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Demand, Services and Social Aspects of Mitigation
Supplementary Material

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Table of Contents

Chapter 5, Supplementary Material I: 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; Jorgenson et al. 2018; Hayward and Roy 2019; 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 the First to Fourth Assessment Reports (AR1 to AR4), rational decision-making as defined by microeconomics was the implicit assumption, where homogeneous individual agents maximise self-focused utility or expected utility, with the only consequential variations of this *homo economicus* relating to income, wealth, risk attitude, and time discount rate (Persky 1995). The Fifth Assessment Report (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 and policymakers 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 greenhouse gas (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 the Sixth Assessment Report (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 5.SM.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 Box 5.1, Figure 1). 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 5.SM.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.

Buildings' GHG emissions can be reduced by retrofitting with passive design, effcient technologies and controls, and distributed renewables.	**Heat** and electricity supply from renewables and increased effciency, and reuse of buildings and materials are needed to reduce GHG emissions.	**Energy demand** is growing, *inter alia*, because of increasing floor space and higher need for cooling.	With international trade, not only territorial but also consumption-based **GHG emission** footprints require policy attention.
In **social housing**, gender and care of the elderly, for example, in face of heat waves, are key and require good housing stock and management.	**Cities** are places of visioning, where collective actions instigate changes in infrastructure to low-carbon service provisioning.	**Communities** can instigate local energy and retrofitting projects, and create trust, but operate in the context of broader governance.	Direct environmental **taxes**, if sufficiently high, are highly effective and fair, if complemented with impartial redistribution of revenue.
Rural households are often vulnerable and require information and credit to adapt to climate change.	**Governance** operates on multiple scales and includes many actors, all of relevance for climate change mitigation.	**Sustainability** encompasses holistic goal thinking, drawing bridges between social and physical sciences.	Cost savings motivate reducing energy and material use, but current **cost-benefit** analysis undervalues uncertain environmental damages.
Policy instrument deployment is seen as evolutionary trajectories, requiring adapting policy packages and intelligent sequencing.	Absolute decoupling between **GDP** and GHG emissions has not (yet) been observed at appropriate scale.	**Low-carbon development** builds on complemetary demand- and supply-side policies and decisions.	High growth in **tourism** and aviation endangers climate stabilisation, with COVID-19 opening the opportunity to rethink tourism.
Connected, mixed-use, and medium-density cities with public **transport** systems and cycling infrastrure avoid the necessity of car use.	Rapid substitution of coal and gas by renewable **electricity** is key, especially for emerging economies, and to also realise low-carbon sector coupling.	A small price-elasticity effect on demand can generate wider change in consumption via behavioural contagion and resulting **new social norms**.	**Reducing waste** and reusing it for new purposes are central tenets of a (still speculative) circular economy.
Changing people's mode and distance, e.g., by enabling active **travel**, and by reducing luxury air travel and luxury cars, supports decarbonisation.	Attitudes, perceived behavioural control, and charging station unavailability are key constraints for adoption of **electric vehicles**.	Farm-system solutions, reducing food mileage, and especially **dietary** shift can reduce GHG emissions dramatically and improve health.	Changing **consumption** to low-GHG emissions, high-wellbeing options build on behavioural change, new social norms, structures and incentives.

Policy cluster Housing cluster Mobility cluster Consumption cluster

Figure 5.SM.1 | Cluster-oriented summary of key demand-side messages drawn from academic publications in social science literature. Source: Creutzig et al. (2021a).

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 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 (Ulgiati 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 Chapter 5) and higher well-being levels.

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 socio-economic 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 socio-economic inequality. Sufficiency in economics (also discussed in Chapter 9 of this report, and Chapter 21 in Johansson et al. (2012)) 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; Mongsawad 2012; Bierwirth and Thomas 2019; Fawcett and Darby 2019; Hayward and Roy 2019; Monyei et al. 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; Rogelj et al. 2018; Van Lange 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 minimising 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; Perrot and Sanni 2018; Vivanco et al.

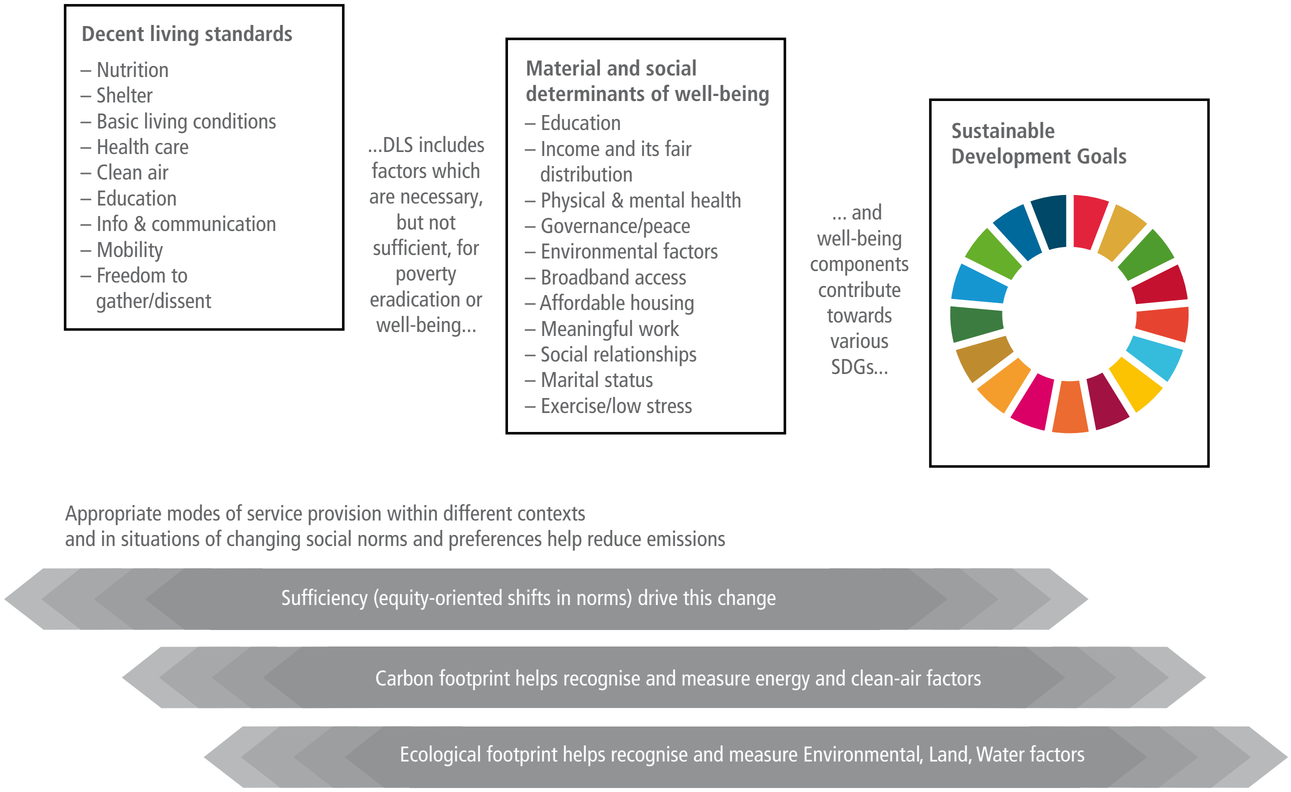

Figure 5.SM.2 | The relationships among indicators of Decent Living Standards, Well-being, Footprints, Sufficiency and the Sustainable Development Goals.

2018; Pigato et al. 2020; Safarzadeh et al. 2020; Freire-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 policymakers 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 (González-García et al. 2018; Beattie and Sale 2009; 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 frames, and systems boundaries (Matthews et al. 2008; Chen et al. 2016; Kanemoto et al. 2016; Bello et al. 2018; Fenner et al. 2018; Lenzen et al. 2018; Pichler et al. 2019; Zheng and Suh 2019).

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; Raymond et al. 2019; Richardson 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 5.SM.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).

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).

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 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; Creutzig et al. 2016, 2018; Grubler et al. 2018; Mundaca et al. 2019). It broadens the individually focused agency framework of micro- and behavioural economics and psychology by also including considerations of structure and meaning, that is, 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 (Bamberg et al. 2007a; Mills and Schleich 2012; Poortinga et al. 2019; Niamir et al. 2020a); 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 everyday 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; Sawer et al. 2020). Social practice theory emphasises interactions between artefacts, competences, and cultural meanings (Røpke 2009; Shove and Walker 2014). 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. 2017) and thus accommodates the five drivers of change and stability discussed in Sections 5.4 and 5.5 in Chapter 5 of the contribution of Working Group III to AR6.

This primer provides additional information about key concepts and processes described in AR6 Chapter 5. Section 5.SM.1 elaborates on key concepts from Section 5.2 of Chapter 5: well-being, equity, and decent living standards and their relation to equity, social trust, and governance. Sections 5.SM2 to 5.SM.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 Figure 5.SM.3: 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 UNEP 2020). Section 5.SM.5 provides additional

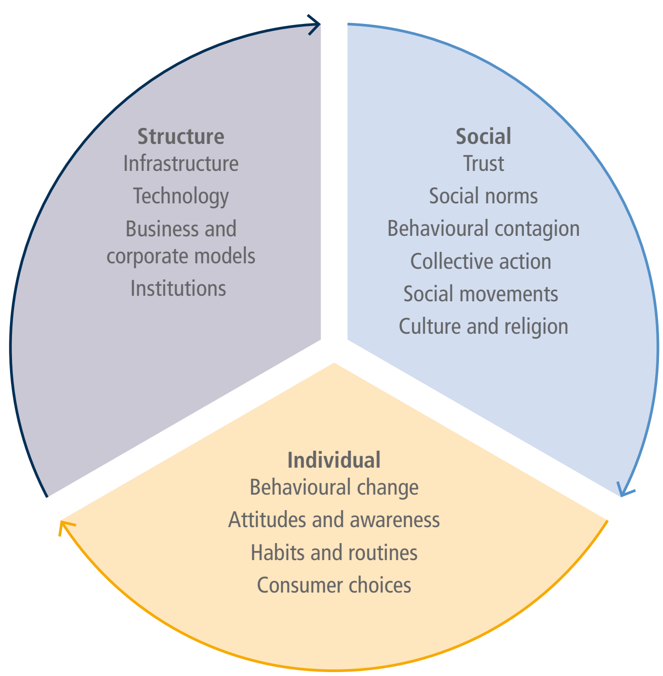

Figure 5.SM.3 | Drivers of change: Perspectives and underlying concepts and processes.

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background on transitions and Section 5.SM.6 provides several case studies drawn from both developed and developing countries as illustrative examples of social processes in various contexts of technology uptake, service provisioning and shifts in choices.

5.SM.1 Well-being, Decent Living Standards, Equity, and the SDGs

Well-being for all is a cornerstone of sustainable development (Princen 2003; Dasgupta and Dasgupta 2017) 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; McGregor and Pouw 2017; Sekulova et al. 2017; Fioramonti et al. 2019; Gabriel and Bond 2019; Hayward and Roy 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 (e.g., 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 (Arrow et al. 2013; Dasgupta et al. 2015; UNEP 2018; Sugiawan and Managi 2019). Another measure for considering aspects of social progress beyond economic activity is the social progress index, 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 – 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; Antony and Visweswara Rao 2007; Saramet 2007; Acs and Turner 2008; Saramet et al. 2009; Rao and Baer 2012; Frye 2013; Brand-Correa and Steinberger 2017; Rao and Min 2018b) (Chapter 9, Section 9.1). Services which make up DLS include adequate nutrition, shelter, hygiene, clothing, health care, 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 (Doyal and Gough 1991; Wilkinson and Pickett 2009; Frank 2010; Stiglitz 2012; Oishi et al. 2018; Xie et al. 2018; Wilkinson and Pickett 2019a). 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).

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, social, and service-oriented mitigation approaches (Estrada-Oyuela 2000).

Mitigation, equity and well-being go hand in hand (Box 5.3 and Figure 5.5 in Chapter 5) Both distributive justice and procedural justice are important in mitigation action (Roy et al. 2018a). As outlined in AR6 Chapter 5, 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; Easterlin et al. 2010; D'Ambrosio and Frick 2012; Diener et al. 2013; McCubbin et al. 2013; Schneider 2016; Shields 2016; Lamb and Steinberger 2017; White 2017; Stone et al. 2018; Tu and Hsee 2018; Wang et al. 2019). Once subsistence needs are met, relative well-being is much more significant for human happiness than absolute consumption levels (Frank 1999; Wilkinson and Pickett 2009; Stiglitz 2012; Reyes-García 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; Reyes-García et al. 2016; Schröder 2018). Some social components of well-being, such as community cohesion, social capital, and trust, are higher in more equitable societies (Delhey and Dragolov 2014; Schneider 2016; Roser et al. 2019). 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 (Schneider 2016; Kragten and Rözer 2017; Ngamaba et al. 2018). More equitable societies are also more economically efficient societies (Wilkinson and Pickett 2009; Stiglitz 2012; Singer 2018).

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; Phan 2008; Jordahl 2007; 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; Jordahl 2007; Steijn and Lancee 2011; Levin-Waldman 2012; Stiglitz 2012; You 2012; Yamamura 2014; Lazarus and van Asselt 2018; Okereke 2018; Di Gregorio et al. 2019).

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).

5.SM.2 Individual Perspectives

5.SM.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, and so on. 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.

5.SM.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 legally, socially or 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 consumers to take steps to avoid such violations. The large point is that demand-side behaviour is above all a 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 consumers' well-being, and consumers 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).

5.SM.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 disproportionally 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 people's values and interests. 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 to 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 a 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 (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.

5.SM.3 Social Perspectives

5.SM.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 Witt 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 socio-demographic, 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 (Le Gallic et al. 2018; Van den Berg et al. 2019). 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 (Darnton et al. 2011; DEFRA 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 (Frenkel et al. 2013; Thøgersen 2017b), 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 de-emphasises 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 reducing long-haul flights (Dubois et al. 2019; Nash 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 (Le Gallic et al. 2018; Millot 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).

5.SM.3.2 Education

Modifying climate change awareness and perception help the dynamics of this radical shift (Halady and Rao 2010; Odjugo and Ovuyovwiroye 2013; Dombrowski et al. 2016; 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 (Velazquez et al. 2006; Ferrer-Balas et al. 2009; Fisher and McAdams 2015; 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 little 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 and/or reinforce a culture of climate awareness through new educational forms based on a convergence between education and communication ('educommunication') (Rodrigo-Cano et al. 2019) that 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).

5.SM.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 collection action on climate change (Haluza-DeLay 2014). They can draw on shared symbols, identities and narratives to promote collective action on climate change (Roy et al. 2012; Bomberg and Hague 2018). For example 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 attitudes 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 programmes that train clergy remain silent on climate change or ecological issues; in North America only 24% of programmes included instructions (Heistein et al. 2017). Joint programmes between academia and clergy have potential to bring climate action to communities that otherwise lack resources to interact with non-subsistence issues and to connect climate change mitigation with local contexts.

5.SM.3.4 Civil Society, NGOs, and Social Movements

People, governed by values and social norms, make individual decisions on how to live, eat, travel, and so on: 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 the IPCC Special Report on Global Warming of 1.5°C (SR1.5) 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).

5.SM.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 cookstoves 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).

SR1.5 recognised that narratives and storytelling can enable the imagining of novel visions of place-based 1.5°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., 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 on 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).

5.SM.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 (Tozer and Klenk 2019). These 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).

5.SM.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 the 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 policymakers and energy companies. Adopting alternative meanings of communities, for example 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 (Walker et al. 2010; Barnett et al. 2012). Engagement that overlooks technology meanings can produce unintended consequences, prolonging social conflict and reducing trust (Devine-Wright 2011; Wolsink 2007).

5.SM.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' refers 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 (Short 2002; Woods 2003), 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).

5.SM.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 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 2013). 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 inconsistently 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 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; Thaler and Sunstein 2009; Niamir 2019). 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 (=1996) appraised 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 (Sunstein and Reisch 2014; Bamberg et al. 2015; Niamir et al. 2020a). Some norms are obstacles to human well-being and autonomy. It is appropriate for laws to alter norms if they diminish well-being and autonomy (Sunstein 1996; Thaler and Sunstein 2009).

Being part of a group or organisation that values the environment and advocates mitigation actions promotes mitigation actions (Ruepert et al. 2017; Sloot et al. 2018), particularly when individuals strongly identify with the peer group (Biddau et al. 2016; Fielding and Hornsey 2016; Jans et al. 2018) or have strong ties with this group (Weenig and Midden 1991). When people feel strongly connected to a group,

5SM

they may come to adopt the goals of the group as their own goals (Jans et al. 2018). Similarly, block leader approaches in which change is initiated from the bottom-up are effective in promoting mitigation behaviours (Abrahamse and Steg 2013); local ambassadors are more successful at convincing others when they have already adopted the promoted behaviour or programmes themselves as this increases their credibility (Kraft-Todd et al. 2018).

5.SM.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 change 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.

5.SM.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; and a change in consumption habits and the adaption of lifestyles compliant with more power supply interruption (Maïzi et al. 2017; Maïzi and Mazauric 2019). 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; McMeekin and Southerton 2012; Hyysalo et al. 2013; Shove et al. 2014), 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): (i) cognitive activities involve the learning of new skills and competencies, (ii) interpretive and sense-making activities imbue new technologies with meanings, (iii) 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: (i) 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), (ii) tinkering themselves with the technology (Hyysalo et al. 2013; Nielsen et al. 2016), and (iii) 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: (i) business environments, including the development of business models, supply chains, repair facilities and infrastructures (Markard 2011; van Waes et al. 2018), (ii) 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 (iii) institutional environments, including safety regulations, reliability standards and performance requirements (Reddy et al. 1991; Andrews-Speed 2016; Bohnsack et al. 2016).

5.SM.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) (Chapter 5, Section 5.4.5). The literature around policy processes and implementation with respect to demand and services relates that timing and policy choice are 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 sector, 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).

5.SM.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) (Botsman and Rogers 2011; Belk 2014a; Schor 2014; Möhlmann 2015; Frenken and Schor 2017; Parente et al. 2018). However, there are criticisms regarding business relationships 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 to 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) is economically motivated since most room-sharing hosts pay their rent and utility bills by sharing their living spaces. Environmental motivations are important particularly for mobility, such as 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 for 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 is still edible but has 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, and 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).

5.SM.5 Transition

5.SM.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 (Røpke 2009; Shove and Walker 2014). The energy cultures framework highlights feedbacks between materials, norms, and behavioural practices (Stephenson et al. 2015; Jürisoo et al. 2019). 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 (McMeekin and Southerton 2012; Geels et al. 2017).

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; Battilana et al. 2009; Dolata 2009).

The energy cultures framework and socio-technical transitions theory both understand demand-side transitions as involving interactions between: (i) radical social or technical innovations, which deviate in one or more dimensions from dominant configurations, (ii) relatively stable dominant energy cultures or socio-technical systems, (iii) 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; Seto et al. 2016; Clausen et al. 2017; Ivanova et al. 2018).

5.SM.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 (Klitkou et al. 2015; Seto et al. 2016; Clausen et al. 2017; Ivanova et al. 2018). Existing activities and demand patterns are often stabilised by behavioural lock-in mechanisms identified by psychological and economic literature: (i) 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); (ii) preferences and attitudes can orient people positively towards existing practices over alternatives, for example private car travel over public transport (Sheller 2004); and (iii) 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: (i) 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); (ii) existing policy paradigms shape how policymakers frame problems and think about solutions (Kern et al. 2014; Rosenbloom 2018; Buschmann and Oels 2019; Schmidt et al. 2019), often leading to a focus on upstream technologies, market-based instruments, and hands-off policy styles (Whittle et al. 2019), and (iii) incumbent firms use corporate political strategies and resistance tactics to delay or water down strong climate policies (Kolk and Pinkse 2007; Geels 2014; Smink et al. 2015; Ferguson et al. 2016; Supran and Oreskes 2017). 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) mean 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 (Demski et al. 2015; Plumecocq et al. 2018).

5.SM.5.3 Rates of Change, Acceleration

Rates of change are usually slow in the first and second transition phases, because experimentation, social and technological learning, the creation of standards, and the reduction of uncertainty take a long time, often decades (Wilson 2012; Bento 2013; Bento et al. 2018). 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., Mansfield 1968; Martino et al. 1978; Davis 1979; Tornatzky and Klein, 1982; Mahajan et al. 1990; Ausubel 1991; Grubler 1991; Feder & Umali, 1993. Bayus 1994; Comin and Hobijn 2003; Rogers 2003; Van den Bulte and Stremersch 2004; Meade and Islam 2006; Comin and Hobijn 2010; Peres et al. 2010).

Diffusion rates are determined by two broad categories of variables, those intrinsic to the technology, product or 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., Geels 2002; Fouquet 2008), 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 (with other things remaining same), (i) larger systems take more time to evolve, grow, and change compared to smaller ones; (ii) the creation of entirely new systems (diffusion) takes a longer time than replacements of existing technologies or practices (substitution); and (iii) late adopters tend to adopt faster than early pioneers.

The micro-level literature on technology- (or product-) specific rates of adoption is vast (Tornatzky and Klein 1982; Grübler et al. 1999; Rogers 2003; Peres et al. 2010) and has identified three clusters of variables: (i) relative advantage; (ii) adoption effort required and complexity; and (iii) 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 see Sovacool and Geels (2016).

5.SM.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 5.SM.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 (especially 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 a 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 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 5.SM.1 | Assessment of feasibility/barriers for the diffusion of demand-side mitigation options.

	Behavioural	Technology, infrastructure	Business	Institutional	Socio-cultural
Improve options: Electric vehicles, light-weight vehicles, wood as building material, solar thermal devices, insulation, energy-efficient appliances and light bulbs, low-carbon fabrics, improved clean cookstoves	**Small–medium** – Small change in behavioural routines – Costs or lack of interest may hold back purchase	**Small–medium** – Most component substitutions are technically feasible – Some options require infrastructure change (e.g., recharging)	**Medium** – More expensive than existing technologies (although learning curves reduce costs) – Infrastructure change would increase costs – Incumbent firms may delay reorientation to new technical capabilities	**Small** – No major institutional change needed (as existing systems mostly remain intact) – Diffusion slow without policy support and financing models	**Small** – No major cultural change needed
Shift options: Shift from cars to public transport or cycling, less material-intensive construction, district heating, passive house, smaller devices, circular economy, shift from meat to other protein sources	**Medium–large** – Medium change in behavioural routines – Not widespread consumer interest	**Small–medium** – Increased use of existing or new technologies – New provisioning systems and sometimes new infrastructures	**Medium–large** – Investments in technologies, supply chains, business models, infrastructure – Resistance from incumbent industries	**Medium–large** – Medium institutional change (new agencies, responsibilities) – Large policy change (new goals, programmes, instruments) – Substantial political resistance and struggle	**Medium–large** – Large scale cultural change for some shift options (e.g., less meat)
Avoid options: Integrated transport and land-use planning, tele-working, compact cities, smaller apartments, shared common spaces, multi-generational housing, change dress codes, change work times, change temperature settings, consume less goods, keep calories in line with health guidelines, daylighting	**Large** – Large change in behavioural routines – Small to limited consumer interest	**Small–medium** – Limited technical change (except for some options) – Mostly using existing or proven technologies	**Variable** – High costs for some options (e.g., compact cities), low costs for others (e.g., change dress codes)	**Large** – Large institutional change (e.g., overcoming silo-problem, new agencies) – Large policy change for some options (e.g., compact cities, tele-working)	**Large** – Large cultural change in many options (e.g., smaller apartments, consume less in some contexts)

5.SM.6 Case Studies

5.SM.6.1 Consumer-led Innovation in Solar Photovoltaics

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 USA, Japan, Germany, Australia, and China – in that sequence – over seven decades (Nemet 2019) (Figure 5.SM.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

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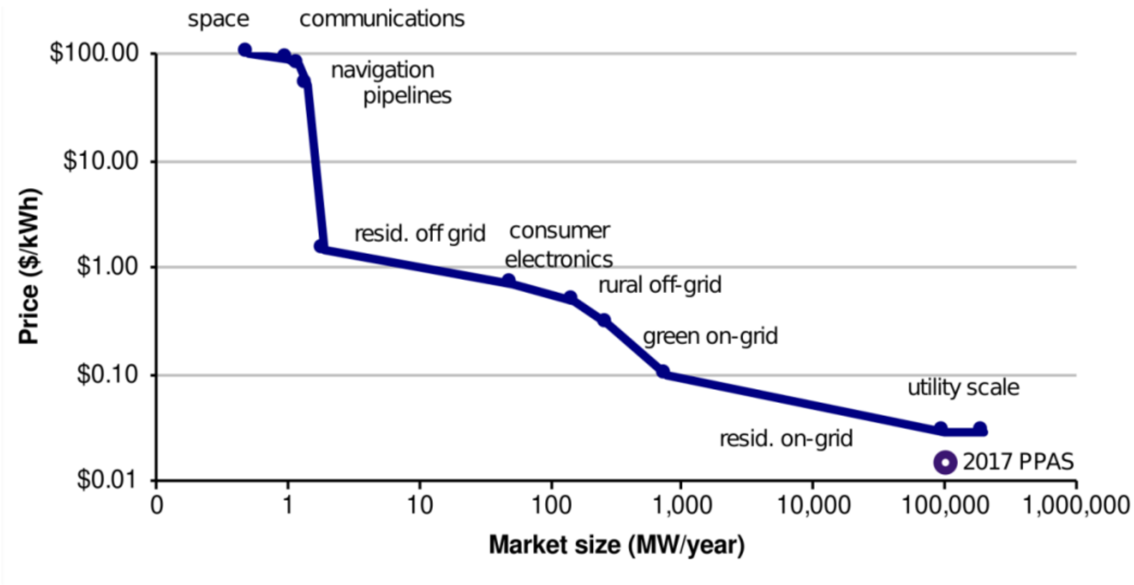

Figure 5.SM.4 | Technological learning curve of photovoltaic solar energy. Prices decline with production and associated innovation and economics of scale. As a granular technology that can be matched to diverse settings, technological learning is faster than in most other technologies. Source: Nemet (2019).

transformed into the Ministry of Non-conventional Energy Sources (MNES) in 1992 and the Ministry of New and Renewable Energy (MNRE) in 2006. The 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 solar programme 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 programme 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 ofits '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 out, 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).

5.SM.6.2 Energy Services for Cooking: Improved Cookstoves and the Shift to New Forms of Energy

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 livelihoods (Batchelor et al. 2019). For example, about 85% of the fine particulate matter (PM2.5) emissions in Africa in 2018 came from the burning of biomass indoors (IEA 2019).

Cleaner and safer cooking solutions in South Asia and Africa can obtain a range of benefits: reduce firewood collection from the forest (Pattanayak et al. 2004; Sharma et al. 2020); reduce the burden on women (Hazra et al. 2014); deliver better health (Pant 2008; Thakuri 2009); higher labour productivity (Kalyanaratne 2014) for the users and reduce emissions of greenhouse gases (Zhang et al. 2013; Somanathan and Bluffstone 2015; Lafave et al. 2019; Bluffstone et al. 2021). Studies have shown that net reduction in emissions from the switch from biomass as a cooking fuel to LPG has clear climate and non-climate benefits (Anenberg et al. 2017; Singh et al. 2017; Ghilardi et al. 2018; Goldemberg et al. 2018). In India between 2001 and 2011 an increase in LPG use led to a net emissions (Kyoto and non-Kyoto gases) reduction of 6.73 $MtCO_2$-eq (0.94 $MtCO_2$-eq in rural areas and 5.79 $MtCO_2$-eq in urban areas) with 7.2 million tonnes of fuel wood displaced (0.99 million tons in rural areas and 6.19 million tons in urban areas) (Singh et al. 2017).

To improve the affordability of the cleaner fuel and cookstove choice, actors at the households level need motivation through pricing policies like subsidies and installation cost waivers (Troncoso and Soares da Silva 2017; Dickinson et al. 2018; Sankhyayan and Dasgupta 2019). Well intended subsidy programmes often do not help world's poorest to adopt cleaner fuel, suggesting a need for targeted programmes (Bhattarai et al. 2018). The decision towards actual transition to a cleaner cooking fuel and technology is often governed by other demand-side drivers and barriers like lifestyle and socio-cultural norms and practices.

The useful energy demand for cooking is a crucial component of the choice between various cooking technology options and has been the subject of numerous studies (Balmer 2007; Nerini et al. 2016; Van de Ven et al. 2019; Forouli et al. 2020; Silaen et al. 2020; Taylor et al. 2020). Daioglo et al. (2012) conclude that a mean of 3 MJ cap^{-1} day^{-1} (range 0.77 to 7.22) of useful energy is required for cooking (equivalent to 125 kWh $month^{-1}$ for a household of five. Accommodating cooking energy services in off-grid electrification technologies, 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. (2018) 0.2 kWh could be enough to cook rice for a household of four in a rice cooker.

Shifts towards electric and LPG stoves in Bhutan (Dendup and Arimura 2019), India (Pattanayak et al. 2019), Ecuador (Martínez et al. 2017; Gould et al. 2018) and Ethiopia (Tesfamichael et al. 2021); are taking over now compared to past trends towards improved biomass stoves in China (Smith et al. 1993). Significant subsidy (Litzow et al. 2019), information (Dendup and Arimura 2019), social marketing and availability of technology in the local markets are some of the key instruments to increase adoption of improved cookstoves (Pattanayak et al. 2019); through supply chain creation availability was scaled up enormously in India (Sankhyayan and Dasgupta 2019). Shift in use of energy-efficient cooking appliances like pressure cookers and rice cookers is now almost universal in South Asia and beginning to penetrate the African market as consumer attitudes are changing towards household cooking appliances with higher energy efficiencies (Batchelor et al. 2019).

There is substantial evidence that more awareness programmes are needed to break the behavioural barriers towards usage of modern cooking fuel (Giri and Aadil 2018). While designing improved cookstoves, along with technical aspects like energy efficiency, emission mitigation, and improving health outcomes, researchers also need 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 a barrier to using it. Studies from Senegal and Mexico show 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 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 and vessels used have an impact on the choice of cooking fuel and technology (Ravindranath and Ramakrishna 1997; Atanassov 2010; Mukhopadhyay et al. 2012; Bielecki and Wingenbach 2014; Troncoso et al. 2019); the perception of food tastes (Wiedinmyer et al. 2017; Mukhopadhyay et al. 2012; Hooper et al. 2018), and differences in housing style and whether the cooking area is indoors or outdoors (Chattopadhyay et al. 2017) delay transition to a cleaner fuel or new technology. In Mozambique the dissemination of solar cookstoves has seen limited success as their design failed to capture end users' need for cooking processes like boiling, steaming or frying and how the food is prepared, for example standing versus sitting (Otte 2014).

Universal access to clean and modern cooking energy could cut premature deaths from household air pollution by two-thirds relative to baseline in 2030, while reducing forest degradation and deforestation and contributing to the reduction of up to 50% of CO_2 emissions from cooking relative to baseline by 2030 (IEA 2017; Hof et al. 2019). 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 electric cooking at mass scale (Figure 5.SM.5a).

5.SM.6.3 Shift in Mobility Service Provision through Public Transport in Kolkata

In densely populated cities in India, mobility is still predominantly dependent on public transport, walking and cycling (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' strategies in new cities like Ahmedabad, Bangalore, and Pune (Ghosh et al. 2018; Roy et al. 2018b; Ghosh and Schot 2019).

In the megacity Kolkata, as many as twelve different 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 a few hundred in metro or suburban trains. Sharing also happens 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, and 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 systems and so on. 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 of Housing and Urban Affairs 2005), National Urban Transport Policy (2006) (Ministry Of Urban Transport 2006) and Kolkata's comprehensive urban mobility plan (2008) (IDFC 2008).

A key role is played by the state government to improve the system as a 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 have been 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 the 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, and so on. Each of Kolkata's diverse public transport regimes has changed along different pathways in the past decade, owing partly to new standards and regulations, but also to new values, beliefs and expectations, and cognitive and normative meanings. Four distinctive regime-level change processes are: (i) improvements and new meaning to public buses, (ii) greening and formalisation of auto-rickshaws, (iii) institutional and socio-cultural support for the emergence of the 'app-cab' service, and (iv) a cycling ban policy on 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 a '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 systems, and so on. A crucial driver of this policy has been to discourage users to shift their demand from public to private mobility. The primary focus of these strategies has been to cater to people's 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 a 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 class passengers, autorickshaws gained new meaning and with digitalisation, taxi services were 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 effects on social justice, equity and inclusion are 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 on many major arterial roads as a traffic management strategy under the pressure of congestion and to avoid road accidents in overcrowded 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 to 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 direction of change (Roy et al. 2018b; Schot and Steinmueller 2018). 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

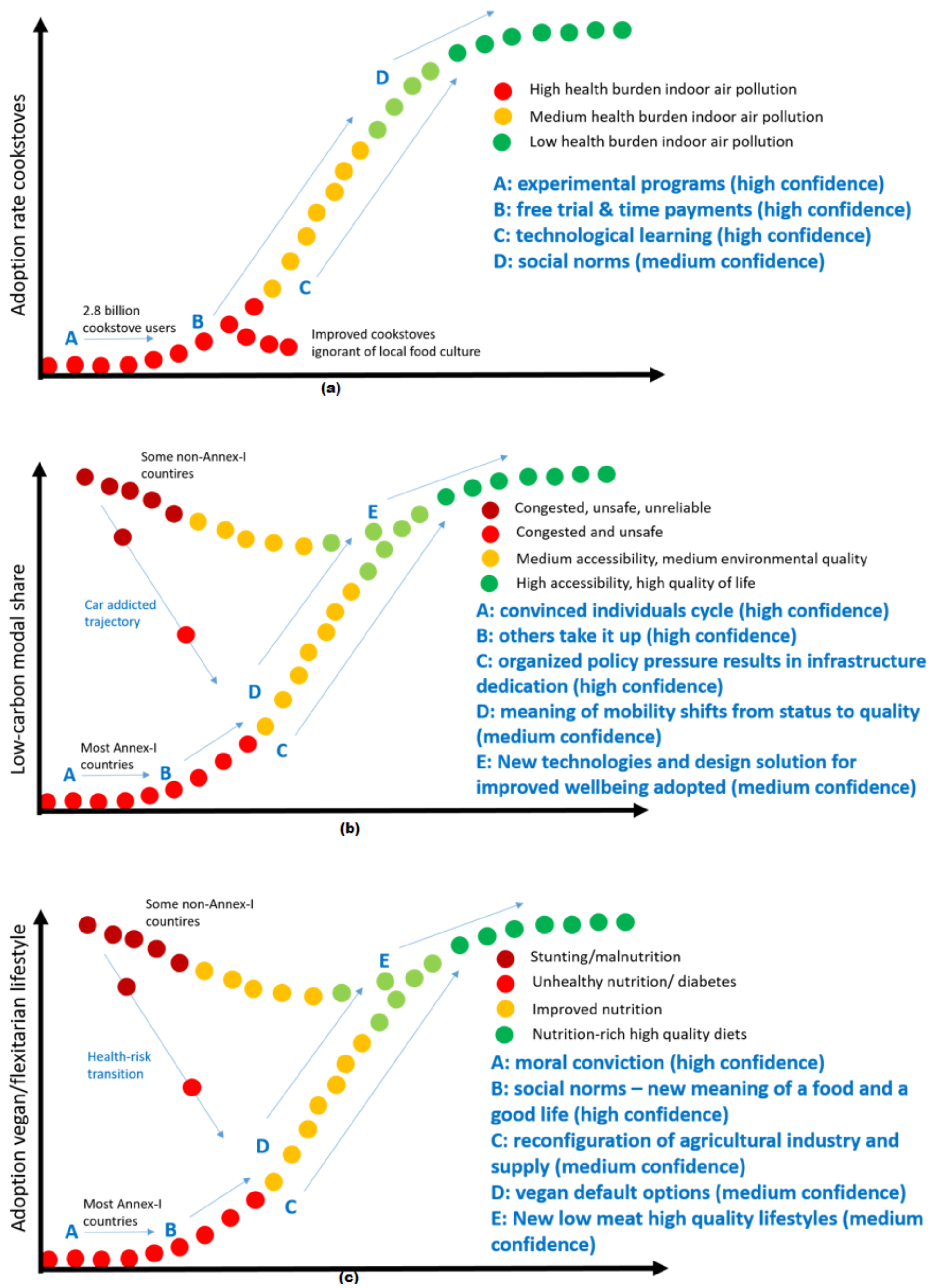

Figure 5.SM.5 | Exemplary transition dynamics for the cases of improved cookstoves, modal shifts, and diet shift.

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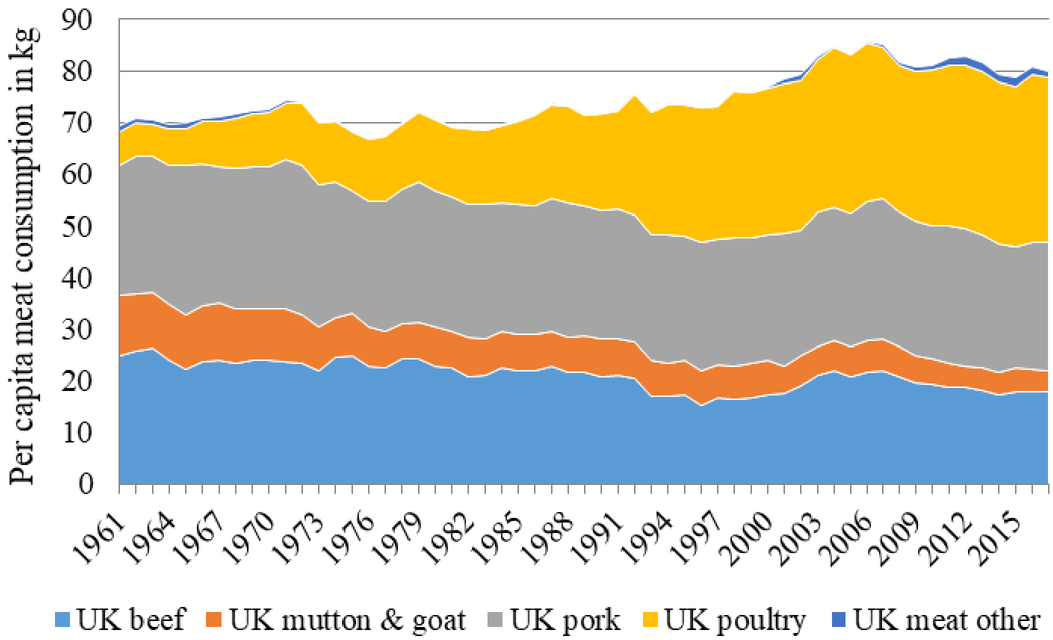

Figure 5.SM.6 | UK per capita meat consumption (kg). Source: constructed from FAO Food Balances database.

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 momentum 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 is important, instead of chasing global trends, especially if such trends increase inequality at the cost of an 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 5.SM.5b).

5.SM.6.4 Dietary Change and Reduced Meat Consumption

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 (Figure 5.SM.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 the 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 5.SM.5c).

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Chapter 5, Supplementary Material II

Table 5.SM.2 | Demand-side mitigation: indicative potential by 2050 – data and references.

Sector/ service	Emissions in 2050	Demand-side mitigation achieved through	Specific mitigation strategies	Explanation	Reduction potentials in 2050	References
Food/nutrition *Demand-side mitigation potential: 44.2% (7.96 $GtCO_2$-eq)*	18 $GtCO_2$-eq *(bottom-up studies: including 9.08 land use change)*	**Socio-cultural factors**	**a)** shift in dietary choice with reduced animal protein **b)** avoid food waste **c)** avoid over-consumption	**a)** green procurement; diet shifts; plant-based or plant-forward eating **b)** food waste prevention; food sharing programmes **c)** lifestyle changes, avoid over-consumption	40% = 7.2 $GtCO_2$-eq Range: 18–87% (*High confidence*) (1.9 $GtCO_2$-eq 'economic' potential in the AFOLU sector accounting only for diverted agricultural production and excluding land use change)	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); 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 Sections 5.3.1.1 and 5.6.2.2, Chapter 7 (Section 7.4.5), and Chapter 12 (Section 12.4)
		Infrastructure use	**a)** Enhances role of choice architectures, information, and incentives through financial instruments **b)** waste management; recycling infrastructure	**a)** choice architecture instruments; food labels; food-based dietary guidelines; regulations on novel foods; marketing restrictions on energy-dense food; 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 and composting, anaerobic digestion	7% = 0.76 $GtCO_2$-eq (*Medium confidence*)	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 Section 5.3.1.1, Chapter 7 (Section 7.4.5), and Chapter 12 (Section 12.4)
		End-use technology adoption	–	–	–	–
Industry/manufactured product *Demand-side mitigation potential: 28.7% (4.13 $GtCO_2$)*	15.4 $GtCO_2$ (Mean of IEA WEO2020, STEPS (14.4 $GtCO_2$) and IP-ModAct projection (16.3 $GtCO_2$)	**Socio-cultural factors**	Shift in demand towards sustainable consumption such as, intensive use of longer lived repairable products; benchmarking and labelling low emissions materials and products	Promoting products designed with longer lifespan so users can extend their lifetime through repair, refurbishing, and remanufacturing, instigated via standardisation, modularity and functional segregation Standardisation, modularity and functional segregation can help extending the lifespan of steel in products and therefore present a significant opportunity to reduce demand and carbon dioxide emissions from steel production. Similar approaches are possible with other emission intensive materials	5% = 0.72 $GtCO_2$ Range: 3–7% (*High confidence*)	Cao et al. (2009); Cooper et al. (2014); Ryen et al. (2015); Grubler et al. (2018); Cao et al. (2019); IEA (2019a, 2020a,b); Lausselet et al. (2021) Also see Section 5.3.1.1, and Chapter 11 (Sections 11.2.1 and 11.3.2). Note that the range cited here includes material sufficiency strategies that are beyond the scope of Chapter 11
		Infrastructure use	Networks established for recycling, repurposing, remanufacturing and reuse of metals, plastics and glass, labelling low emissions materials and products	Once a product is at the end of its technical lifespan, increasing the reusability and recyclability of a product's components and materials. For example, old cars are dismantled into components to be reused for repairing cars while old components that cannot be reused are recycled as scrap metals; both approaches can reduce demand for primary materials	5% = 0.68 $GtCO_2$ Range: 4–7% (*High confidence*)	Petersen and Solberg (2005); Cooper and Gutowski (2017); Material Economics and Economics (2018); Ellen MacArthur Foundation (2019); Hertwich et al. (2019); IEA (2019b, 2020a,b); IRP et al. (2020); Pauliuk et al. (2021) Also see Section 5.3.1.1, and Chapter 11 (Section 11.3.3, Table 11.6)
		End-use technology adoption	Green procurement to access material efficient products and services; access to energy efficient and CO_2 neutral materials	**a)** materials-efficient service provision involves avoided material demand through dematerialisation, the sharing economy, materials-efficient designs, and yield improvements in manufacturing **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 reduced energy needs	21% = 2.72 $GtCO_2$ Range: 15–28% (*High confidence*)	Carruth et al. (2011); Milford et al. (2011); Allwood and Cullen (2012); Das et al. (2016); Gutowski et al. (2017); IEA (2017); Rakib et al. (2017); UNEP (2017); Grubler et al. (2018); Material Economics (2018); Cabrera Serrenho et al. (2019); Hertwich et al. (2019); Horton et al. (2019); Shanks et al. (2019); Crijns-Graus et al. (2020); IEA (2020a,b); IRP et al. (2020); Coenen et al. (2021); Cordella et al. (2021); Fishman et al. (2021); Glöser-Chahoud et al. (2021); Hart et al. (2021); IEA 2021; Lausselet et al. (2021); Pauliuk et al. (2021); Pauliuk and Heeren (2021); Reis et al. (2021); Wolfram et al. (2021) Also see Section 5.3.1.1, and Chapter 11 (Sections 11.2.1 and 11.3.2). Note that the range cited here includes material sufficiency strategies that are beyond the scope of Chapter 11
Shipping/mobility *Demand-side mitigation potential: 30% (0.348 $GtCO_2$)*	1.4 $GtCO_2$ (Mean of IEA WEO2020, STEPS (1.2 $GtCO_2$) and IP-ModAct projection (1.6 $GtCO_2$)	**Socio-cultural factors**	–	–	–	
		Infrastructure use	–	–	–	
		End-use technology adoption	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	30% = 0.348 $GtCO_2$ Range: 1%–40% (*Low confidence*)	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) Also see Section 5.3.1.1
Aviation/mobility *Demand side mitigation potential: 53.80% (0.968 $GtCO_2$)*	1.8 $GtCO_2$ (Mean of IEA WEO2020, STEPS (1.8 $GtCO_2$) and IP-ModAct projection (1.9 $GtCO_2$)	**Socio-cultural factors**	Avoid long haul flights; shift to trains wherever possible	Avoiding long-haul flights and shifting to train wherever possible can contribute to aviation GHG emissions reduction	40% = 0.72$GtCO_2$ Range: 0–50% (*Medium confidence*)	Wynes and Nicholas (2017); Schäfer et al. (2019); Timperley (2019); UK Department for Business, Energy & Industrial Strategy (2020); IATA (2020); Gössling et al. (2021); IEA (2021); Sharmina et al. (2021) Also see Sections 5.3.1.1 and 5.4.2
		Infrastructure use	–	–	–	
		End-use technology adoption	Adoption of energy-efficient technologies; technologies with improved aerodynamics	Adopting energy-efficient/ evolutionary technologies, like engine efficiency or aerodynamics improvement	23% = 0.248 $GtCO_2$ Range: 0–30% (*Medium confidence*)	Zeinali et al. (2013); Wynes and Nicholas (2017); Schäfer et al. (2019); Falter et al. (2020); IATA (2020); IEA (2021); Sharmina et al. (2021) Also see Section 5.3.1.1

Sector/ service	Emissions in 2050	Demand-side mitigation achieved through	Specific mitigation strategies	Explanation	Reduction potentials in 2050	References
Land transport mobility *Demand-side mitigation potential: 66.75 % (4.671GtCO$_2$)*	6.9 GtCO$_2$ (Mean of IEA WEO2020, STEPS (7.0 GtCO$_2$) and IP-ModAct projection (6.7 GtCO$_2$)	**Socio-cultural factors**	**a)** teleworking or telecommuting **b)** active mobility such as walking and cycling	**a)** key 'Avoid' strategies involve telecommuting and teleworking behaviour and lifestyle changes **b)** active mobility, such as walking and cycling; behavioural and lifestyle changes; change travel behaviour, prioritising car-free mobility	5% = 0.350 GtCO$_2$ Range: 0–15% (*High confidence*)	Kitou and Horvath (2003); Roth et al. (2008); Fu et al. (2012); Lari (2012); Zhu and Mason (2014); Creutzig et al. (2016); O'Keefe et al. (2016); Martínez-Jaramillo et al. (2017); Asgari and Jin (2018); Shabanpour et al. (2018); Akbari and Hopkins (2019); Elldér (2020); Hook et al. (2020); Ivanova et al. (2020); O'Brien and Yazdani Aliabadi (2020); Riggs (2020); Brand et al. (2021); Pomponi et al. (2021) Senbel et al. (2014); Mrkajic et al. (2015); Creutzig et al. (2016); Zahabi et al. (2016); Maizlish et al. (2017); Wynes and Nicholas (2017); Keall et al. (2018); Gilby et al. (2019); Neves and Brand (2019; Zhang et al. (2019); Bagheri et al. (2020); IEA (2020c); Brand et al. (2021) Also see Sections 5.3.1.1, 5.3.3, and 5.3.4.1, and Chapter 10 (Section 10.2)
		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	30% = 1.994 GtCO$_2$ Range: 20–50% (*High confidence*)	Baptista et al. (2012); d'Orey et al. (2012); Wang et al. (2013); Baptista et al. (2015); Husnjak et al. (2015); Namazu and Dowlatabadi (2015); Creutzig et al. (2016); ITF (2016); Samaras et al. (2016); Barann et al. (2017); Basarić et al. (2017); Fan et al. (2017); Fournier et al. (2017); ITF (2017a,b,c); Monzon et al. (2017); Tarulescu et al. (2017); Jung and Koo (2018); Lu et al. (2018); Namazu et al. (2018); Underwood and Fremstad (2018); Wu et al. (2018); Yin et al. (2018); Coulombel et al. (2019); Ding et al. (2019); Simpson et al. (2019); Alarfaj et al. (2020); IEA (2020a,c,d); ITF (2020a); Noussan and Tagliapietra (2020); Te and Lianghua (2020); Wilson et al. (2020); Yi and Yan (2020); Zhang et al. (2020); Arbeláez Vélez and Plepys (2021); Sheppard et al. (2021) Also see Sections 5.3.1.1, 5.3.4.2, and 5.6.2.2, Chapter 8 (Sections 8.2 and 8.4), and Chapter 10 (Section 10.2)
		End-use technology adoption	**a)** electric vehicles **b)** efficient cars/smart cars	Technology adoption, particularly banning internal combustion engines and setting targets for electric vehicles and efficient lightweight cars	50% = 2.327 GtCO$_2$ Range: 30–70% (*High confidence*)	Lutsey (2015); Majumdar and Jash (2015); Sato and Saijo (2016); Plötz et al. (2017); EEA (2018); Biresselioglu et al. (2018); Broadbent 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); Gómez Vilchez and Jochem (2020); IEA (2020c,a); ITF (2020b); Nimesh et al. (2020); Peters et al. (2020); Rajper and Albrecht (2020); Rodriguez et al. (2020); Xu et al. (2020); Ehrenberger et al. (2021); Hou et al. (2021) Also see Sections 5.3.1.1, 5.3.3, and 5.6.2.3, Chapter 8 (Sections 8.2 and 8.4), and Chapter 10 (Sections 10.4 and 10.7)
Buildings/Shelter *Demand-side mitigation potential: 66% (5.763 GtCO$_2$)*	10.3 GtCO$_2$ (Mean of IEA WEO2020, STEPS (8.7 GtCO$_2$) and IP-ModAct projection (11.8 GtCO$_2$)	**Socio-cultural factors**	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 (Chapter 9 presents it under non-technological and behavioural mitigation options and strategies section (9.5) and potentials (9.6))	15% = 1.310 GtCO$_2$ Range: 5–50% (*High confidence*)	Darby (2006); Smith et al. (2007); Wei et al. (2007); Fujino et al. (2008); Dietz et al. (2009); Murakami et al. (2009); Eyre et al. (2010); Brown et al. (2013); Creutzig et al. (2016); Podgornik et al. (2016); Rai and Henry (2016); Alders (2017); Chang et al. (2017); Niamir et al. (2018); Zhang et al. (2018); Ahl et al. (2019); Institute for Global Environmental Strategies et al. (2019); Niamir (2019); IEA (2020a,b); Niamir et al. (2020b); Khanna et al. (2021) Also see Sections 5.3.1.1, 5.4.1, and 5.4.2, Chapter 8 (Section 8.3.3), and Chapter 9 (Sections 9.5 and 9.6)
		Infrastructure use	**a)** compact cities **b)** living floor space rationalisation **c)** architectural design	**a)** 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 (Chapter 9 presents it under the sufficiency pillar and discusses the global and regional emission reduction potentials in 2050, see Figure 9.16) **c)** architectural design; passive building; increase green, blue spaces; ecosystem based/nature-based solutions	20% = 1.484 Range: 10%-40% (*High confidence*)	Raman (2010); négaWatt Association (2011); Van Den Wymelenberg (2012); Volochovic et al. (2012); Lin et al. (2013); Fell et al. (2014); Rafsanjani et al. (2015); Creutzig et al. (2016); Darby et al. (2016); Hasegawa (2016);Lohrey and Creutzig (2016); Taniguchi et al. (2016); Borck and Brueckner (2017); Sun and Hong (2017); Bai et al. (2018); Grubler et al. (2018); Levesque et al. (2018); négawatt (2018); Peng and Bai (2018); Rao and Min (2018); Ürge-Vorsatz et al. (2018); Bierwirth and Thomas (2019); Cabrera Serrenho et al. (2019); Ellsworth-Krebs et al. (2019); Levesque et al. (2019); Mastrucci and Rao (2019); Rao et al. (2019); Elnagar and Köhler (2020); IEA (2020e,a); Ivanova and Büchs (2020); Kuhnhenn et al. (2020); Mata et al. (2020); Millward-Hopkins et al. (2020); Kikstra et al. (2021); Seto et al. (2021) Also see Sections 5.2, 5.3.1.1, and 5.4, Chapter 8 (Sections 8.2, 8.3, 8.4, 8.5.1, and 8.6), and Chapter 9 (9.5, 9.6.2, Figure 9.16)
		End-use technology adoption	**a)** energy efficiency **b)** shift to renewables	**a)** adopting energy-efficient solutions: preference for net-zero new buildings, retrofits including improved building envelope, improved building technical systems for heating, ventilation, and air conditioning, cooking and electrical uses; choice for smart home and digitalisation; efficient appliances, control systems (for more information, see chapter 9 the global and regional potential emissions reduction from demand-side energy efficiency (9.6.2, Figure 9.16)) **b)** choice of installation of renewables: on-site/rooftop renewables (e.g., solar thermal and solar PV) microgrids, switch to lower carbon fuels (also see chapter 9 the global and regional potential emissions reduction from on-site renewable energy technologies (9.6.2, Figure 9.16))	50% = 2.969 Range: 30–70% (*High confidence*)	Dolman et al. (2012); Brown et al. (2013); Hidalgo (2013); Hazra et al. (2014); Krey et al. (2014); Ürge-Vorsatz et al. (2014); Markandya et al. (2015); Niamir et al. (2020c); Novikova et al. (2015); UNFCCC (2015); Grubler et al. (2016); Oluleye and Smith (2016); Purohit et al. (2016); Ruparathna et al. (2016); Timilsina et al. (2016); Virage-énergie Nord-Pas de Calais (2016); Wittchen et al. (2016); Baranzini et al. (2017); Braulio-Gonzalo and Bovea (2017); Hansen and Hauge (2017); Iten et al. (2017); Mastrucci and Rao (2017); Purohit and Höglund-Isaksson (2017); Puzzolo and Pope (2017); Sharma et al. (2017); Climact (2018); Economidou et al. (2018); Giraudet et al. (2018); Oluleye et al. (2018); Mata et al. (2018); Niamir et al. (2018); Peñaloza et al. (2018); González-Mahecha et al. (2019); Institute for Global Environmental Strategies et al. (2019); Irshad et al. (2019); Langevin et al. (2019); Mastrucci and Rao (2019); Niamir (2019); van der Grijp et al. (2019); Cabeza and Chàfer (2020); IEA (2020a,e); Mahadevan et al. (2020); Mastrucci et al. (2020); Mata et al. (2020); Niamir et al. (2020a); Markewitz et al. (2015) Also see Sections 5.3.1.1 and 5.6, and Chapter 9 (Sections 9.4, 9.6.2, Figure 9.16)

Table 5.SM.3 Electricity illustrative scenario by 2050: electrification and demand-side measures – data and references.

Emissions in 2050	Electrification and demand side measures	$GtCO_2$ changes in 2050	References
10.5 $GtCO_2$ *(IEA WEO2020, STEPS)*	additional electrification of industry	+1.93	Bruckner et al. (2014); BloombergNEF (2020); IEA (2021)
	additional electrification of transport	+1.98	Bruckner et al. (2014); Sims et al. (2014); Creutzig et al. (2015); BloombergNEF (2020); IEA (2021)
	additional electrification of buildings	+2.39	Bruckner et al. (2014); Lucon et al. (2014); BloombergNEF (2020); IEA (2021)
	demand-side measures of industry	–1.4	See socio-cultural factors and infrastructure use under industry
	demand-side measures of transport	–2.3	See socio-cultural factors and infrastructure use under land transport
	demand-side measures of buildings	–2.8	See socio-cultural factors and infrastructure use under buildings
	load/demand management	–1.22	Bruckner et al. (2014); IRENA (2018); BloombergNEF (2020)

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