / legumes / pulses eggs / fruit / vegetable* / non-white bread / non-full fat milk, environment* / sustainable purchases, recycling, reduce excess packaging, select recycled packaging, own shopping bags	UK	7
		CH	6
		AU	5
		US	3
Homes low-carbon behaviour: ownership and use (space and energy)	Fit* / installed / seriously considered: solar panels, wind turbine, TV on standby, put lights off, save or saving water / energy, reduce* / lower heating / thermostat, reduce home energy, fuel used: coal / firewood / straw / gas / electricity / methane / solar / biofuel, fuel expenditure per person[1]	UK	7
		CH	1
		AU	1
		US	1

[1] Scale reversed (i.e., scale directionally consistent with low-carbon lifestyle); Abbreviations: CH (China), UK (United Kingdom), AU (Australia), US (United States of America).

Table 8
Thematic summary of key terms used to identify low-carbon lifestyle contexts.

Theme	Sub-theme	Variable description	Country code	n items
Material context	Affordability and wealth	Equivalent / equivalised annual gross income, family / household / income per capita, respondent income, home ownership, own home / dwelling	UK	2
			CH	2
			AU	2
			US	2
	Living conditions	Neighbourhood / community deprivation: (rubbish, vandalism, mugging*, burglary, theft, stolen cars, drunks, graffiti, racial insults)[1], fear / afraid[1], socio-economic homogeneity, social status, neighbourhood satisfaction, number of bedrooms, occupancy rate, dwelling type	UK	9
			CH	3
			AU	4
			US	2
		Urban / rural residence, population / neighbourhood / community size	UK	1
			CH	1
			AU	1
			US	1
	Access to enabling infrastructure	Access internet / Wi-Fi, own OR use desktop pc / computer / laptop / tablet / digital TV / mobile / cell phone, social networking, computer / digital skills, use internet / computer for: study / work / social* / entertainment / shopping / commercial activities / communication / career / emails	UK	10
			CH	8
			AU	7
			US	3
		public transport / bus / train network, waiting time, distance to nearest bus stop / station, community public facilities	UK	1
			CH	3
Social Context	Family and educational capital	Household / family size, number of persons / people in household	UK	1
			CH	1
			AU	1
			US	1
		Educated / education degree level, highest education* qualification, highest year of school completed, years of education	UK	1
			CH	1
			AU	1
			US	1
		Gender (sex), age	UK	2
			CH	2
			AU	2
			US	2
		Number of children / kids, have children / kids, dependent children, age groups	UK	1
			CH	1
			AU	1
			US	1
	Social connectedness	Buckner's Social Cohesion Instrument (Buckner, 1988), relations* neighbours, emotional attachment, community, inter-personal relation*, get along with others, together, friend*, socially, spend time / evening	UK	1
			CH	5
			AU	1
			US	1

[1] scale reversed (i.e., scale directionally consistent with low-carbon lifestyle); Abbreviations: CH (China), UK (United Kingdom), AU (Australia), US (United States of America).

Appendix 1b. Overview of secondary data sources.

The UK Understanding Society (UKUS) is a large longitudinal panel study of UK households, conducted at the University of Essex, UK. Data is collected by annual interviews commencing in 2009 with a clustered and stratified, probability sample of around 24,000 households in Great Britain, and a simple random sample of around 2,000 households in Northern Ireland. The core sample comprises all household members and their

descendants (living in the UK). Four waves of the UKUS were accessed through the UK Data Service (https://www.ukdataservice.ac.uk). Further information on the UKUS sample design and methodology are reported in (Understanding Society, 2021).

The China Family Panel Studies (CFPS) is an annual longitudinal survey of communities, families and individuals residing in China. The survey has been conducted since 2010 by the Institute of Social Science (Institute of Social Science, 2015). Interviews are conducted face-to-face with the aid of computer-assisted personal interviewing technology. All household (economically independent dwelling unit) members older than nine years of aged are interviewed. Households were selected through a stratified three-stage (administrative district/counties; rural villages/urban communities; households) probability-proportional to size random sampling method. We accessed four waves of the CFPS available through https://opendata.pku.edu.cn/. The methodology is further described in Xie and Lu (Xie and Lu, 2015) and Xie and Hu (Xie and Hu, 2014).

The General Social Survey (GSS) conducted in the USA by the National Opinion Research Center (NORC), University of Chicago comprise two studies – a panel study and a cross-sectional study (Smith et al., 2015). The GSS is a nationally representative longitudinal study. Interviews are conducted face-to-face for full-probability samples of individual aged 18+ years living in non-institutional residences. We draw upon GSS Panel data (release 2018) downloaded from https://gss.norc.org/Get-The-Data. Panel interviews were conducted from 2006 to 2014 using a three-wave (four year period) rolling panel design (NORC, 2017); we use data from panel 2010 which began with 2,044 respondents in 2010, 1,551 in 2012, and 1,304 in 2014.

The Australian Household, Income and Labour Dynamics (HILDA) Survey is a longitudinal household-based panel study administered by the Melbourne Institute, The University of Melbourne (Summerfield et al., 2011). All household members (15 years and over) are interviewed annually from a probability sample of private dwellings. This study utilises data for the years 2012, 2016–2019 (n = 17,133; 8,954 households), from HILDA Release 19.0 (Department of Social Services; Melbourne Institute of Applied Economic and Social Research, 2020) accessed through the Australian Data Archive (https://dataverse.ada.edu.au/dataset.xhtml?persistentId=https://doi.org/10.26193/3QRFMZ).

Appendix 2. Demographic representation

Across all countries (apart from USA) our data over represents the age group 50–64 years (see Table 9(a) orange figures) and under-represents the age group 20–34 years (see Table 9(a) blue figures).

Sensitivity testing shows that the age group 20–34 is heterogeneous across the four lifestyle types. Age is a major source of heterogeneity (Pearson chi2(12) = 280.9329; Pr = 0.000). (Table 9(b)).

Age does not directly determine the clusters in our analysis but explains their composition. In Table 1 in the main text, we identity age heterogeneity between lifestyle types based on two distinctive measures (1) mean age and (2) proportion of 18–34 age group. We confirm that 'Active' types are younger based on mean age (51 years) and have the largest proportion of 18–35 age group (16%). 'Constrained' types who have the highest mean age (55 years) also have the lowest proportion of 18–35 age group (9%).

Within China, USA and UK there a very marginal differences in mean income when compared with global/national statistics (see Table 10). Within Australia our sample is over-representative of higher income households see Table 10). Sensitivity testing shows that income remains a major source of heterogeneity between our universal lifestyle types Chi2(3) = 277.8162; Pr = 0.000 (see Table 11).

Table 9a
Population structure comparison, % adult population (Statistica, 2019; Statistica, 2020a; Statistica, 2020b).

age band	China		Australia		USA		UK	
	Statistica (2020a)	This Study	Statistica (2019)	This Study	Statistica (2020b)	This Study	Office for National Statistics (2020)	This Study
20-34y	26.9	**11.3**	29.6	**18.2**	27.3	27.1	25.5	**7.5**
35-49y	28.2	32.0	26.9	27.4	25.0	26.8	24.9	27.0
50-64y	27.3	**37.6**	22.1	**30.7**	25.3	28.6	25.2	**33.6**
65-79y	14.3	17.0	16.1	20.1	17.1	13.9	17.7	**27.4**
80+y	3.3	2.1	5.4	3.5	5.3	3.7	6.6	4.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 9b
Population structure, age.

Lifestyle type		Age group					
		20–34	35–49	50–64	65–79	80+	Total
Resourceful	n	520	1,084	1,135	746	107	3,592
	%	14.48	30.18	31.6	20.77	2.98	100
Active	n	749	1,533	1,637	794	82	4,795
	%	15.62	31.97	34.14	16.56	1.71	100
Constrained	n	399	1,105	1,506	1,056	193	4,259
	%	9.37	25.95	35.36	24.79	4.53	100
Cautious	n	428	838	1,077	758	153	3,254
	%	13.15	25.75	33.1	23.29	4.7	100
Total	n	2,096	4,560	5,355	3,354	535	15,900
	%	13.18	28.68	33.68	21.09	3.36	100

Table 10
Income comparison.

Income	China		Australia		USA		UK	
	World Population Review (World Population Review, 2021)	This Study	World Population Review (World Population Review, 2021)	This Study	World Population Review (World Population Review, 2021)	This Study	Office for National Statistics (Office For National Statistics., 2020)	This Study
	US$		US$		US$		£	£
Mean	4,246	5,117	21,329	46,816	25,332	29,425	23,945	25,362

Appendix 3. Empirical consistency of the four-cluster solution in each country

We further test the four-cluster solution for consistency in cognitive and behavioural profiles in each country. We compare centroid scores across all cognitive and behaviour variables. To enable multi-country comparison, in each country, we partition every variable into three equal terciles (calculated from the distribution). These distinguish between high centroid scores (upper tercile), moderate scores (mid tercile), and low scores (lower tercile). Significant differences in each country are tested using a Scheffe multiple comparison of means test (Field, 2013). Differences and similarities between countries are based on evaluation.

Table 11
Comparison of Centroid Values.

	Resourceful				Active			
Cluster variables	UK	Australia	USA	China	UK	Australia	USA	China
pbc	mod	high	high	mod	mod	mod	high	high
value orientation	high	mod	high	high	high	mod	low	mod
health orientation	mod	high	high	mod	high	high	high	high
environmental beliefs	high	mod	high	high	mod	high	high	low
low-carbon cognitions	high	high	high	high	high	mod	mod	mod
low carbon mobility beh	high	high	high	not sig	mod	low	high	not sig
low carbon food beh	high	high	mod	high	mod	mod	high	mod
low carbon homes beh	mod	high	mod	high	mod	mod	high	mod
low carbon behaviour	high	high	mod	high	mod	mod	high	mod
	Constrained				**Cautious**			
cluster variables	UK	Australia	USA	China	UK	Australia	USA	China
pbc	low	low	low	low	high	mod	mod	mod
value orientation	low	low	mod	low	low	high	mod	mod
health orientation	low	low	low	low	mod	mod	mod	mod
environmental beliefs	low	low	low	low	mod	mod	low	mod
low-carbon cognitions	low	low	low	low	mod	mod	mod	mod
low carbon mobility beh	low	mod	high	not sig	low	mod	low	not sig
low carbon food beh	low	low	mod	low	mod	high	low	mod
low carbon homes beh	not sig	mod	mod	low	not sig	low	low	mod
low carbon behaviour	low	mod	mod	low	mod	low	low	mod

Key to table

high	Denotes mean centroid score is in the upper tercile of the total distribution of cluster variable
mod	Denotes mean centroid score is in the middle tercile
low	Denotes mean centroid score is in the lower tercile
orange shading	Difference is significantly higher
blue shading	Difference is significantly lower

Although there are some differences in individual constructs, we confirm consistency in the four-cluster solution across low-carbon cognitions and low-carbon behaviour for all four countries. 'Resourceful' types have centroid values which are significantly higher (compared to other lifestyle groups). In contrast 'Constrained' types have centroid values which are lower and significant. The 'Active' types tend to be high to moderate, while 'Cautious' types are moderate to low in their centroid values.

Finally, we test for similarity in the profiling of clusters across social and material characteristics. These are reported in the main document (see Section 4.2, Table 6).

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