Supplementary Material I Chapter 5: Social Science Primer

The Supplementary Material for Chapter 5 (Social Science Primer) aims to present multiple fundamental frameworks and concepts that help explain the variety in social aspects of demand-side responses to climate mitigation. It does not aim to resolve any debates about the diversity in perspectives and approaches on this topic in the literature. Instead, its goal is to describe more fully some common concepts and terminologies that are mentioned in this first-ever full chapter (Chapter 5) in an IPCC report on demand-side, energy-service, and social aspects of mitigation. Chapter 5 uses social science perspectives to examine societal level challenges and opportunities for mitigation options that involve end-users, with an eye on policy relevant insights about the drivers, processes, and potential of demand-side solutions. Glossary definitions provide insufficient background information for new concepts used in this IPCC report to present social science perspectives. The Social Science Primer provides the theoretical underpinnings for these concepts, drawing from various social sciences (see also (Creutzig et al. 2018; Hayward and Roy 2019; Jorgenson et al. 2018; Hess and Sovacool 2020)). This primer is not meant to be complete and comprehensive but is an easily accessible short handbook and a living document in the IPCC process.

There has been continuous advancement in the way demand-side choice processes have been viewed and modelled in the IPCC and energy and carbon mitigation policy community. From AR1 to AR4, rational decision making as defined by microeconomics was the implicit assumption, where homogeneous individual agents maximise self focused utility/expected utility, with the only consequential variations of this *homo economicus* relating to income, wealth, risk attitude, and time discount rate (Persky 1995). AR5 (Kunreuther et al. 2014) introduced a broader range of goals that are held by *homo sapiens* (material goals like those of *homo economicus*, but also self- and other-regarding social goals, and psychological goals such as confidence and feeling in control). It also considered a broader range of decision processes (calculation-based but also affect-based, and role- and rule-based processes) designed to allow timely decisions within a context of bounded rationality as the result of attentional and processing limitations. AR5’s perspective on decisions and action, like the rational choice perspective, remained individual- and agency-focused and thus did not explicitly address the role of structural, cultural, and institutional constraints and the pervasive influence of physical and social context beyond simple choice-architecture interventions that modify the context or format in which choice alternatives are presented (Thaler and Sunstein 2003).

AR5 (Kunreuther et al. 2014) reviewed how experts and the general population differ in their responses to risk and uncertain climate information and the importance for experts/scientists/policy makers to understand and predict the public’s reaction in order to communicate climate risks and uncertainties effectively. Its introduction of a broader range of goals and decision processes than those of *homo economicus* has important implications for IPCC scenarios by introducing additional uncertainty about the effects of climate change (e.g., temperature increases or extreme weather) on human behaviour and hence future GHG emissions (Beckage et al. 2018). At the same time, an agency-based framework that includes the many influences on individual decisions that go beyond rational choice and rational expectations (e.g., responses to extreme events, perceived behavioural control, perceived social norms, and social role-based constraints) explains many anomalies observed by social ecologists (Schlüter et al. 2017; Beckage et al. 2018) and generates a broader set of demand-side policy options and more effective ways of implementing them.
This Social Science Primer provides frameworks for understanding the challenges of systemic change, emergent transition phases and patterns, and the drivers of technological choice in light of some of the themes of AR6: assessing growing social inequity, the need for participation in managing the global common good, and the need for increased use of energy and materials to bridge the gap in well-being in some parts of the world while reducing wasteful consumption and production systems in other parts. The societal perspective in Chapter 5 of AR6 very broadly focuses on human society and human agency, where political power structures, infrastructure, and technology interact to deliver services that provide dignified living for all, irrespective of geographic location, which is compatible with cosmopolitan justice theories.

**Modelling and Systematic Review of Demand-Side Mitigation**

Figure SM5.1 on demand-side literature summarises key results of papers in the social science literature with the highest topic score (the topic score measures how well any given paper matches a topic model, vectors of 10 co-occurring keywords, highest amount of references to key social science topics) and/or highest citation count, organised by mitigation sector. It builds on 34 search queries on demand-side climate change mitigation and 99,065 unique papers, which were fed into a machine learning algorithm to identify 60 topic models (vectors of 10 co-occurring keywords) (Creutzig et al. 2021a). Expert judgement identified the 24 topic models most relevant to demand-side climate change mitigation (see also Figure 5.2). In the next step, the key papers from the topic models were summarised, selected from the ten most cited of each topic model with topic score > 0.1 and the 10 with highest topic score. This resulted in a wide array of insights, ranging from the importance of consumption-based carbon footprints, to sectoral interventions, to policy instruments, and the key insight that demand and supply are interdependent and require joint consideration. Figure SM5.1 further condenses these insights into headline statements in a clustered summary.
Demand and Services, in Mitigation Context

Services are activities that help satisfy human wants or needs. While they usually involve interactions between producers and consumers, services are less tangible and less storable than goods, and may involve personal relationships (Arent et al. 2015; Millonig and Haustein 2020). Well-being needs are met through services. Provision of services associated with low-energy demand is a key component of current and future efforts to reduce carbon emissions. Services can be provided in various culturally-appropriate ways, with diverse climate implications. People demand services for dignified survival, sustenance, mobility, communication, comfort and material well-being (Nakićenović et al. 1996; Johansson et al. 2012; Creutzig et al. 2018). Access to services is fundamental, rather than only physical

**Figure SM5.1 Cluster-oriented summary of key demand-side messages drawn from academic publications in social science literature.**

Source: (Creutzig et al. 2021a)
resources (biomass, energy, materials, etc.) and technologies (e.g., cars, appliances). Three key concepts for evaluating the efficiency of service provision systems are: resource cascades and exergy (Grubler et al. 2012) as well as energy (Ugliati et al. 1995). These concepts provide powerful analytical lenses through which to identify and substantially reduce energy and resource waste in service provision systems both for decent living standards (see section 5.3.3 in the main chapter) and higher well-being.

Low-carbon ways of producing the services that are necessary for everyone’s well-being are the foundation of the post-carbon societal transition. Advancing this transition depends not just on progress indicators that measure well-being, equity, and sufficiency in relation to emissions and ecological health, but also on technological innovations and access to them, evolving social norms, policy frameworks, and global networking to share successful ways of building global socioeconomic equity while reducing global emissions. The tight links between equity, well-being for all, and emissions reductions are demonstrated in growing interdisciplinary literatures, (also outlined in AR6 Chapter 5, Section 5.2).

From an economics perspective, for example, expanding concepts of value to include nonmarketed social and ecological factors, unpaid work, care, and informal-sector production makes possible a broader understanding of economic participation and a more inclusive view of economic activity along with its total benefits and costs. Individual and collective choices, including not only what to consume but how best to foster local contexts for well-being are reflected in new literatures on relative provisioning, sufficiency, decent standards of living for all, and the costs of socioeconomic inequality. Sufficiency in economics (also discussed in AR6 Chapter 9 of this report, GEA 2012 Chapter 21 on lifestyles, well-being and energy) expresses the idea that ecological limits necessitate restraint to prevent overconsumption; short and long-term risks including those related to climate change can only be mitigated by going beyond cooperation and efficiency to sufficiency (Princen 2003; Monga 2012; Bierwirth and Thomas 2019; Fawcett and Darby 2019; Monyei et al. 2019; Hayward and Roy 2019). Depending on policy contexts, and with wide variations in the literature on methods, assumptions, and data, behavioural changes that reduce energy consumption can lead to rebound and spillover effects that can partially counter the benefits, reinforce them, or enhance welfare (Chakravarty et al. 2013; Brockway et al. 2017; Van Lange et al. 2018; Rogelj et al. 2018; Shao et al. 2019; Vita et al. 2019b; Yan et al. 2019; Court and Sorrell 2020; Sorrell et al. 2020; Saunders et al. 2021). For example, policies are more successful in minimizing rebounds, reducing emissions and increasing welfare when they consider the step-wise interactions among invention and diffusion of energy-efficient low-carbon technologies, changing social norms, infrastructures, and institutional transformation (van den Bergh 2010; Roy et al. 2013a; Safarzadeh et al. 2020; Perrot and Sanni 2018; Vivanco et al. 2018; Pigato et al. 2020; Frei e-González 2021). Intersectional inequities related to geography, gender, race, Indigeneity, ethnicity and other factors interrupt the fair distribution of income, resources, energy access and emissions, restricting the margin of manoeuvre for climate action and the urgency of operationalising sufficiency norms. One way to foster this is through multi-dimensional affordability, which includes not only economic affordability but also social, motivational, and institutional/environmental affordability, as part of consumption choice processes—all influenced by policies (Spangenberg and Lorek 2019). Information for consumers, communities and policy-makers about the equity and emissions implications of their decisions, such as that provided by the Ecological Footprint (Kopp and Dorn 2018; Lin et al. 2018; Yunani et al. 2020) and the Carbon Footprint (Wiedmann and Minx 2008), can facilitate multi-dimensional choice processes (Beattie and Sale 2009; González-Garcia et al. 2018; Wood et al. 2020).

Empirical social sciences research is addressing earlier discrepancies in methods and challenges in estimating these indicators across global supply chains, income levels, energy technologies, time.

Decent Living Standards (DLS), as described further below, is another way to express the socio-political goal of prioritising necessities over luxuries while limiting emissions (Darby 2007; Gorge et al. 2014; Rao and Pachauri 2017; Otto et al. 2019; Rao et al. 2019; Millward-Hopkins et al. 2020). Like the early footprint indicators, DLS omits intermediate service provision and some important components of well-being such as collective, land-based cultural values (Ikuenobe 2016; Bullock et al. 2018; Choy 2018; Richardson et al. 2019; Raymond et al. 2019) in its focus on material prerequisites of well-being (Rao and Min 2018). Socially-determined and contextual measures of value and individual/collective well-being also interrelate with social norms regarding acceptable or expected consumption levels, as shown in Figure SM5.2. This has implications for emissions, since appropriate modes of service provision within different cultural contexts, and in situations of changing social norms and preferences, can facilitate the effective decoupling of service provision from energy use (Jackson 2005; Akenji 2014; Komiyama 2014; Brand-Correa and Steinberger 2017; Mastrucci and Rao 2017; O’Neill et al. 2018; Rao and Min 2018a; Mastrucci and Rao 2019; Vita et al. 2019a, 2020; Wiedenhofer et al. 2020).

There are multiple components of systemic change, and one way to dynamically represent change in the demand for GHG-emission-intensive products and services is to map it across the key concepts of agency, structure, meaning, relations, and norms (Sovacool and Hess 2017, Hess and Sovacool 2020). This involves the potential of individuals to change their consumption patterns and to act collectively in driving institutional change (agency), the redesign of infrastructures and technologies to foster low-carbon consumption patterns (structure), and the (re)establishment of cultures and social norms in alignment with consumption patterns that have few associated GHG emissions (meaning). Even a broad

![Figure SM5.2 The relationships among indicators of Decent Living Standards, Well-being, Footprints, Sufficiency and the Sustainable Development Goals](image-url)

Demand-side contributions to mitigation allow consumers/users to select the best way to further their own well-being, making trade-offs across sectors and technologies as best suits their needs and contexts (Creutzig et al. 2021b).
set of individual-based decision factors accounts at best for 30-40% of the variance in climate action, suggesting that behavioural change is not only a function of individual agency but also depends on other enabling factors, such as infrastructures, social norms, and professional roles (Bamberg et al. 2007b; Whitmarsh et al. 2017). Chapter 5 reflects this more inclusive view of different disciplinary and philosophical perspectives on individual and collective energy decisions (Grubb 2014; Riahi et al. 2015; Grubler et al. 2018; Mundaca et al. 2019; Creutzig et al. 2016, 2018). It broadens the individually focused agency framework of micro- and behavioural economics and psychology by also including considerations of structure and meaning, i.e., the hardware and software of the social, cultural, and physical context studied by disciplines like geography, ecology, sociology, urban planning, and anthropology.

Disciplines vary in their approaches and research questions on demand-side issues. For example, psychologists and behavioural economists focus on emotional factors and cognitive biases in decision making (Poortinga et al. 2019; Mills and Schleich 2012; Niamir et al. 2020a; Bamberg et al. 2007a); economists elaborate on how, under rational decision-making, carbon pricing and other fiscal instruments can trigger change in demand (Ameli and Brandt 2015) and help transitions to low carbon futures (Roy et al. 2013b); normative economics focuses on enabling conditions for sustainable human development; sociologists emphasise every-day practices, structural issues, and socio-economic inequality; anthropologists address the role of culture in energy consumption; urban planners take the role of infrastructures as an entry point; and studies in technological innovation consider socio-technical transitions and the norms, rules and pace of adoption that support dominant technologies. Political scientists consider the roles of ideology, democracy, institutions, and politics in shaping societal transformation. Generally, social sciences share a focus on interpersonal and collective outcomes—how people shape their cultures and livelihoods together across gender and intersectional markers of identity and difference (Woodward and Woodward 2015; Buchanan et al. 2020; Sawyer et al. 2020). Social practice theory emphasises interactions between artefacts, competences, and cultural meanings (Shove and Walker 2014; Røpke 2009). The energy cultures framework highlights feedbacks between materials, norms, and behavioural practices (Stephenson et al. 2015; Jürisoo et al. 2019). Socio-technical transitions theory addresses interactions between technologies, user practices, cultural meanings, business, infrastructures, and public policies (McMeekin and Southerton 2012; Geels et al. 2017a) and thus accommodates the five drivers of change and stability discussed in Section 5.4 and 5.5 in chapter 5 of WGIII of AR6.

This primer provides additional information about key concepts and processes described in AR6 Chapter 5. Section SM5.1 elaborates on key concepts from Section 5.2 of Chapter 5: well-being, equity, and decent living standards (DLS) and their relation to equity, social trust, and governance. Sections SM2-4 then provide background information on the five drivers of change introduced in Section 5.4 of Chapter 5, divided into the three categories shown in: Individual concepts and processes provide background on the behavioural drivers of change; social concepts and processes elaborate on the socio-cultural drivers of change; and structure elaborates on the business, technology, and institutional drivers of change (see (United Nations Environment Programme 2020)) (Figure SM5.3). Section SM5.5 provides additional background on transitions and Section SM5.6 provides several case studies as illustrative examples drawn from both developed and developing countries of social processes in various contexts of technology uptake, service provisioning and shifts in choices.
Figure SM5.3 Drivers of change: Perspectives and underlying concepts and processes

SM 5.1 Well-being, decent living standards, equity, and the SDGs

Well-being for all is a cornerstone of sustainable development (Dasgupta and Dasgupta 2017; Princen 2003) and directly underpins the Sustainable Development Goals (SDGs). A focus on human well-being improves upon GDP, which is an inadequate and incomplete goal for socio-economic activities (Faber et al. 2012; Zimmerer 2012; Arrow et al. 2013; Dasgupta 2013; Griggs et al. 2013; Hobson 2013; Dasgupta 2014; Gabriel and Bond 2019; Hayward and Roy 2019; McGregor and Pouw 2017; Sekulova et al. 2017; Fioramonti et al. 2019; Perkins 2019; Pollin 2019; Women’s Budget Group 2020). All of this literature shows that, above a certain income threshold, further increases do not produce greater well-being; it is well-being that should be pursued, rather than economic growth. Human well-being is a description of the state of individuals’ life situations in multiple dimensions that captures their life circumstances (Mcgillivray and Clarke 2006). Constituents of well-being include health, happiness, meaningful work and social relationships, freedom and liberty, while determinants are the inputs that enable well-being such as food, shelter, water, access to knowledge and information (Dasgupta 2001).

A well-being focus emphasises equity and universal needs satisfaction within planetary boundaries, compatible with SDG progress (Lamb and Steinberger 2017). GDP growth still dominates the current economic development literature, including the assumptions that ecosystem limits can always be overcome via production technologies and that welfare is predominantly associated with increased levels of consumption of products and services (Roy et al. 2012). However, GDP only measures economic activity with no reference to material limits, neglecting inequality and services delivered by current capital stocks (Haberl et al. 2019); it is therefore, a poor proxy for societal well-being (Ward et al. 2016). Instead, several new indices have emerged to measure well-being (i.e. Human Development Index, OECD better life initiative, QoL Index, Gallup Health, Well-Being Index, Gross National Happiness, Happy Planet Index). Applying a single measure represents a challenge due to the lack of data on many components of well-being (Sugiawan and Managi 2019). Measures such as inclusive wealth (the sum of capital assets that form the productive base of an economy) have been proposed as economic indicators to replace GDP for measuring well-being (Dasgupta et al. 2015; UNEP 2018;
Another measure for considering aspects of social progress beyond economic activity is the social progress index (SPI), a composite index based on a dashboard of outcome-oriented indicators of fulfilment of basic human needs and foundations of well-being (Haberl et al. 2019), considering opportunities such as nutrition, shelter, water, safety, access to knowledge and information, health, education, freedom, rights and environmental quality.

All of these considerations have been fully or partially reflected in the United Nation’s Sustainable Development Goals (SDGs) -- politically agreed-upon goals for human well-being and planetary stability for the year 2030.

Decent Living Standards (DLS) is a tool for assessing well-being for all in terms of needs satisfiers. It is defined as the minimum set of inputs required for a decent human livelihood, anywhere in the world (Doyal and Gough 1991; Neri 2002; Adema 2006; Antóny and Visweswara Rao 2007; Saramet 2007; Acs and Turner 2008; Rao and Baer 2012; Frye 2013; Saramet et al. 2009; Rao and Min 2018b; Brand-Correa and Steinberger 2017) (see also SR6, Chapter 9.1). Services which make up DLS include adequate nutrition, shelter, hygiene, clothing, healthcare, mobility, education, communication, and information access. DLS goes beyond existing multidimensional poverty indicators which set a floor for human needs, by addressing living conditions and social participation -- thus including social as well as individual components of well-being. It also offers a normative basis to assess environmental impacts and climate change (Rao and Min 2018b). DLS is based on human needs theory, which argues that material dimensions of well-being correlate with needs satisfaction, but only up to a threshold, after which additional use of needs satisfiers does not result in significant improvements in needs satisfaction (Frank 2010; Stiglitz 2012; Oishi et al. 2018; Xie et al. 2018; Wilkinson and Pickett 2009, 2019a; Doyal and Gough 1991). It is also closely related to eudaimonic well-being approaches focused on realising human potential, not just seeking pleasure and avoiding pain (Lamb and Steinberger 2017).

Equity. Equal, ‘impartial’ treatment does not always produce equitable outcomes, since different members of society face diverse barriers that influence their opportunities, choices, responsibilities, political agency and access to justice among other factors. These variances are particularly important for climate mitigation, especially demand side, socia, and service-oriented mitigation approaches (Estrada-Oyuela 2000).

Mitigation, equity and well-being go hand in hand (see Box 5.2 and Figure 5.5) Both distributive justice and procedural justice are important in mitigation action (Roy et al. 2018a). As outlined in AR6 section 5.2, the social science literature includes strong consensus about a number of mutually-reinforcing relationships among well-being, social equity, social trust, and effective governance for managing energy transition and rapid emissions reductions.

Well-being is reinforced in equitable societies. Human well-being is socially-based and has a large relational component (Yellowfly 1992; Ball and Chernova 2008; D’Ambrosio and Frick 2012; Diener et al. 2013; McCubbin et al. 2013; Shields 2016; White 2017; Stone et al. 2018; Tu and Hsee 2018; Easterlin et al. 2010; Schneider 2016; Lamb and Steinberger 2017; Wang et al. 2019). Once subsistence needs are met, relative well-being is much more significant for human happiness than absolute consumption levels (Wilkinson and Pickett 2009; Frank 1999; Stiglitz 2012; Reyes-Garcia et al. 2016; Oishi et al. 2018; Xie et al. 2018; Wilkinson and Pickett 2019), and the higher the income inequality, the more people compare themselves with their neighbours (Luttmer 2005; Cheung and Lucas 2016).

Income inequality is associated with lower well-being, not only of the poor, but of everyone (Wilkinson 2005; Wilkinson et al. 2010; Cooper et al. 2014; Schröder 2018; Reyes-Garcia et al. 2016). Some social components of well-being, such as community cohesion, social capital, and trust, are higher in more equitable societies (Delhey and Dragolov 2014; Roser et al. 2019; Schneider 2016). While differences in study indicators and methodologies complicate conclusions about the link between well-being and income, this shifts emphasis onto contextual social factors such as people’s knowledge, values, norms
and beliefs (Kragten and Røzer 2017; Schneider 2016; Ngamaba et al. 2018). More equitable societies are also more economically efficient societies (Singer 2018; Stiglitz 2012; Wilkinson and Pickett 2009).

**More social trust leads to equity and vice versa.** There is a well-documented correlation between social trust and income equality (Rothstein and Uslaner 2005; Jordahl 2011; Phan 2008; You 2012; Ivarsflaten and Strømsnes 2013; Bergh and Bjørnskov 2014). Trust is associated with greater human development ( Özcan and Bjørnskov 2011) and with individual and country-level happiness (Tokuda et al. 2017) and life satisfaction (Mikucka et al. 2017). Social trust and trust in government institutions reduce well-being inequality and foster resilience, especially for those at lower levels of well-being (Nannestad et al. 2014; Helliwell et al. 2016).

**Equity strengthens governance.** Institutions work more fairly, with more public trust. Equitable income, wealth distribution, and tax policies make democracies stronger and more flexible (Sturm 2007; Steijn and Lancee 2011; Levin-Waldman 2012; Yamamura 2014; Lazarus and van Asselt 2018; Okereke 2018; Di Gregorio et al. 2019; Jordahl 2011; Stiglitz 2012; You 2012).

**Effective governance fosters well-being for all.** There is strong evidence across many countries that government quality indicated by quality of service delivery and quality of democracy is linked to national happiness, mainly because effective governance implies better service delivery (Helliwell and Huang 2008; Ott 2011; Helliwell et al. 2018). Democratic satisfaction and social trust embedded in impartial, fair, and efficient institutions are also linked directly with well-being (Rothstein and Stolle 2008; Orviska et al. 2014). Democratic governance alone, however, does not always lead to reduced wealth inequality or vice versa; voter preferences, social cleavages, and/or democratic capture by the rich can perpetuate inequalities even in democracies (Acemoglu et al. 2013; Scheve and Stasavage 2017).

**SM 5.2 Individual perspectives**

**SM 5.2.1 Agency**

Agency is defined as the capacity to act, both individually and collectively, as shaped by different physical, social, historical, cultural, and other contexts. Using their agency, people engage in existing social practices, and also may step outside routines and engage in new behaviours. Agency is realised through different social roles for action, which include as citizen, role model, community member, worker, investor, professional, household member, consumer, etc. In the demand-side mitigation options space, agency is expressed by actors (individuals and households) who differ in motivations and goals, and in their capacities for change as shaped by different physical, social, historical, and cultural contexts.

**SM 5.2.2 Behaviour change**

Decisions or action that directly or indirectly reduce energy demand can be motivated by market- and non-market forces, and can be either legally vs. socially vs. ethically binding. It has long been thought useful to conceive of consumers as “rational actors,” attentive to incentives, including all relevant costs and benefits (Becker 2013). If the price of certain goods increases, people will buy less of them. Under this framework, moral commitments, and social norms, may or may not matter (Becker and Murphy 2000). If they do, it is because violations of a social norm operate as a kind of “tax”, leading a consumers to take steps to avoid such violations. The large point is that demand-side behaviour is above all reflection of what consumers perceive as costs and benefits. If, for example, consumers believe that it
is in their interest to engage in consumption patterns that lead to a high-carbon economy, then a high-carbon economy is much more likely.

A transition to a low-carbon economy will require a significant shift in incentives. This understanding of consumer behaviour has clear implications for policy – suggesting, for example, that appropriate taxes or subsidies can lead to major reductions in greenhouse gas emissions. But focusing solely on material incentives misses important features of human judgment and decision making (Kahneman 2011; Thaler 2015), with relevant implications for environmental policy (Sunstein and Reisch 2014; Creutzig et al. 2016). For example, people may show “status quo bias,” which means that they might continue to do what they have been doing, even if it would be in their interest to change (Samuelson and Zeckhauser 1988). Consumers may show “present bias,” in the sense that they might focus on the short-term, even if it would be in their interest to consider the long-term (O’Donoghue and Rabin 2015). Whether consumers are responsive to material incentives depends on whether those incentives are made salient (Gabaix and Laibson 2018). Some characteristics of activities and products are “shrouded,” even though they matter to consumer’s well-being, and consumer may not pay a great deal of attention to them. In addition, norms matter, and can greatly affect behaviour (Lessig 1995).

To influence consumer demand, policymakers have an assortment of tools, including prohibitions, mandates, taxes, fees, subsidies, and “nudges” (Thaler and Sunstein 2009), defined to include such choice-preserving interventions as information, warnings, reminders, uses of social norms, and default rules such as automatic enrolment in “green energy” in the form of wind or solar (Ebeling and Lotz 2015). It would make little sense to say, in the abstract, that one tool is better than another; the choice of tool depends on its effects on well-being in the relevant context. In principle, a carbon tax has many advantages over any other approach, because it forces consumers to bear the cost of their activities (Nordhaus 2013). But automatic enrolment in green energy might be a useful complement to a carbon tax, especially if that tax is too low. Responses and actions by relevant actors interact in complex ways that differ from the more linear integration in conventional (integrated assessment) models or macroeconomic computable general equilibrium models. Novel ways of capturing these influences and feedback processes (Stern 2016; Niamir et al. 2018, 2020b; Constantino et al. 2021) that include complex adaptive systems models (Levin et al. 2013) or agent-based models (Lamperti et al. 2018) allow for emergence of tipping points or other nonlinear change dynamics that may be necessary to bring about behaviour change on energy at the speed and scale required (Nyborg et al. 2016). Correctly understanding the roles, goals, and needs of these different actors, their perceptions and decision processes (Kunreuther et al. 2014), and the feedback between their actions is imperative in designing effective policies and decision support systems (Roelich and Giesekam 2019).

**SM 5.2.3 Consumer decisions**

On a global scale, households influence, directly and indirectly, 72% of GHG emissions (Hertwich and Peters 2009; Roy et al. 2012). Energy use is disproportionately dominated by electricity in developed countries, and most cities in the developing countries, whereas non electric cooking fuels constitute the largest share of energy use in rural areas of developing countries; energy use for mobility is significant and rising most rapidly (Ahmad et al. 2015). Demand-side solutions require both the motivation to change and the capacity for change, in the form of availability and knowledge about change options and the resources to consider, initiate and maintain change. Existing willingness to change (to lower carbon sources of energy (Shift) or energy efficient devices (Improve) or to reduce energy use (Avoid)) is motivated by different factors in different demographics and geographies. For some, perceptions of climate risks and concerns about the environment and future generations trigger action. For others, prices drive energy decisions and subsidies of carbon energy can be problematic, as they set up cultural
norms and individual habits, a path-dependence of sorts that requires additional interventions to be overcome. Individuals’ perceptions of climate risks, first covered in AR5, continue to be studied as a perhaps necessary if not sufficient condition for behaviour change.

**Core Human Values.** Social change is a complex process that tries to integrate value and interest of people. Much of human behaviour is goal directed and core values reflect the general goals that people strive for. Four classes of values are most relevant to understand climate actions, and people differ in the extent to which they hold these values and goals: hedonic values (with the goal to seek pleasure, convenience and comfort), egoistic values (with the goal to safeguard personal resources), altruistic values (with the goal to protect the well-being of other people) and biospheric values (with the goal to protect nature and the environment (Steg et al. 2014).

Group differences in climate risk perception and motivation to act suggest the need for segmentation in information or climate action campaigns, with age, education, core values, political ideology, and personal experience being important segmentation variables. Such segmentation is not always easily accomplished; however, information relevant for different segments (e.g., metrics that allow individuals reduce their energy consumption for different reasons) can be provided in the same display. The fuel-economy sticker issued by the US Environmental Protection Agency in 2013 displays a car’s energy requirements in monetary terms for buyers interested in financial savings, in technical terms for buyers interested in car performance, or in GHG ratings for buyers interested in climate impacts. These multiple ratings are almost perfectly correlated and their high-density display on a single label could be seen as confusing. However, consumers selectively attend to the information that conforms to their motivation (Ungemach et al. 2017). The full EPA fuel-economy label resulted in the highest willingness-to-pay for fuel economy, suggesting that duplication of information in slightly different formats is a communication asset rather than liability (Kormos and Sussman 2018).

Professional actors play important roles in climate mitigation. Working as building managers, landlords, energy efficiency advisers, technology installers and car dealers, they influence patterns of mobility and energy consumption (Shove 2003) by acting as ‘middle actors’ (Janda and Parag 2013; Parag and Janda 2014) or ‘intermediaries’ in the provision of building or mobility services (Grandclément et al. 2015; De Rubens et al. 2018). As influencers on the process of diffusion of innovations (Rogers 2003), professionals can enable or obstruct improvements in efficient service provision or shifts towards low-carbon technologies (LCTs) (e.g. air and ground source heat pumps, solar hot water, underfloor heating, programmable thermostats, and mechanical ventilation with heat recovery) and mobility (e.g. electric vehicles) technologies.

**SM 5.3 Social perspectives**

**SM 5.3.1 Lifestyles**

‘Lifestyle’ means a coherent pattern of behaviours and cognitions consistent with certain situational factors (Axsen et al. 2012; Hedlund-de Witt 2012). Behaviours include actions, activities, technology adoption, and consumption choices. Cognitions include values, worldviews, concerns and beliefs. Lifestyles typically apply to individuals, but can also be used to describe households. Lifestyles also depend on situational factors, which shape the accessibility of certain behaviours or the achievability of certain cognitive goals. Geography, infrastructure, and culture are all examples of situational factors relevant to lifestyles. Behaviours, cognitions and situational factors are common elements of lifestyle, but are emphasised differently depending on the perspective taken. Three common perspectives emphasise patterned behaviour, cognitive direction, or reflexive identity.
A patterned view sees lifestyle as manifest in routine, habitual patterns of behaviour (Darnton et al. 2011). These behavioural patterns are situational, in that they may vary between home, work, travel, leisure and other domains of everyday life (Barr et al. 2011). This patterned view lends itself to the identification of lifestyles through consumption activity and other observable behaviours (Schipper 1989). Put simply, lifestyle describes “how people spend their money and their time” (Mowen and Minor 1998).

A cognitive view similarly sees lifestyle as a regular pattern of behaviour, but rather than being primarily situational, it is led by intentions and so is directed towards an overarching goal (Jensen 2009). Intentions can be antecedent to specific choices such as where to live (Frenkel et al. 2013), or can be linked to broader cognitive constructs such as values or worldviews (Hedlund-de Wit 2012). This cognitive view is consistent with the idea of individuals pursuing a ‘low-carbon lifestyle’ to reduce their impact on climate change.

A reflexive view sees lifestyle as a way for individuals to organise and express their self-identity through their behaviour, while the behaviours then reflexively help constitute an individual’s identity. This reflexive view is associated with the work of the sociologist, Anthony Giddens, who defined lifestyles as “routines that include the presentation of self, consumption, interaction and setting” (Giddens 1991).

Despite differences in emphasis, all three of these views recognise that lifestyle is shaped by context and so is both dynamic and plural. As examples, lifestyles change when people migrate from the countryside into cities (Chen et al. 2019), or when there is easier access to certain infrastructures like bike lanes or bus routes (Etminani-Ghasrodashti et al. 2018).

In the context of climate change, lifestyle is used both descriptively to identify clusters of low-carbon behaviours and quantify their emissions impact, and normatively to explore individuals’ efforts to reduce their carbon footprint. As lifestyles are situational as well as behavioural and cognitive, these efforts can be strongly shaped by public policy and infrastructure. In all these applications, lifestyle can sometimes be used interchangeably with behaviour. This is not appropriate as behaviours are discrete actions, whereas lifestyles comprise coherent sets of actions linked in a consistent way to cognitions and identity (Lawson and Todd 2002).

Lifestyles can be identified and measured using both qualitative and quantitative methods. Qualitative methods explore self-identity, situational influences, and the dynamics of how lifestyles are expressed. Common qualitative methods used to research lifestyles include interviews (Barr et al. 2011) and narratives (Hagbert and Bradley 2017). Quantitative methods link lifestyles to outcomes and impacts, and identify segments and variation in a population. Common quantitative methods include cluster analysis, factor analysis (Kuan et al. 2019), hierarchical tree analysis (Baiocchi et al. 2015), and decision tree analysis (Le Gallic et al. 2018). These methods identify groups of individuals, who share similar sets of cognitions and behaviours in certain contexts. Quantitative methods are commonly applied to survey datasets, which combine information on behaviours with self-reported cognitions. Examples of datasets include national social surveys, household expenditure surveys, and time use surveys. These allow lifestyle groups or types to be identified in a population, and linked to sociodemographic, geographic or other widely-available indicators. For example, a recent study in France used census, housing, travel and household budget surveys to identify lifestyles grouped along eight dimensions: cohabitation, relationship with technology, mobility practices, attitude to work, dwelling location, living standard, leisure practices and demographics (Millot et al. 2018).
Measuring lifestyles is useful for different reasons. First, lifestyles can be tested as predictors or explanations of an outcome of interest such as risk of dementia (Lourida et al. 2019), food preferences (Nie and Zepeda 2011), or propensity to buy an electric vehicle (Axsen et al. 2012). The outcome of interest varies widely across research fields. Second, lifestyles can descriptively characterise common patterns of behaviour in specific domains or ‘sites of practice’ like shopping, food, domestic living, or energy and water consumption (Barr and Gilg 2006). This allows the relationship between lifestyles and situational factors to be explored in more depth. Third, lifestyles can explain variation between households in a population. This captures an important dimension of heterogeneity which can then be applied in modelling and scenario studies of how lifestyles may change into the future (Van den Berg et al. 2019; Le Gallic et al. 2018). Fourth, lifestyles can also explain variation between populations in different countries or cultures. Data from the periodic World Values Survey reveals systematic differences in lifestyles between regions with certain cultural characteristics such as pragmatism or respect for tradition. Variation can also be situational. For example, housing-related lifestyles were found to be similar across different European countries whereas food-related lifestyles were not (Thøgersen 2017a, 2018).

Pro-environmental, green, sustainable, or ‘low-carbon’ lifestyles have two different interpretations, one defined by intention and the other by impact (Van den Berg et al. 2019). Emphasising intentions, a green lifestyle has been defined as “a collection of practices by which people today try to address an interrelated set of environmental problems” (Lorenzen 2012). Applied to climate change, ‘low-carbon’ lifestyles can be identified by the values, intentions or goals of individuals seeking to reduce their carbon footprint. In their second interpretation, low-carbon lifestyles can also refer to low levels of use of energy and other materials or other consumption-based reductions in greenhouse gas emissions (Le Gallic et al. 2018), which may not reflect choices but constraints.

These two interpretations of low-carbon lifestyles can be in tension as low-carbon intentions do not always translate into low-carbon impacts (e.g., a globetrotting IPCC scientist), and low-carbon impacts may not be the result of low-carbon intentions (e.g., a low-income household living in fuel poverty). Such tensions between cognitions, behaviours and impacts on emissions are almost always evident in population-level analyses of low-carbon lifestyles. This reinforces that lifestyles are situational as well as cognitive and behavioural, and that lifestyles are multiple and reflexively constructed so can never offer a single unifying explanation for an individual's impact on emissions.

Research focused on very specific low-carbon lifestyle groups characterised by self-sufficiency, frugality or voluntary simplicity can avoid these tensions between intention and impact (Lorenzen 2012; Hagbert and Bradley 2017). Here the challenge is in scaling or replicating this type of intentional low-carbon lifestyle more widely. Conversely, research focused on resource-efficient consumption across the population as a whole is more widely applicable but is also more uncertain and contingent in terms of its emissions impact (Vita et al. 2019b). Low-carbon lifestyles can be defined broadly or situationally. Studies taking a broad view seek to generalise low-carbon lifestyles that are consistent across multiple domains of everyday life. Such studies inform social marketing and educational campaigns to encourage more sustainable lifestyles (DEFRA 2011; Darnton et al. 2011). Other studies test whether low-carbon lifestyles are generalisable explanations for technology adoption decisions in multiple domains, such as electric vehicles, solar panels and green electricity tariffs (Axsen et al. 2012). Recognising the importance of situational factors, many studies focus on low-carbon lifestyles in a specific domain of resource-intensive activity. This includes domestic energy use and waste generation (Tudor et al. 2016), dwelling location and type (Thøgersen 2017b; Frenkel et al. 2013), mobility and travel (Lanzendorf 2002; Thøgersen 2018), leisure and tourism (Barr et al. 2011), and food (Hur et al. 2010; Thøgersen 2017a). Some studies find that much of the variation in energy or resource consumption can be explained by domain-specific lifestyle factors (Sanquist et al. 2012). However, it is hard to generalise...
insights across domains as relationships between low-carbon lifestyles and emissions tend to be heterogeneous as well as situational or context-dependent.

In addition to heterogeneity and the tension between intention and impact, a third limitation of low-carbon lifestyles research is its concentration in technophile and/or environmentally-conscious population segments in the global North. Available studies in emerging economies tend to place less emphasis on intentions, and more emphasis on demographic, social or institutional factors which shape emissions-intensive lifestyles such as migration from countryside to cities (Chen et al. 2019) or literacy, theft and corruption (George-Ufot et al. 2017).

The 'consumer lifestyle approach' assigns upstream or indirect emissions to the final consumption of energy, materials, food or other resources by individuals and households (Ding et al. 2017; Chen et al. 2019). Similar to consumption-based accounting, this approach typically finds that over three quarters of emissions are attributable to the consumption activities which constitute lifestyles (Bin and Dowlatabadi 2005). Lifestyle change is therefore a potential means of delivering significant emission reductions.

Scenario and modelling studies confirm this potential by taking examples of low carbon behaviours and scaling them up to the population level to determine aggregate system outcomes (van Sluisveld et al. 2016; Van Vuuren et al. 2018). Common examples of low-carbon behaviours amenable to modelling analysis include reducing meat in diets, substituting driving for active travel modes or public transport, and turning thermostats down. Scenario narratives that describe why such behaviours become more common tend to emphasise the spread of green values, environmental consciousness, or awareness of climate risks. This implies an intentional understanding of lifestyle change, and deemphasises the influence of situational factors.

Differences underlying lifestyle choices influence efforts to meet targets for emissions reduction. A combined assessment of costs, lifestyles and technologies in France up to the year 2072 showed that an individualistic lifestyle with high take-up of digital technologies led to increased GDP but not carbon neutrality, in contrast to a society characterised by more collective lifestyles that resulted in less growth but greater emissions reductions (Millot et al. 2018). Voluntary lifestyle change typically focuses on relatively low impact behaviours (e.g. switching off lights at home, recycling) in a piecemeal manner instead of high impact behaviours (e.g. adopting a low meat diet or long-haul flights (Nash et al. 2019; Dubois et al. 2019). Changes in social, technological or demographic factors can also be enshrined in scenario narratives of future lifestyle change. Examples include a shift in consumption culture from owning goods to using services including through sharing economies (Vita et al. 2019b), and a demographic shift from rural to urban, from physical to virtual work, and from analogue to digital (Millot et al. 2018; Le Gallic et al. 2018). Such studies in the controlled environment of a simulation model show significant emission reduction potentials from low-carbon lifestyle change. This is not just limited to the direct impact of lifestyle change on emissions, but also to the indirect impact of reducing the speed of required transformation upstream in energy and land-use systems (Grubler et al. 2018).

Turning scenarios into reality is inevitably more complex and contingent. There is good evidence that interventions targeting specific behaviours can be effective, particularly if they combine different mechanisms such as price, norms, information, competences, and infrastructure (Stern et al. 2016). Robust principles for designing effective interventions for low-carbon behaviour change also benefit from a large body of evidence from public health (Michie et al. 2011). However interventions targeting low-carbon lifestyles in general rather than specific low-carbon behaviours are harder to define beyond general informational, educational, and marketing strategies (Haq et al. 2008). The signal of low-carbon
lifestyle change is also difficult to detect amidst the noise of a continually changing technological, social and demographic landscape. This is particularly the case in emerging economies with rapidly changing income distributions, urban settlements, and living standards (Hubacek et al. 2007; Chen et al. 2019).

SM 5.3.2 Education

Modifying climate change awareness and perception help the dynamics of this radical shift (Halady and Rao 2010; Dombrowski et al. 2016; Odjugo and Owuyowioro 2013; Niamir et al. 2020a). This requires a complete remodelling of educational methods, where the barriers to be tackled include not only a lack of funding, but the conservative environment of the educational system itself (Ferrer-Balas et al. 2009; Fisher and McAdams 2015; Velazquez et al. 2006; Leal Filho et al. 2018).

Traditional education is still structured on mercantilist and neoliberal ideologies and delivered in politicised educational institutions where environmental issues are invisible most of the time (Mendoza and Roa 2014). This situation calls for a move away from this commercial, individualised and entrepreneurial training model towards the commitment to education for solidarity and care that was highlighted by (Anderson et al. 2019) in the specific context of food, but that can be applied to the climate crisis. Even if the role of universities in climate change education has been acknowledged as extremely important there is few investment to embed climate change education in a higher education context. When achieved, there is a variety of approaches and it is difficult to identify a clear pattern at the country or even university level (Molthan-Hill et al. 2019). This is why there is a need to achieve or/and reinforce a culture of climate awareness through new educational forms based on a convergence between education and communication (ducommunication) (Rodrigo-Cano et al. 2019) could be used as a base for action and social and environmental intervention unlike communication and disinformation campaigns that use the environment to convey a commercial message (Delmas and Burbano 2011; Megias-Delagado et al. 2018).

SM 5.3.3 Religion

As a central component of many cultures, religion interacts with climate change in numerous and diverse ways (Jenkins et al. 2018). Some religious identities are associated with the denial of climate change, notably White US Evangelical Christians (Smith and Leiserowitz 2013), even though the situation may differ in other countries, for example in Sweden, where Evangelic Christians rather support progressive climate policies (Björnberg et al. 2017). Different religions interpret climate change in different ways, but nearly all contain elements related to the protection of divine creation, including the environment. Faith groups are both social institutions and sites of action on climate change (Haluza-DeLay 2014). They can draw on shared symbols, identities and narratives to promote collective action on climate change (Bomberg and Hague 2018; Roy et al. 2012). Pope Francis’ encyclical (2015) reframes climate action from being an economic and technological issue to one of moral stewardship of public goods. Understanding religion helps in understanding attitude towards climate change across communities and traditions (Jenkins et al. 2018). However, further research is required to capture the heterogeneous practices of diverse faith groups globally in relation to climate mitigation (Haluza-DeLay 2014).

Religious groups can communicate with social groups not necessarily involved in climate change action. However, most educational programs that train clergy remain silent on climate change or ecological issues; in North America only 24% of program included instructions (Heistein et al. 2017). Joint programs between academia and clergy has potential to bring climate action to communities that otherwise lack resources to interact with non-subistence issues and to connect climate change mitigation with local contexts.
SM 5.3.4 Civil society, NGOs, and social movements

People, governed by values and social norms, make individual decisions on how to live, eat, travel, etc.: what they need in life, why and how they need it, and (within their means) what forms of consumption they choose. Collectively, the same values and social norms affect voting, politics, private sector and informal sector decision-making and policy, with the potential to induce even faster change (Adger 2003). Since people are both consumers and producers in economic terms, their collective decisions depend on many factors which also affect various individuals and groups differently (Johnson et al. 2020; Siciliano et al. 2021). For example, “just transition” movements advance climate-related politics and policies by linking people’s interests as workers (e.g. for jobs and workplace safety) to their concerns as consumers (e.g. for healthy products, well-being, and reduced climate risk). “Just transition” is an interdisciplinary frame for inclusive climate and energy policy that is synergistic with changing social norms (Healy and Barry 2017; McCauley and Heffron 2018; Harrahill and Douglas 2019; Cha 2020; Clarke and Lipsig-Mummé 2020; Pianta and Lucchese 2020).

Collective action by individuals as part of formal social movements or informal ‘lifestyle movements’ (Haenfler et al. 2012) can significantly impact climate mitigation. Both AR5 and SR15 reports recognised the role of collective action as part of cultural shifts in consumption patterns and dietary change. Collective action has the potential to both enable and constrain societal shifts in emissions reduction. Movements that shift social norms can produce ‘tipping points’ towards lifestyles with reduced emissions, for example veganism (Cherry 2006). On the other hand, landscape conservation groups have opposed the deployment of onshore wind turbines in several European countries (McLaren Loring 2007; Toke et al. 2008).

SM 5.3.5 Meaning

A people-centred view of mitigation recognises that individuals and groups make sense of climate change through meanings, not just information processing (Jerome 1990). Meanings associated with climate mitigation are not neutral, but part of an active process of constructing possible futures in which some actors have more influence over shared narratives than others. Meanings are associated with climate mitigation at different levels – from an individual person’s values or identity (e.g. choosing to describe oneself to others as a vegan), to the symbolism associated with low-carbon technologies (e.g. how cook stoves or solar panels confer status on their owners), to the level of collective imaginary futures at community, city, national or global levels (e.g. stories about smart urban futures or environmental catastrophes).

SR15 recognised that narratives and storytelling can enable the imagining of novel visions of place-based 1°C futures, creating space for agency, deliberation and the co-construction of meaning around desirable pathways of transition (Veland et al. 2018). Stories about climate change are ways of collectively making sense of uncertain futures, involving processes of interpretation and understanding through communication and social interaction (Smith et al. 2017). Culture – including religious beliefs - is central to climate mitigation, influencing how individuals perceive demand for services in relation to emissions and their expectations about what is both possible and desirable (Moezzi et al. 2017; Batel 2018).

Collective narratives about climate change refer to imaginary futures that can be either utopian or dystopian (e.g. Amitav Ghosh 2016), often presenting apocalyptic stories and imagery in an effort to capture attention and evoke emotional and behavioural response (O’Neill and Smith 2014). The idea of the Anthropocene has gained traction as a way of imagining a new era of human-environment relations characterised by unprecedented human influence over natural ecosystems, and to mobilise a sense of
grief at the potential for mass extinction of species, including humanity (Lovelock 2007; Head 2016; Heise 2017). In turn, epistemic evolution, the increasing dependency of global society in further developments in knowledge and technology to continue surviving in the Anthropocene, mirrors a narrative of opportunity (Renn 2018).

While climate stories themselves do not have agency in driving societal transformations, they can open up new ways of involving people in conversations about systemic changes that can provide motivation and confidence for people to participate in more inclusive ways (Smith et al. 2017). Science fiction has afforded indigenous communities a creative means to imagine climate futures divergent from conventional top-down narratives (Streeby 2018), signalling the role of power in shaping which climate stories are told and how prevalent they are (O’Neill and Smith 2014). Further research is required to study the impact of social media platforms on emerging narratives of climate change within societies and local communities (Pearce et al. 2019).

SM 5.3.6 Discourse and narratives

Meanings play a number of roles, both enabling and constraining action on mitigation (Buschmann and Oels 2019). At the societal level, imaginaries about the cities or homes of the future play important roles in enabling innovation by attracting attention, legitimating certain technology choices, rejecting or undermining others and attracting investment e.g. (Tozer and Klenk 2019). The e imaginaries have been shown to be important in the innovation of wind and solar energy, biopower, nuclear energy and smart meters (Sovacool et al. 2018). Analysis of shifts in discourse over time has revealed ‘turning points’ that facilitate change in systems of energy provision, providing the basis for new narratives to emerge and to become legitimate (Buschmann and Oels 2019).

One aspect of current unsustainable societies is the prevalence of common sense assumptions about systems of provision that effectively lock in (Unruh 2002) social actors to certain patterns of thinking or behaviour, limiting awareness and take up of alternatives (e.g. assuming that domestic heating must come from household boilers instead of district heating systems) (Owens and Driffill 2008). Political beliefs play an important role in influencing the uptake of narratives. ‘Climate justice’ narratives polarise individuals along ideological lines, while narratives that centre on saving energy, avoiding waste and embedding the uptake of low carbon energy in patriotic values were more widely supported (Whitmarsh and Corner 2017).

Climate policies need to go beyond an emphasis upon the rational provision of information and the functional attributes of new services, to place greater emphasis on symbolic meanings and emotions as a means to encourage social change. Presenting narrative meanings instead of factual information can lead to greater public engagement and pro-environmental action on climate change through arousing emotional responses (Morris et al. 2019).

SM 5.3.7 Meanings of technology

At the design stage, expectations of potential users of energy technologies and services (e.g. cookstoves, meters, thermostats) are often scripted into the appearance and functionalities of those devices. Experts and designers may hold common assumptions that public users are characterised by deficits of knowledge, competence and interest in energy systems (Burningham et al. 2015; Skjølsvold and Lindkvist 2015; Owens and Driffill 2008). These assumptions shape pathways of technology development and deployment (Marvin et al. 1999) leading to smart technologies with passive roles for users rather than smart users playing more active roles in systems of provision, distribution, storage and consumption (Goulden et al. 2014).
Contrasting meanings signal more active roles, including ‘prosumers’ who act as producers as well as consumers in decentralised energy systems (Espe et al. 2018), ‘energy citizens’ who are motivated by altruistic and environmental concerns, not only self-interest (Devine-Wright 2007; Ryghaug et al. 2018) and collectives such as ‘clean energy communities’ (Gui and MacGill 2018) engaged in peer-to-peer trading of energy services (Fell et al. 2019). Policy has an important role to play in communicating which of these expectations are preferred pathways of low carbon transition.

Meanings shape the willingness of individuals to use existing technologies or adopt new ones. Individuals develop attachments to material possessions (Belk 1988), which symbolise consumer-related identities (Dittmar 2008). Use of private cars for commuting is influenced by emotional and symbolic assumptions about driving (e.g. ideas of status, freedom and independence) as much as instrumental motives (Steg 2005). When new technologies are installed (e.g. feedback displays, smart meters), they become ‘domesticated’ into pre-existing daily routines (Monreal et al. 2016; Shove and Southerton 2000) that can involve negotiation and sometimes conflict within households (Hargreaves et al. 2013). Smart meters raise concerns about reduced autonomy and independence (Wilson et al. 2017). Failure of policy to recognise these emotional and symbolic processes can lead to overestimates of technology potentials, including emissions reduction.

When energy technologies are resisted by the public, meanings about objectors influence the responses of policy makers and energy companies. Adopting alternative meanings of communities, e.g. viewing them as repositories of expertise and local knowledge, and enabling genuine participation and benefit sharing can reduce conflict and increase acceptance (Bell et al. 2013; Walker and Baxter 2017). ‘NIMBY’ (Not In My Back Yard) is both a label used to describe objectors and an explanation for why protests over the siting of low carbon energy technologies take place (Burningham 2000). The concept suggests that objectors are characterised by ignorance, irrationality and selfishness (Devine-Wright 2005; Wolsink 2007; Burningham et al. 2015). When developers hold these views, it leads to strategies of community engagement that prioritise the provision of factual information and financial incentives as well as the avoidance of ‘angry’ crowds (Barnett et al. 2012; Walker et al. 2010). Engagement that overlooks technology meanings can produce unintended consequences, prolonging social conflict and reducing trust (Devine-Wright 2011; Wolsink 2007).

SM 5.3.8 Meanings of place and landscape

Renewable energy resources are widely dispersed across geographical areas, leading to consequences for patterns of development in rural areas (Pasqualetti 2000). ‘Energy landscapes’ refer to ways that meanings associated with rural areas evolve as land use changes from conventional agriculture to technological systems of heat and power generation and new ‘energy crops’ (Pasqualetti and Stremke 2018). Since landscapes are important symbols of cultural and social identity (Woods 2003; Short 2002), changes to their meaning influence the acceptability of technology siting (Devine-Wright 2009). Locations perceived as pristine and natural are considered less suitable for the siting of large scale energy infrastructures such as wind turbines and power lines (Wolsink 2010). Objections are often based on fears that technologies will ‘industrialise’ or ‘urbanise’ rural areas and are opposed by individuals with strong emotional attachments to those places (Devine-Wright and Howes 2010). Novel wave and tidal energy technologies have been positively associated with place attachments and public support, in part due to the ways they enhance a sense of local distinctiveness (Devine-Wright 2011).
SM 5.3.9 Social norms

Human behaviour is affected by the social environment, and in particular by what people commonly do or what other people think and expect (Cialdini 2006), even though people often do not acknowledge this (Nolan et al. 2008; Noppers et al. 2014); social influence seems more influential in some countries than others (Pettifor et al. 2017). Specifically, injunctive norms reflect perceptions of which behaviour is commonly approved or disapproved, and guide behaviour, as people are motivated to gain social approval and avoid social disapproval. Injunctive norms are related to a wide range of mitigation behaviours, including limited meat consumption, limited car use, the use of energy-saving light bulbs (Harland et al. 1999), energy use (Farrow et al. 2017) and recycling (Geiger et al. 2019), although the effects are not always strong (Gardner and Abraham 2008; Farrow et al. 2017).

Descriptive norms refer to behaviour commonly shown by others, and affect behaviour because it provides information about which behaviour is most sensible in a given situation. Descriptive norms (or peer effects) are related to different mitigation behaviours, including household energy savings (Nolan et al. 2008), car use (Gardner and Abraham 2008), energy use (Farrow et al., 2019), the adoption of electric vehicles and participation in smart energy systems (Noppers et al. 2019), and recycling (Geiger et al. 2019). Similarly, descriptive norm information or socially comparative feedback (in which case one’s own performance is compared to the performance of others) can encourage mitigation actions, although the overall effect size is not strong (Abrahamse and Steg 2008). A study in Uganda suggests that peer effects mostly affect attitudes towards cookstoves, but not the actual purchase of cookstoves (Beltramo et al. 2015). Socially comparative feedback seems more effective when people more strongly identify with the reference group (De Dominicis et al. 2019). Descriptive norms are more strongly related to mitigation actions when injunctive norms are strong too, when people are not strongly personally involved with mitigation topics (Göckeritz et al. 2010), when people are currently acting inconsistent with their preferences, when norm-based interventions are supported by other interventions and when the context supports norm-congruent actions (Miller and Prentice 2016). Weak descriptive norms, in which case people think others do not act on climate change, may inhibit mitigation actions (Schultz et al. 2007). Yet, trending norms that communicate that the number of people engaging in a behaviour is increasing, even if this concerns only a minority of people, can encourage the targeted behaviour, although the effect size is relatively small (Mortensen et al. 2019).

Human behaviour and choices are a function of personal and social norms and the content of norms depends on the context (Sunstein 1996; Niamir 2019; Thaler and Sunstein 2009). Climate change challenges pose major collective action problems, where a group benefits from a certain action, but no individual has sufficient incentive to act alone (Nyborg et al. 2016; Niamir 2019). Here, formal institutions (e.g., laws and regulations) are not always able to impose collectively desirable outcomes. Instead, informal institutions, such as social norms, can play a crucial role. If conditions are right, policy can support social norm changes, helping address global problems (Nyborg et al. 2016; Niamir 2019).

Sunstein (Sunstein 1996) appraise people’s choices and preferences in terms of intrinsic value, reputational effects, and effects on self-conception. Law and regulations potentially play an important role, by which the function of law in expressing social values with the goal of shifting social norms. There can be a serious obstacle to freedom in the fact that individual choices are a function of social norms, social meanings, and social roles, which individuals may deplore, and over which individuals have little or no control (Sunstein 1996). Here collective action and movements may be necessary to enable people to change norms that they do not like (Bamberg et al. 2015; Sunstein and Reisch 2014; Niamir et al. 2020a). Some norms are obstacles to human well-being and autonomy. It is appropriate for law to alter norms if they diminish well-being and autonomy (Thaler and Sunstein 2009; Sunstein 1996).
SM 5.4 Structural perspectives

Sociological and historical analyses of energy demand (Royston et al. 2018) deduce that patterns and dynamics of consumption are shaped by shifting configurations of infrastructures, technologies and collective conventions (Frantzeskaki and Loorbach 2008). When the aim is to reverse the current growing trend in demand, it is imperative to effectively activate and combine the three leverage points underlying structures (rules, organisations and infrastructures) to trigger social consistent with mitigation targets. If these leverage points are activated separately there is a high probability that path dependencies and behavioural lock-ins cannot be overcome; if they are activated together but independently, they can cause unwanted bounce effects or induce unexpected trends. There is a high probability that the ex-ante design of a relevant combination of infrastructures, organisations and rules, together with collective change of behaviours and adapted governance, will enable a real change in demand-side mitigation. Past lessons are helpful to fine-tune the required combination.

SM 5.4.1 Infrastructures and technologies

Infrastructures, defined in relation to organised practices (Star and Ruhleder 1996), should not be treated as independent systems, levers and drivers of change as it is often the case, but rather as systemic interconnections between infrastructures and practices (Cass et al. 2018). Indeed, the ways in which infrastructures intersect explain their potential influence (Thacker et al. 2019). For instance, the introduction of cycling lanes is embedded within multiple systems in flux, including the staged societal transformations with specific forms of governance and intervention associated with each phase of cycling lane history (Oldenziel et al. 2016). Similar results can be derived from an analysis of district heating systems (Hawkey 2012) or at urban level (Bulkeley et al. 2014). In the power sector, huge investments in electricity generation are foreseen, due to both the strong growth in emerging countries and a shift in usage towards “decarbonable” sources. Therefore, there is a need for the transformation of networks because of urban concentration and more dispersed electricity generation resulting from the rise of renewables. It implies that a compromise has to be found between two transition options; the design of a new electricity system to maintain its qualities of supply and sustain its current levels of reliability; a change in consumption habits and the adaption of lifestyles compliant with more power supply interruption (Maïzi and Mazauric 2019; Maïzi et al. 2017). This illustrates the multiple-level relationships between infrastructures, technology choices, economic development and individual choices.

Disciplines identify different drivers of technology adoption. Using rational choice models, mainstream economists propose relative costs and performance of new technologies compared to existing ones as the main driver of adoption (Nelson et al. 2004). Adding to this, evolutionary economists and innovation scholars suggest that technological development experiences positive feedbacks and increasing returns to adoption (like scale economies, learning-by-using, network externalities, informational increasing returns, and technological interrelatedness) that improve a technology’s price/performance.
characteristics as more people adopt (Arthur 1989; Creutzig et al. 2017). Psychologists argue that adoption decisions are shaped by people’s attitudes and beliefs with regard to instrumental considerations (perceived usefulness and ease of use) and wider norms and values (Davis 1989; Ajzen 1991). These disciplines conceptualise adoption as one-off purchase decisions, which is particularly useful with regard to ‘improve’ options that do not require wider changes in lifestyles and user routines.

Offering a broader and more longitudinal view, sociologists of innovation and social practice theorists focus on the co-evolution of technologies with lifestyles, social practices and user routines (Hand et al. 2005; Gram-Hanssen 2008; Hyysalo et al. 2013; Shove et al. 2014; McMeeekin and Southerton 2012), which is particularly relevant for ‘shift’ and ‘avoid/reduce/’ options. On the one hand, new technologies are not just purchased, but also integrated into daily life routines and user practices, which involves several activities (Shove and Southerton 2000; Monreal et al. 2016): a) cognitive activities involve the learning of new skills and competencies, b) interpretive and sense-making activities imbue new technologies with meanings, c) practical activities involve adjustments in everyday routines and material contexts. On the other hand, users do not just adopt new technologies, but can also actively contribute to development and innovation processes by: a) providing feedback to engineers about how technologies function in real-world user contexts (Heiskanen and Lovio 2010; Schot et al. 2016; Sopjani et al. 2019), b) tinkering themselves with the technology (Nielsen et al. 2016; Hyysalo et al. 2013), c) developing new organisational templates and business models (Truffer 2003; Ornetzeder and Rohracher 2013; De Vries et al. 2016).

Moving beyond adoption, sociologists of innovation have shown that new technologies need to be embedded in multiple contexts (Ó Tuama 2015; Kanger et al. 2019; Mylan et al. 2019), which involve not just user environments but also: a) business environments, including the development of business models, supply chains, repair facilities and infrastructures (Markard 2011; van Waes et al. 2018), b) civil society, including discourses, narratives, and public debates that shape cultural legitimacy and societal acceptance of new technologies (Geels and Verhees 2011; Rosenbloom et al. 2016), and c) institutional environments, including safety regulations, reliability standards and performance requirements (Reddy et al. 1991; Bohnsack et al. 2016; Andrews-Speed 2016).

**SM 5.4.2 Institutions**

Policymaking is a political process in that policies are conceived and implemented by governments and their policy coalitions with particular political priorities and values, and within a wider socio-economic context (Eyre and Killip 2019). Government policy contributes to shaping demand for energy services, travel and mobility, and given range of energy using activities, the policy agenda involves reaching out to a wide range of actors that includes practitioners and the general public. Doing this effectively will require a systematic deployment of effective regulatory and enforcement framework, consisting of regulations, market-based instruments, and information based instruments to voluntary agreements at various governance levels to address a wide range of stakeholders and their concerns (Park 2015; Mundaca and Markandya 2016).

The function of institutions in shaping policies and the interaction of various policy instruments is critical for the transition to a low carbon economy (O’riordan and Jordan 1999). One important characteristic of institutions, understood as ‘rules of the game in society’, consists of formal rules such as laws and regulations and informal norms or conventions that set the incentive structure for decision making (Vatn 2015). For example, Feed-in Tariffs and similar regulations set rules that enable citizens to participate in energy transitions as energy prosumers (Inderberg et al. 2018) (see also 5.4.4.3). The literature around policy processes and implementation with respect to demand and services relates that timing and policy choice is dynamic. At certain times there may be ‘policy windows’ for ambitious climate change policies, but such windows may also close unpredictably (Carter and Jacobs 2014).
Another way to understand institutions is that they shape the political context for decision making, empowering some interests and reducing the influence of others (Steinmo et al. 1992; Hall 1993; Moser 2009). An example of this is the fossil fuel subsidy that advantages incumbent actors in this sector over those from the renewable, leaving individuals or businesses who wish to invest in green energy, receiving much less support (Lockwood 2015; Healy and Barry 2017; Rentschler and Bazilian 2017).

In some countries, establishing carbon reduction as a policy priority is shared across the political spectrum (UK, Germany, India, South Africa), but even then much of the consensus has remained in single issue areas of intervention such as expansion of renewable energy; and rarely around structural change in areas such as sustainable prosperity in a circular economy (Jackson 2017) or sufficiency (Darby and Fawcett 2018; Thomas et al. 2019). These are both politically contentious and suffer from institutional inertia where the tendency is that institutions move slowly and resist change in challenges that call for structural and system-wide change (Munck af Rosenschöld et al. 2014).

SM 5.4.3 Sharing economy

The term sharing economy is used interchangeably with shareconomy, collaborative consumption, collaborative economy, the gig economy, and the mesh (Botsman and Rogers 2011; Martin 2016). The sharing economy has grown in a variety of sectors and platforms over the past years (Belk 2014a; Böcker and Meelen 2017). It defines a system that connects users/renters and owner/providers through consumer-to-consumer (C2C)/peer-to-peer (P2P) (e.g. Uber, Airbnb, couch surfing) or business-to-consumer (B2C) or business-to-business (B2B) platforms, and allowing rentals in more flexible, social interactive terms (e.g. Zipcar, WeWork) (Schor 2014; Franken and Schor 2017; Parente et al. 2018; Möhlmann 2015; Botsman and Rogers 2011; Belk 2014a). However, there are criticisms regarding business relationship masquerading as communal sharing so-called pseudo-sharing because these practices may not be beneficial to all parties as well as friendly to the environment and to reducing inequalities in access of products and services (Belk 2014b).

The motivation to participate in the sharing economy differs among socio-demographic groups, between users and providers and among different types of shared goods (e.g. cars, rides, accommodation, and tools). For example, empirical data analysis shows that sharing expensive goods (e.g. accommodation)’s economically motivated since most of room sharing hosts pay their rent and utility bills by sharing their living spaces. Environmental motivations are important particularly for mobility, ride sharing, in which a passenger travels in a private vehicle driven by its owner, for free or for a fee, and ride hailing, which uses a third party that connects riders with taxi services in the area (Böcker and Meelen 2017). Food sharing, which is a practice where individuals or groups of people make a commitment to ensure that food is shared instead of wasted, involves highly personal interactions, especially meal sharing, often motivated by social desires (Böcker and Meelen 2017). However, not all food sharing initiatives are based on social motivations. In fact, there are companies enjoying remarkably rapid growth and initiatives driven by economic benefits such as businesses seeking to match farmers and/or distributors to consumers for fresh produce that are still edible but contain defects in size, colour, shape and size; the so-called market for “ugly food” (Richards and Hamilton 2018). Other popular meal sharing initiatives are EatWith, Meal Sharing, Traveling Spoon, in which hosts offer affordable food and a closer look into local life to tourists. Although younger and low-income groups are more economically motivated to use and provide shared assets; younger, higher-income and higher-educated groups are less socially motivated; and women are more environmentally motivated (Böcker and Meelen 2017).
SM 5.5 Transition

SM 5.5.1 Transition perspectives

The literature offers several theoretical approaches that attempt to explain how transitions take place: social practices, energy cultures, and socio-technical transitions. Social practice theory emphasises interactions between artefacts, competences, and cultural meanings (Shove and Walker 2014; Røpke 2009). The energy cultures framework highlights feedbacks between materials, norms, and behavioural practices (Stephenson et al. 2015; Jürisoo et al. 2019) highlights. And socio-technical transitions theory, which spans both provisioning systems and use contexts, addresses interactions between technologies, user practices, cultural meanings, business, infrastructures, and public policies (Geels et al. 2017b; McMeekin and Southerton 2012).

Cultural meanings and discourses shape the beliefs, preferences and motivations of various actors and what they consider to be desirable, legitimate or acceptable (Stryker 1994; Phillips et al. 2004). Structural elements such as regulations, institutions, technologies and infrastructures provide the more tangible contexts within which actors act (Currie and Spyridonidis 2016; Solér et al. 2020). Actors like households, firms, civil society organisations, and policymakers reproduce or transform cultural and structural contexts through storytelling, political lobbying, innovation activities and infrastructure building (Lounsbury and Glynn 2001; Dolata 2009; Battilana et al. 2009).

The energy cultures framework and socio-technical transitions theory both understand demand-side transitions as involving interactions between: 1) radical social or technical innovations, which deviate in one more dimensions from dominant configuration, 2) relatively stable dominant energy cultures or socio-technical systems, 3) external influences such as shocks or gradually increasing pressures.

Radical demand-side innovations like new technologies, new business models or alternative behavioural practices initially emerge in small, peripheral niches (Kemp et al. 1998; Schot and Geels 2008). These projects and initiatives offer protection from mainstream selection pressures and nurture the development of radical innovations (Smith and Raven 2012). Dominant energy cultures, social practices or socio-technical systems resist radical change, because they are stabilised by multiple lock-in mechanisms (Klitkou et al. 2015; Clausen et al. 2017; Ivanova et al. 2018; Seto et al. 2016).

SM 5.5.2 Lock in mechanisms of existing systems and practices

Although there are many demand-side mitigation options, low-carbon transitions do not happen easily because multiple lock-in mechanisms stabilise existing systems of service provision and social practices and thus hinder major change (Clausen et al. 2017; Ivanova et al. 2018; Seto et al. 2016; Klitkou et al. 2015). Existing activities and demand patterns are often stabilised by behavioural lock-in mechanisms identified by psychological and economic literature: a) routines and habits tend to be repeated over time as ‘normal’ dietary, heating or travel patterns (Barnes et al. 2004; Maréchal 2010; Kurz et al. 2015; Hoolohan et al. 2018); b) preferences and attitudes can orient people positively towards existing practices over alternatives, e.g. private car travel over public transport (Sheller 2004); and c) cost-benefit calculations make people purchase technologies that are more practical or cheaper than alternatives (e.g. cars over public transport in rural areas; petrol cars over electric cars).

Structural elements of existing systems and practices are also stabilised by lock-in mechanisms as sociological, political science and innovation literature have demonstrated. Institutional lock-in mechanisms can stabilise existing policies that support existing technologies and demand patterns: a) policy networks facilitate interactions between policymakers, specialists, and established business interests and tend to shape policymaking towards status quo protection or incremental reform rather
than more radical policy change (Walker 2000; Knox-Hayes 2012; Geels 2014; Normann 2017; Roberts and Geels 2019); b) existing policy paradigms shape how policymakers frame problems and think about solutions (Kern et al. 2014; Rosenbloom 2018; Schmidt et al. 2019; Buschmann and Oels 2019), often leading to a focus on upstream technologies, market-based instruments, and hands-off policy styles (Whittle et al. 2019), c) incumbent firms use corporate political strategies and resistance tactics to delay or water down strong climate policies (Kolk and Pinkse 2007; Smink et al. 2015; Ferguson et al. 2016; Supran and Oreskes 2017; Geels 2014). Technological lock-in mechanisms such as core competencies and sunk investments in factories and employees generate vested interests and technological regimes that incumbent firms will try to protect through incremental innovation (Berkhout 2002; Raven and Verbong 2004; Vanloqueren and Baret 2009). Infrastructural lock-in mechanisms such as capital-intensity, asset durability, obduracy, and systemic interrelatedness (van der Vleuten 2004; Markard 2011) means that infrastructure-related technologies and practices are difficult to change. Existing roads, petrol stations and land-use patterns stabilise car-based mobility patterns (Seto et al. 2016), while gas infrastructures stabilise home-based boiler heating practices (Gross and Hanna 2019).

Existing meanings may also lock-in existing systems and practices. Discourse and cultural studies literature have found that established meanings, values and discourses help legitimise and normalise the status quo (Bosman et al. 2014; Buschmann and Oels 2019). For example, discourses that frame cars as status symbols that embody success, power, freedom, and autonomy help entrench auto-mobility and hinder shifts to public transport (Stephenson et al. 2015). Discourses that portray dairy milk as healthy and natural stabilise particular diets and hinder transitions to plant-based milk (Mylan et al. 2019). Most people and communities hold a plurality of cultural values; environmental protection and climate mitigation is only one value cluster amongst others such as efficiency, security and stability, social justice and fairness, autonomy and freedom, and improved quality of life (Plumecocq et al. 2018; Demsik et al. 2015).

SM 5.5.3 Rates of change, acceleration

Rates of change are slow in the first and second transition phase, because experimentation, social and technological learning, the creation of standards, and the reduction of uncertainty take a long time, often decades (Bento et al. 2018; Bento 2013; Wilson 2012). Rates of change increase in the third phase, as radical innovations diffuse from initial niches into mainstream markets, propelled by the self-reinforcing mechanisms, discussed above. The rate of adoption (diffusion) of new practices, processes, artefacts, and behaviours is determined by a wide range of factors at the macro- and micro-scales, which have been identified by several decades of diffusion research in multiple disciplines (for comprehensive reviews see, e.g., Tornatzky and Klein, 1982; Feder & Umali, 1993.;) (Ausubel 1991; Bayus 1994; Van den Bulte and Steemersch 2004; Comin and Hobijn 2003, 2010; Davis 1979; Meade and Islam 2006; Mahajan et al. 1990; Mnsfield 1968; Martino et al. 1978; Peres et al. 2010; Grubler 1991; Rogers 2003).

Diffusion rates are determined by two broad categories of variables, those intrinsic to the technology/product/practice under consideration (typically performance, costs, benefits), and those intrinsic to the adoption environment (e.g., socio-economic and market characteristics).

The literature on systems or macro-determinants of diffusion (technology growth and behavioural change) rates comprises three streams: historical energy transition research (e.g., Fouquet 2008; Geels 2002), systems theories of technological change (Grübler et al. 1999), as well as the recent literature on scaling-(up) dynamics of technologies (Wilson 2009) which has also been applied for validation of climate mitigation scenarios (Wilson et al. 2013). Common to them all is the recognition of the importance of scale, or market size, as well as time and place as determinants of rates of change. Three main conclusions emerge from this literature. Ceteris paribus, a) larger systems take more time to
evolve, grow, and change compared to smaller ones; b) the creation of entirely new systems (diffusion) takes longer time than replacements of existing technologies/practices (substitution); and c) late adopters tend to adopt faster than early pioneers.

The micro-level literature on technology- (or product-) specific rates of adoption is vast (for reviews see, (Tornatzky and Klein 1982; Grübler et al. 1999; Peres et al. 2010; Rogers 2003)) and has identified three clusters of variables: a) relative advantage; b) adoption effort required and complexity; and c) compatibility, observability, and trialability. All variables, except adoption effort, are positively correlated with (rapid) rates of change.

The acceleration of transitions is a complex issue, because of the multitude and combination of both macro- (societal, economic, markets) and micro- (e.g., firm- or consumer-) level determinants. A recent debate (Sovacool 2016) vs. (Grubler et al. 2016) led to a special journal issue on the duration and acceleration of energy transitions from a variety of (opposing) perspectives, which ranged from political urgency and malleability (Bromley, 2016) to inertia in large- techno-economic systems (Smil 2016) for a summary of the debate cf. (Sovacool and Geels 2016).

### SM 5.5.4 Feasibility and barriers of demand-side transitions

While demand-side solutions have very high mitigation potential, the widespread diffusion and transitioning of many options is challenging. Table SM5.1 provides a high level assessment of feasibility barriers for avoid, shift and improve options on behavioural, technological, business, institutional and socio-cultural dimensions. This assessment shows that improve options, which are mostly about technical component substitutions that do not require wider changes, face low to medium feasibility barriers, related to higher costs (specially if new technologies also require new infrastructures), limited consumer interest, and some industry reluctance. Shift options, which involve different ways of fulfilling desired services, face medium to large feasibility barriers, due to substantial required changes in behavioural routines, technologies, institutions, and investments. Avoid options, which involve deep changes in lifestyles and social practices, face large feasibility barriers in behavioural routines, institutions and cultural meanings, small to medium technical barriers and variable economic barriers.

There is variability within this high-level assessment of feasibility and speed of transition. Some improve options may diffuse rapidly (e.g. LED lightbulbs), but other improve options, such as improved cooking stoves remain at low levels due to mismatch with cultural practices or cost barriers. Avoid and shift options often require longer time scales, especially if new infrastructures, such as tram lines or building retrofits, are involved. Sometimes they unfold rapidly, however. For example, digital service provision models ranging from communication to entertainment, retail, or banking via integrated digital platforms (typically via smartphone apps) diffused quickly, replacing conventional analogue and/or physical service provisioning systems (home entertainment systems, bank offices, or shops (TWI2050 2019).

Demand-side transitions thus face the dilemma that improve options are in some cases more feasible, but only exploit part of the solution space, because they are less deep. Shift and avoid options have higher mitigation potential, but face larger feasibility barriers, for instance for living car-free and restricting long-haul flights (Dubois et al. 2019). While the diffusion of most demand-side options is likely to be slow without stronger policies, this dilemma means that the diffusion of shift and avoid options would particularly benefit from stronger policy support that also address social norms. Importantly, feasibility barriers are not fixed or static, but malleable and evolving over time. Obstacles and feasibility barriers are high in early transition phases. But over time, the various barriers decrease
as a result of technical and social learning processes, network building, scale economies, cultural debates and institutional adjustments.

Table SM5.1 Assessment of feasibility/barriers for the diffusion of demand-side mitigation options

<table>
<thead>
<tr>
<th>Behavioural Options</th>
<th>Technology, infrastructure</th>
<th>Business</th>
<th>Institutional</th>
<th>Socio-cultural</th>
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</thead>
<tbody>
<tr>
<td>Improve options:</td>
<td></td>
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<tr>
<td>Electric vehicles,</td>
<td>Small-medium</td>
<td>Small-</td>
<td>Medium</td>
<td>Small</td>
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<tr>
<td>light-weight</td>
<td>- Small change in behavioural routines</td>
<td>medium</td>
<td>- More expensive than existing technologies (although learning curves reduce costs)</td>
<td>- No major institutional change needed (as existing systems mostly remain intact)</td>
</tr>
<tr>
<td>vehicles, wood as</td>
<td>- Most component substitutions are technically feasible.</td>
<td>- Infrastructure change would increase costs</td>
<td>- Diffusion slow without policy support and financing models</td>
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<tr>
<td>building material,</td>
<td>- Some options require infrastructure change (e.g. recharging)</td>
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<tr>
<td>solar thermal</td>
<td>- Costs or lack of interest may hold back purchase</td>
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<td>devices, insulation,</td>
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<td>energy-efficient</td>
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<td>appliances and light</td>
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<td>bulbs, low carbon</td>
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<td>fabrics, improved</td>
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<td>clean cookstoves</td>
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<td>Shift options:</td>
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<tr>
<td>Shift from cars to</td>
<td>Medium-large</td>
<td>Small-</td>
<td>Medium-large</td>
<td>Medium-large</td>
</tr>
<tr>
<td>public transport</td>
<td>- Medium change in behavioural routines</td>
<td>medium</td>
<td>- Investments in technologies, supply chains, business models, infrastructure</td>
<td>- Large scale cultural change for some shift options (e.g. less meat)</td>
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<tr>
<td>or cycling, less</td>
<td>- Not widespread consumer interest</td>
<td>- Increased use of existing or new technologies</td>
<td>- Resistance from incumbent industries</td>
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<td>material-intensive</td>
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<td>construction,</td>
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<td>district heating,</td>
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<td>passive house,</td>
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<td>smaller devices,</td>
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<td>circular economy,</td>
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<td>shift towards from</td>
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<td>meat to other</td>
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<td>protein sources</td>
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<tr>
<td>Avoid options:</td>
<td>Large</td>
<td>Small-</td>
<td>Variable</td>
<td>Large</td>
</tr>
<tr>
<td>Integrated transport</td>
<td>- Large change in behavioural routines</td>
<td>medium</td>
<td>High costs for some options (e.g. compact cities, low costs for others (e.g. change dress codes)</td>
<td>- Large institutional change (e.g. overcoming silo-problem, new agencies)</td>
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<tr>
<td>and land-use planning, teleworking, compact cities, smaller apartments, shared common spaces, multi-generational housing, change</td>
<td>- Limited technical change (except for some options)</td>
<td>- Mostly using existing or</td>
<td>- Large policy change for some options</td>
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<td></td>
<td>- Small to limited consumer interest</td>
<td>or</td>
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<td>- Mostly using existing or</td>
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SM5-26 Total pages: 68
SM 5.6 Case studies

SM 5.6.1 Consumer-led innovation in solar photovoltaics (CS1)

Although solar PV has attained massive scale as an energy supply technology, its success in becoming a low-cost mitigation option is attributable in large part to the collective agency of energy consumers who embraced the unique services that PV’s modularity provides. These bottom-up socio-cultural forces catalysed a supportive policy environment, which enabled improvements in the technology by innovative firms. PV’s technological evolution can be summarised as the result of distinct contributions by the US, Japan, Germany, Australia, and China—in that sequence over seven decades (Nemet 2019) (Figure SM5.4).

Since its first commercial application in 1958, PV has provided distinct energy services to a sequence of increasingly large consumer niche markets with high but decreasing willingness to pay (Dracker and De Laquil III 1996; Jacobsson and Lauber 2006). Modularity is among PV’s most consequential attributes; the smallest electronics application to utility-scale spans nine orders of magnitude (Shum and Watanabe 2009). Nearly every scale in between has been applied to provide needed services—often serving not a policy-driven market but one arising from idiosyncratic consumer needs, for which PV was well suited. In the 1950s, the US Navy bought cells for early satellites from an electronics entrepreneur who had been selling solar-powered radios (NRC 1972; Perlin 1999). In India in early days activist entrepreneurs marketed solar-powered lanterns in rural areas with unreliable electricity (Roy 1997; Roy and Jana 1998). Off-grid housing, water pumps in Mali, and electronics provided important consumer niche markets (Perlin 2013). It has played a substantial role in reducing poverty in China (Zhang et al. 2020).

Institutionally, the most important policy for the improvements observed in PV was Germany’s Erneuerbare Energie Gesetz (EEG) passed in 2000, guaranteeing prices paid to prosumers (i.e. citizens acting as both producers and consumers) of renewable electricity for 20 years (RESA 2001). The EEG quadrupled the size of the German solar market in one year and stimulated corporate actors to invest in designing PV-specific production equipment that was crucial for subsequent improvements and cost reductions accomplished by Chinese producers (Palz 2010). In India in 1982 the Department of Non-conventional Energy Sources was set up which eventually got transformed into Ministry of Non-conventional Energy Sources (MNES) in 1992 and in 2006 to MNRE in 2006. Indian Renewable Energy Development Agency (IREDA) was established in 1987 to finance renewable energy projects (Bhattacharya and Jana 2009).

The EEG adopted the policy innovation of guaranteed long term contracts that California regulators had designed to provide grid access to small energy producers in the 1980s (CPUC 1983; Hirsch 1999). It also adopted the Japanese innovations of a declining subsidy and the first national rooftop top solar program in 1995 (Kimura and Suzuki 2006). The adoption behaviour of the 200,000 Japanese
households who installed PV in the next ten years showed the world that consumer demand for PV energy services was strong (Shimamoto 2014). The Japanese subsidy was far less generous than the subsequent German program and surveys of adopters indicate that environmental values were a stronger driver than economics (Kimura and Suzuki 2006). Corporate actors, in the form of Japanese electronic conglomerates, became the world’s largest PV producers using experience incorporating PV’s unique attributes, scale and mobility, into consumer products, like watches, calculators, and electronic toys (Honda 2008).

The EEG only became politically feasible in Germany because of an environmental activist social movement, originating in the 1968 student protests, advocating a shift to consumer-led green energy production (Morris and Jungjohann 2016). PV had the potential to avoid: environmental damage, oil dependence, hegemony of electric utilities, nuclear power, and later climate change. PV thus attained meaning beyond its technical elegance; its main advocate in the German Parliament, Hermann Scheer emphasised the importance of its “emancipatory motivation” (Palz 2010). In 1998, when a policy window opened, broad social acceptability existed, cities had de-risked the technology, and policy implementation details had been worked leading to a cascade of technology adoption, performance improvement, and cost reductions that set the stage for broader systemic change (Lauber and Jacobsson 2016).

Today’s massive utility-scale PV projects are now a factor of 10,000 cheaper than the first PV cells in satellites. They are also inextricably linked to a seven-decade evolution in which the agency of consumers has consistently played a key role in multiple countries, such that deriving half of global electricity supply from solar is now a realistic possibility (Creutzig et al. 2017).

SM 5.6.2 Energy services for cooking: Improve cookstoves and shift to new forms of energy (CS2)

The majority of households in developing countries use traditional solid biomass fuel through inefficient and incomplete combustion for cooking and heating (Bhattacharya and Cropper 2010; Nepal et al. 2010; Bonjour et al. 2013; IEA 2017; Wester et al. 2019; Jeuland et al. 2021). This has been a major concern for deforestation (Kissinger et al. 2012) and for health, gender relations, and economic

Figure SM5.4 Technological learning curve of photovoltaic solar energy. Prices decline with production and associated innovation and economics of scale. As granular technology that can be matched to diverse settings, technological learning is faster than in most other technologies.

Source: (Nemet 2019)
In India during 2001 and 2011 increase in LPG use has led to a net emissions (Kyoto and non-Kyoto Gases) reduction of 6.73 MtCO₂-eq (0.94 MtCO₂-eq in rural area and 5.79 MtCO₂-eq in urban area) with fuel wood displaced 7.2 million tons (0.99 million tons in rural area and 6.19 million tons in urban area) (Singh et al. 2017).

Shifts towards electrification technologies. Zubi et al. (Zubi et al. 2017) estimate that a three litre multi-cooker needs just 0.6 kWh day⁻¹ to cook lunch and dinner for a household of six, which is equivalent to 0.36 MJ cap⁻¹ day⁻¹. Similarly, according to Batchelor et al. (Batchelor et al. 2018) 0.2 kWh could be enough to cook rice for a household of four in a rice cooker.

There is substantial evidence that more awareness programs are needed to break the behavioural barriers towards usage of modern cooking fuel (Giri and Aadil 2018). While designing ICS, along with technical aspects like energy efficiency, emission mitigation, and improving health outcomes researchers are also needed to factor in functionality, aesthetics and consumers’ need and preference. A tailoring in the technology is also needed based on the region, climate and culture (Bielecki and Wingenbach 2014). Many of the families who are first time users of LPG often find safety issues as a barrier to use it. Studies from Senegal and Mexico shows that even though households are complaining...
of smoke and itchy and watery eyes during cooking with solid fuels, and are aware of the health benefits
of using LPG or other efficient technology, they still find traditional cooking practices using solid fuels
to be more desirable (Pine et al. 2011; Hooper et al. 2018). Many country-specific studies have also
shown that the types of diet, modes of cooking and types of utensils, vessels used have an impact on
the choice of cooking fuel and technology (Ravindranath and Ramakrishna 1997; Atanassov 2010;
Mukhopadhyay et al. 2012; Troncoso et al. 2019; Bielecki and Wingenbach 2014) the perception of
food tastes (Wiedinmyer et al. 2017; Mukhopadhyay et al. 2012; Hooper et al. 2018), differences in the
housing-style and location of the cooking area-indoor or outdoor (Chattopadhyay et al. 2017) delays
transition to a cleaner fuel or new technology. In Mozambique the dissemination of solar cookstove
has seen limited success as its design failed to capture end-user need of cooking process like boiling,
steaming or frying and how the food is prepared like standing versus sitting (Otte 2014).

Universal access to clean and modern cooking energy could cut premature death from HAP by two-
third relative to baseline in 2030 while reducing forest degradation and deforestation and contribute to
the reduction of up to 50% of CO2 emissions from cooking relative to baseline by 2030 (Ho et al. 2019;
IEA 2017). However, in the absence of policy reform and substantial energy investments, 2.3 billion
people will have no access to clean cooking fuels such as biogas, LPG, natural gas or electricity in 2030
(IEA 2017). The increasing efficiency improvements in electric cooking technologies, together with the
ongoing decrease in prices of renewable energy technologies, could enable households to shift to
electrical cooking at mass scale (Figure SM5.5a).

SM 5.6.3 Shift in mobility service provision through public transport in Kolkata (CS3)

In densely populated cities in India, mobility is still predominantly dependent on public transport,
walking and cycling modes (Tiwari et al. 2016). There is an increasing shift of narratives towards
comfortable, affordable public transport systems in public policy, which is translated into infrastructure
investments, procurement of equipment, road safety legislation, and even public consultations on
mobility in smart cities (Roy et al. 2018b; Ghosh and Arora 2019). This transition in mobility systems
in historically public transport dominated cities like Kolkata and Mumbai is happening through ‘fit and
conform’ strategies, but also by ‘stretch and transform strategy’ in new cities like Ahmedabad,
Bangalore, Pune (Ghosh et al. 2018; Ghosh and Schot 2019; Roy et al. 2018b).

In the megacity Kolkata, as many as twelve different modes of public transportation ‘regimes’ - each
with its own system, structure, network of actors and meanings - co-exist and offer means of mobility
to its 14 million citizens. Most public transport modes are shared mobility options ranging from sharing
between two people in a rickshaw or between a few hundred in metro or sub-urban trains. Sharing also
happen as daily commuters avail shared taxis organised by organically formed local taxi associations
and neighbours borrow each other’s car or bicycle for urgent or day trips. However, there are also formal
efforts by several actors and initiatives to transform the existing systems in sustainable directions. Many
factors have contributed to transformative changes in Kolkata’s public transport regimes, including
socio-cultural awareness generated through mass-media like television and newspaper reports, research
and communication by NGOs on the detrimental effects of existing standards of fuel and equipment,
environmental campaigns by civil society organisations involving school children, students and the
elderly. There were efforts to improve efficiency in managing fleets and service provision through
smart, real time and integrated display and fare collection system etc. A crucial driver of this policy has
been to discourage users to shift their demand from public to private mobility and new meaning to
buses, autorickshaws were getting added continuously. Many of these changes were driven by new
policy at national and urban levels, for instance the National Urban Renewal Mission (2005) (Ministry

Figure SM5.

A key role is played by the state government to improve the system as whole and formalise certain
semi-formal modes of transport. An important policy consideration has been to make Kolkata’s mobility
system more efficient (in terms of speed, reliability and avoidance of congestion) and sustainable
through strengthening coordination between different mode-based regimes as each of these regimes are
transformed individually and collectively over the past 10 years (Ghosh 2019). Such transformations
within the regimes arose from a broad range of drivers such as need for new infrastructure, increased
fuel efficiency, digitalisation of operation, and pollution mitigation. Many of these interventions were
to address wider sustainability challenges such as increasing demand for individual mobility, high
concentration of pollutants in the air, lack of affordability etc. Each of Kolkata’s diverse public transport
regimes have changed along different pathways in the past decade owing partly to new standards and
regulations, but also to new values, beliefs and expectations-(cognitive and normative meanings. Four
distinctive regime level change processes are: improvements and new meaning to public buses, greening
and formalisation of auto-rickshaws, the institutional and socio-cultural support to the emergence of
‘app-cab’ niche, a cycling ban policy in major arterial roads of Kolkata.

Each of Kolkata’s diverse public transport regimes have changed along different pathways in the past
decade owing partly to new standards and regulations, but also to new values, beliefs and expectations
(cognitive and normative meanings). Four distinctive regime level change processes are elaborated
here: 1) improvements and new meaning to public buses; 2) greening and formalisation of auto-
rickshaws; 3) the institutional and socio-cultural support to the emergence of ‘app-cab’ niche; 4) a
cycling ban policy in major arterial roads of Kolkata.

**Public Buses attracting the middle class:** Supported by the National Urban Renewal Mission in 2010,
the West Bengal government rolled out 1200 new fuel efficient, low floor buses with an aim to provide
‘modern and efficient bus service to the urban middle class citizens of Kolkata, who will be willing to
pay a premium fare for a comfortable and reliable bus service’ (Ghosh and Schot 2019). Several changes
in the state bus regime followed this effort to improve public bus infrastructure to match the demands
for a new urban lifestyle. There were efforts to improve efficiency in managing fleets and service
 provision through smart, real time and integrated display and fare collection system etc. A crucial driver
of this policy has been to discourage users to shift their demand from public to private mobility. The
primary focus on these strategies have been to cater to their preferences for safety, reliability and
comfort. A way to incentivise the middle class, urban population of Kolkata to keep using public buses
was through transforming the socio-cultural meaning of the public bus regime by rebranding and
advancing a new image of the bus as a comfortable and efficient mode of transport.

**Auto-rickshaws and new meanings:** While the transformation of the public bus was triggered by
social pressures like affordability, safety and reliability, transformation in the auto-rickshaw regime
started off in response to the environmental challenges from the unsustainable fuel used in these
vehicles. Emissions from auto-rickshaws operated with a cheap toxic mixture of petrol, kerosene and
naphtha accounted for 60% of the city’s air pollution. Since 2009, new legislation has mandated the use
of single mode liquified petroleum gas (LPG). This improvement in fuel infrastructure coupled with
consequent initiatives by the state government to formally recognise and integrate auto-rickshaws as
part of the public transport portfolio of the city, resulted in a transformation of the socio-cultural
meaning of auto-rickshaws from one considered to be noisy, polluting, unregulated and informal
paratransit mode into an environment-friendly, fast and efficient mode of shared mobility.

**Emergence of ‘app-cab’ niche:** Public buses started attracting middle classes, Autorickshaws got new
meaning and with digitalisation Taxi services got transformed. The existing social norm of sharing
public transport modes coupled with a rapid uptake of smartphones facilitated the emergence of ‘app-
cabs’ in Kolkata (Ghosh 2019). Since 2014, the global mobility platform, Uber and the Indian app-cab
company, Ola started operating services in Kolkata, gaining quick momentum in shifting the demand
of users from yellow taxis to app-based taxi services. Both Uber and Ola have ‘pool’ (ride-sharing)
options which are considerably cheaper than booking the entire car. Commuters could even buy a
monthly pass for cheaper daily access. Owing to these facilities, transparency of payment and safety
promises, shifts have taken place in the expectations and routines of commuters from “car is the only
comfortable way of travelling” to “sharing a cab is much faster and efficient” (Ghosh and Schot 2019).
Such deeper shifts in the beliefs of the more affluent urban population are crucial for transitioning
towards sustainable mobility in coherence with emerging lifestyle preferences in megacities like
Kolkata. However, there is also a change in behaviour of the urban middle-class, who are willing to
replace their bus, metro or auto-rickshaw rides with app-cabs because of additional benefits like door
to door service.

Cycling ban policy: While the effect on social justice, equity and inclusion is clear in the cases of the
bus, auto-rickshaw or app-cabs, some recent policy actions in Kolkata are directly related to socio-
economic exclusion. Since 2014, Kolkata police have banned cycling in many major arterial roads as a
traffic management strategy under the pressure of congestion and to avoid road accidents in over
crowded narrow streets. Civil society activists and NGOs have protested against the ban on grounds of
environmental impacts and injustice against the poor. The ban was partially retracted in 2016 (Ghosh
2019). Scholars have argued that such policy measures exacerbate inequalities by disadvantaging the
urban poor, and hence are undesirable, even though it might seem to be a congestion mitigation strategy
in the short term (Raven et al. 2017; Sur 2017). The agency of political actors in implementing
regulatory policies in individual bus, auto or taxi regimes is important, but not enough to maintain the
existing sustainable practices of shared mobility. The transformation processes in state bus and auto-
rickshaw regimes highlight that policies need to align with specific user demands (for safety, reliability,
comfort) and focus on changing deeper beliefs and practices across multiple mobility regimes in the
city. The emergence of the app-cab service suggests the role of digitalisation beyond policies and
markets to renew the taxi regime following the existing ride sharing culture that already exists in
Kolkata. The cycling ban case highlights the exclusionary effects of policy, which the agency of civil
society actors in social movements can hold into account in a democratic context.

To conclude, more thoughtful action at a policy level is required to sustain and coordinate the diversity
of public transport modes through infrastructure design and reflecting on the overall directionality of
change (Schot and Steinmüller 2018; Roy et al. 2018b). The case of urban mobility transitions in
Kolkata shows interconnected policy, institutional, socio-cultural and behavioural drivers for socio-
technical change. Change has unfolded in complex interactions between multiple actors, sustainability
values and megatrends where direct causalities are hard to identify. However, the prominence of policy
actors as change-agents is clear as they are changing multiple regimes from within. The state
government initiated infrastructural change in public bus systems, coordinated with private and non-
governmental actors such as auto-rickshaw operators and app-cab owners who hold crucial agency in
offering public transport services in the city. The latter can directly be attributed to the global
momenum of mobility-as-a-service platforms, at the intersection of digitalisation and sharing economy
trends. However, sensitivity of the policy actors in the developing countries to local needs and
capabilities are important, instead of chasing global trends, especially if such trends increase inequality
at the cost of improved standard of living for a selected section of people. It is a fact that many of these
above mentioned policy changes cater to middle class aspirations and preferences, at the cost of lower
income and less privileged communities. Complexity of governance and risk of increasing inequalities
are also discussed in the literature (Sheller 2018; Nikolaeva et al. 2019) along with new approaches for
collective governance and accessibility in the mobility transition. (Figure SM5.5b).
Figure SM5.5 Exemplary transition dynamics for the cases of improved cookstoves, modal shifts, and diet shift

SM 5.6.4 Dietary change and reduced meat consumption (CS4)

UK per capita meat consumption increased from 69.2 kg yr\(^{-1}\) in 1961 to 85.7 kg yr\(^{-1}\) in 2006, and then declined to 78.6 kg yr\(^{-1}\) in 2015 (\(=8.3\%\)), followed by a small increase in 2016 and decline in 2017 (see Figure SM5.6). Despite ups and downs, the trend since 2006 is downward. Another long-term trend is a relative shift from carbon-intensive red meat towards poultry. Research indicates that this shift away from meat consumption is likely to have resulted from interactions between several actors and multiple dimensions (Vinnari and Vinnari 2014).
A substantial body of literature indicates that self-reported consumer motivations for shifting away from meat are primarily linked to concerns for personal health. Food safety, cost, and animal welfare, are also important, with concerns about climate change less so (Latvala et al. 2012; Dibb and Fitzpatrick 2014; Hartmann and Siegrist 2017; Graça et al. 2019). However, there is little evidence to link these motivations to actual behaviour change (Bianchi et al. 2018; Graça et al. 2019). This can be attributed to lock-in mechanisms, such as established habits of food provision; skills deficits in preparing non-meat meals (Pohjolainen et al. 2015); positive socio-cultural meanings attached to meat eating, including vitality and sociality (Mylan 2018) and limitations in the availability of non-meat options when eating out of the home (Graça et al. 2019).

NGO campaigns that aim to change public discourses and attitudes toward meat production and consumption (Laestadius et al. 2016), have gained prominence in UK over the past decade, drawing attention to issues including health, climate change and animal welfare. There has also been a proliferation of behaviour change initiatives led by social movements including ‘meat-free-Mondays’ and ‘Veganuary’ which, in addition to information provision, aim to encourage behaviour change by providing practical guidance and creating normative pressures (Morris et al. 2014). The effectiveness of these civic led interventions, and accompanying attempts to ‘nudge’ consumers toward meat reduction by altering the visual appeal, position, or size of meat offerings at the point of purchase, is being debated in the literature (Garnett et al. 2015; Godfray et al. 2018; Taufik et al. 2019; Harguess et al. 2020; Sahakian et al. 2020).

Companies have started to respond to the growing demand for ‘meat free’ products, with 16% of new UK food products launched in 2018 presenting ‘non animal’ claims – a doubling since 2015 (MINTEL 2019). These ‘meat alternatives’ vary in material form, with more ‘radical’ products such as cultured meat, or algae and insect-based proteins, facing substantial structural barriers (technological, organisational, institutional), which presently hinder their widespread diffusion (van der Weele et al. 2019). Nevertheless, it is clear that both corporate food actors and new entrants offering more innovative ‘meat alternatives’ view consumer preferences as an economic opportunity, and are responding by increasing the availability of meat replacement products. Farmers and meat industry actors have opposed these developments through political lobbying, which in 2019 led the European Parliament’s agriculture committee to prohibit these new companies from using the terms “burger” or “sausage” to describe products that do not contain meat.
Policy support for meat alternatives or behavioural change has remained limited in the UK, where reduced meat consumption is low on the political agenda (Wellesley and Froggatt 2015). The extent to which policymakers are willing to actively stimulate reduced meat consumption thus remains an open question (Godfray et al. 2018). Agricultural policies in the UK serve to support meat production with large subsidies that lower production cost and effectively increase the meat intensity of diets at a population level (Simon 2003; Godfray et al. 2018). Deeper, population wide reductions in meat consumption are hampered by these lock-in mechanisms which continue to stabilise the existing meat production-consumption system.

To conclude, analysis of the dynamics across the UK food provisioning system which have accompanied the observed decline in UK meat consumption, indicates that this has resulted from interaction between multiple behavioural, socio-cultural, and corporate drivers (Figure SM5.5c).
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### Table SM5.2 Demand side mitigation: indicative potential by 2050 - Data and References

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<thead>
<tr>
<th>Sector/Service</th>
<th>Emissions in 2050</th>
<th>Demand side mitigation achieved through</th>
<th>Specific mitigation strategies</th>
<th>Explanation</th>
<th>Reduction potentials for STI in 2050</th>
<th>References</th>
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<tbody>
<tr>
<td>Food/Nutrition</td>
<td>18 Gt CO₂eq (bottom-up studies: including 9.08 land use change)</td>
<td>Socio-cultural factors</td>
<td>a) shift in dietary choice with reduced animal protein; b) avoid food waste; c) avoid over-consumption</td>
<td>a) green procurement; diet shifts; plant-based or plant-forward eating; b) food waste prevention; food sharing programs; c) lifestyle changes, avoid over-consumption</td>
<td>40% = 7.2 GtCO₂eq Range: 18%-87% (High confidence)</td>
<td>(Bajželj et al. 2014; Aleksandrowicz et al. 2016; Erb et al. 2016; Hiç et al. 2016; Springmann et al. 2016; Birney et al. 2017; Gunders et al. 2017; Hadjikakou 2017; Muller et al. 2017; Parodi et al. 2018; Poore and Nemecek 2018; Schanes et al. 2018; Springmann et al. 2018a,b; Willett and al. 2018; Graça et al. 2019; Pendrill et al. 2019; Willett et al. 2019; Bajželj et al. 2020; Clark et al. 2020; Jarmul et al. 2020; Makov et al. 2020; Crippa et al. 2021; Xu et al. 2021) Also see 5.3.1.1, 5.6.2.2, Chapter 7 (7.4.5), and Chapter 12 (12.4)</td>
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<td>Infrastructure use</td>
<td>Demand side mitigation potential: 44.2% (7.96 Gt CO₂eq)</td>
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<td>a) Enhances role of choice architectures, information; and incentive through financial instruments; b) waste management; recycling infrastructure</td>
<td>a) choice architecture instruments; food labels; food-based dietary guidelines; regulations on novel foods; marketing restrictions on energy-dense foods; taxes/subsidies to steer food choices towards options contributing to sustainable and healthy dietary pattern; b) food waste management and recycling: use of food waste as animal feed (including insects); improved collection &amp; composting, anaerobic digestion</td>
<td>7% = 0.76 GtCO₂eq (Medium confidence)</td>
<td>(Smith et al. 2013; Muller et al. 2017; Mbow et al. 2019; Clark et al. 2020; Makov et al. 2020; Xu et al. 2021) Also see 5.3.1.1, Chapter 7 (7.4.5), and Chapter 12 (12.4)</td>
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<td>Industry / Manufactured product</td>
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<td>improvements in manufacturing;</td>
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<td></td>
<td>21% = 2.72 GtCO2</td>
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<td></td>
<td>Range: 15%-28% (High confidence)</td>
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<td>(Carruth et al. 2011; Milford et al. 2011;</td>
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<td>Allwood and Cullen 2012; Das et al. 2016;</td>
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<td>Gutowski et al. 2017; IEA 2017; UNEP 2017;</td>
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<td></td>
<td>Grubler et al. 2018; Material Economics and</td>
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<td>Economics 2018; Cabrera Serrenho et al. 2019;</td>
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<td>Hertwich et al. 2019; Horton et al. 2019;</td>
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<td></td>
<td>Shanks et al. 2019; IEA 2020a,b; IRP et al.</td>
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</tbody>
</table>
b) reducing the need for energy consumption through the installation of new efficient technologies in material production plants and through plant systems and operating practices that contribute to reduce energy needs.


Also see 5.3.1.1, and Chapter 11 (11.2.1, 11.3.2). Note that the range cited here includes material sufficiency strategies that are beyond the scope of Chapter 11.

### Shipping / Mobility

<table>
<thead>
<tr>
<th>Demand side mitigation potential: 30 % (0.348 Gt CO₂)</th>
<th>1.16 Gt CO₂ (IEA WEO2020, STEPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Socio-cultural factors</strong></td>
<td>-</td>
</tr>
<tr>
<td><strong>Infrastructure use</strong></td>
<td>-</td>
</tr>
<tr>
<td><strong>Technology adoption</strong></td>
<td>adoption of energy efficient technology/systems, Technology measures and management measures, such as slow steaming, weather routing, and propulsion efficiency devices can deliver more fuel savings than the investment required</td>
</tr>
<tr>
<td></td>
<td>30% = 0.348 GtCO₂ Range: 1%-40% (Low confidence)</td>
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<tr>
<td></td>
<td>(Faber et al. 2009; Wang et al. 2010; Psaraftis and Kontovas 2013; Gilbert 2014; Lindstad et al. 2015; Tillig et al. 2015; Lindstad et al. 2016; Bouman et al. 2017; ITF 2018)</td>
</tr>
<tr>
<td>Also see 5.3.1.1</td>
<td></td>
</tr>
</tbody>
</table>

### Aviation / Mobility

<table>
<thead>
<tr>
<th>Demand side mitigation potential: 53.80 % (0.968 Gt CO₂)</th>
<th>1.8 Gt CO₂ (IEA WEO2020, STEPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Socio-cultural factors</strong></td>
<td>avoid long haul flights; shift to trains wherever possible</td>
</tr>
<tr>
<td></td>
<td>40% = 0.72Gt CO₂ Range: 0-50% (Medium confidence)</td>
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<tr>
<td></td>
<td>(Wynes and Nicholas 2017; GOV.UK 2020; Schäfer et al. 2019; Timperley 2019; IATA 2020; Gössling et al. 2021; IEA 2021; Sharmina et al. 2021)</td>
</tr>
<tr>
<td>Also see 5.3.1.1, 5.4.2</td>
<td></td>
</tr>
<tr>
<td><strong>Infrastructure use</strong></td>
<td>-</td>
</tr>
<tr>
<td><strong>Technology adoption</strong></td>
<td>adoption of energy efficient technologies; technologies with improved aerodynamics adopting energy-efficient/evolutionary technologies, like engine efficiency or aerodynamics improvement</td>
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<tr>
<td></td>
<td>23% = 0.248 Gt CO₂ Range: 0-30% (Medium confidence)</td>
</tr>
<tr>
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<td>(Zeinali et al. 2013; Wynes and Nicholas 2017; Schäfer et al. 2019; Falter et al. 2020; IATA 2020; IEA 2021; Sharmina et al. 2021)</td>
</tr>
<tr>
<td>Also see 5.3.1.1</td>
<td></td>
</tr>
</tbody>
</table>
**Land Transport / Mobility**

**Demand side mitigation potential: 66.75%**

7.0 Gt CO$_2$

*IEA WEO 2020, STEPS*

**Socio-cultural factors**

- a) teleworking or telecommuting;
- b) active mobility such as walking and cycling

**Infrastructure use**

- a) public transport;
- b) shared mobility;
- c) compact city

Infrastructure use (specifically urban planning and shared pooled mobility) has about 20-50% (on average) potential in the land transport GHG emissions reduction, especially via redirecting the ongoing design of existing infrastructures in developing countries, and with 30% as our central estimate.

5% = 0.350 Gt CO$_2$

Range: 0-15%

*(High confidence)*


(Kitou et al. 2003; Mrkajic et al. 2015; Creutzig et al. 2016; Zahabi et al. 2016; Maizlish et al. 2017; Wynes and Nicholas 2017; Keall et al. 2018; Neves and Brand 2019; Gilby et al. 2019; Zhang et al. 2019; Bagheri et al. 2020; Brand et al. 2021; IEA 2020c)

Also see 5.3.1.1, 5.3.3, 5.3.4.1

Chapter 10 (10.2)

30% = 1.994 GtCO$_2$

Range: 20%-50%

*(High confidence)*


Also see 5.3.1.1, 5.3.4.2, 5.6.2.2, Chapter 8 (8.2, 8.4), and Chapter 10 (10.2)
### Technology adoption

- **a)** electric vehicles;
- **b)** efficient cars/smart cars

Technology adoption, particularly banning ICEs and EV targets and efficient lightweight cars

50% = 2.327 GtCO₂

Range: 30%-70%  
*(High confidence)*

### Buildings/Shelter

<table>
<thead>
<tr>
<th>Socio-cultural factors</th>
<th>8.73 Gt CO₂ (IEA, WEO2020, STEPS)</th>
<th>15% = 1.310 GtCO₂</th>
</tr>
</thead>
</table>
| social practices in energy saving; and lifestyle and behavioural changes | social practices in energy saving including passive management and flexibility over time; behavioural and lifestyle changes; adaptive heating and cooling by changing temperature set points; changing dress code; saving energy in water-heating (e.g., shorter showers); switching off extra lights, and appliances | Range: 5%-50%  
*(High confidence)* |

### Infrastructure use

- **a)** compact cities;
- **b)** living floor space rationalization;
- **c)** architectural design

Infrastructure use: making choices towards urban planning interventions, e.g. increasing density, mixed-use, makes large building spaces unnecessary; spatial planning; innovation in urban institutional structure; promote regenerative culture, behaviour

- **b)** decent living standard, floor space per capita, sharing economy
- **c)** architectural design; passive building; increase green, blue

20% = 1.484  
Range: 10%-40%  
*(High confidence)*

(Rutsey 2015; Majumdar and Jash 2015; Sato and Saio 2016; Plötz et al. 2017; EEA 2018; Broadbent et al. 2018; Biresselioğlu et al. 2018; Liu et al. 2018; Onn et al. 2018; Hill et al. 2019; ITF 2019; Khalili et al. 2019; Shi et al. 2019; Skrúcaný et al. 2019; Zhuge et al. 2019; Ayetor et al. 2020; Bastida-Molina et al. 2020; Bhardwaj et al. 2020; Costa et al. 2020; IEA 2020c;a; ITF 2020b; Nimesh et al. 2020; Rajper and Albrecht 2020; Rodriguez et al. 2020; Peters et al. 2020; Gómez Vilchez and Jochem 2020; Ehrenberger et al. 2021; Hou et al. 2021) Also see 5.3.1.1, 5.3.3, 5.6.2.3, Chapter 8 (8.2, 8.4), and Chapter 10 (10.4 and 10.7)
<table>
<thead>
<tr>
<th>Technology adoption</th>
<th>a) energy efficiency; b) shift to renewables</th>
</tr>
</thead>
</table>
| a) adopting energy efficient solutions; preference for net-zero new buildings retrofits including improved building envelope improved building technical systems for HVAC, cooking and electrical uses; choice for smart home and digitalization; efficient appliances; control systems; b) choice for installation of renewables: on-site/rooftop renewables (e.g., solar thermal and solar pv) microgrids; switch to lower carbon fuels | 50% = 2.969  
Range: 30%-70% (High confidence) |
Table SM5.3 Electricity illustrative scenario by 2050: electrification and demand side measures - Data and References

<table>
<thead>
<tr>
<th>Emissions in 2050</th>
<th>Electrification and demand side measures</th>
<th>Gt CO₂ Changes in 2050</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.5 Gt CO₂</td>
<td>additional electrification of industry</td>
<td>+1.93</td>
<td>(Bruckner et al. 2014; BloombergNEF 2020; IEA 2021)</td>
</tr>
<tr>
<td></td>
<td>additional electrification of transport</td>
<td>+1.98</td>
<td>(Bruckner et al. 2014; Sims et al. 2014; Creutzig et al. 2015; BloombergNEF 2020; IEA 2021)</td>
</tr>
<tr>
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<td>additional electrification of buildings</td>
<td>+2.39</td>
<td>(Bruckner et al. 2014; Lucon et al. 2014; BloombergNEF 2020; IEA 2021)</td>
</tr>
<tr>
<td></td>
<td>demand-side measures of industry</td>
<td>-1.4</td>
<td>See socio-cultural factors and infrastructure use under industry</td>
</tr>
<tr>
<td></td>
<td>demand-side measures of transport</td>
<td>-2.3</td>
<td>See socio-cultural factors and infrastructure use under land transport</td>
</tr>
<tr>
<td></td>
<td>demand-side measures of buildings</td>
<td>-2.8</td>
<td>See socio-cultural factors and infrastructure use under buildings</td>
</tr>
<tr>
<td></td>
<td>load/demand management</td>
<td>-1.22</td>
<td>(Bruckner et al. 2014; IRENA 2018; BloombergNEF 2020)</td>
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</tbody>
</table>
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