Chapter 5: Demand, services and social aspects of mitigation

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Executive summary

Focusing on people and the services that are important for their wellbeing offers novel demand-side solutions to climate change mitigation (*high confidence*). Ambitious low-energy demand-side scenarios demonstrate the feasibility of reducing global final energy demand in 2050 to 245 EJ, 40% lower than final energy demand in 2018, while maintaining or improving wellbeing. {5.1.1, 5.3.3}

The twin goal of attaining wellbeing for all, and mitigating climate change shapes demand-side service-oriented solutions (*high confidence*). Decent Living Standards (DLS) is a benchmark of material conditions for human well-being and overlaps with many Sustainable Development Goals (SDGs). It sets minimum requirements of energy use for enabling wellbeing for all {5.2.1, 5.2.2, Table 5.1, Figure 5.5, Box 5.2}

Demand-side service-oriented solutions vary between and within countries and regions according to living conditions and context (*high confidence*). Due to global variations in DLS attainment and per capita emissions, global rich have greater possibilities for emissions reductions while meeting DLS goals. In the near term, many Non-Annex I countries require better access to low-emissions energy sources for DLS service provision, especially in the non-commercial informal sector thus protecting marginalized people. {5.2.2, Figure 5.4, Figure 5.5, Figure 5.6, Box 5.2}

Social equity and fair resource distribution improves governance capacity for mitigating climate change (*high confidence*). Higher social equity increases trust in governance, and thus capacity of good governance, which in turn is a necessary condition to implement climate policies. Both direct improvements in social equity, specifically including gender equity, and climate policies lead to better wellbeing for all. Secondary education for all and equal gender representation in parliaments and other processes are key leverage points that eventually lead to good governance on climate change. {5.2.3, Figure 5.7}

Demand-side, service oriented solutions can deliver additional climate change mitigation, while saving costs (*high confidence*). Low-cost behaviour changes such heating and cooling set-point adjustments, shorter showers, reduced appliance use, shifts to public transit, less meat intensive diets, and improved recycling can deliver an additional 3GtCO$_2$-eq savings in 2050, beyond the savings achieved in traditional technology-centric mitigation 1.5°C scenarios ambitions. The costs of reaching mitigation targets are generally lower when incorporating ASI strategies for deep energy and resource demand reductions. Models with lifestyle case indicated that mitigation costs, expressed as global GDP loss, would be 14% lower than the SSP2 reference scenario in 2100, for both 2C and 1.5C mitigation targets. {5.3.3, Table 5.5}

Decent living standards for all are met through different pathways of service delivery systems; only some of them are compatible with low emissions (*high confidence*). The leverage effect for improvements in end-use service delivery through behavioural, technological, and market organizational innovations is large through upstream resource reduction {5.3.1, Figure 5.9}. Indicative potentials for improvements revealed by exergy analysis range from a factor 10 to 20 with the highest improvement potentials at the end-user and service provisioning levels {5.3.1.1}. Realizable service level efficiency improvement from 14% in 2020 to 41% in 2050 corresponds to saving 334 EJ, i.e. two thirds (66%) of 2020 primary energy use. {5.3.1.2}

Efficiency gains by way of changing service delivery system are the largest in buildings *(high confidence)*. By type of use, efficiency gains are the largest for buildings (including appliances): -160 EJ (pervasive adoption of "Passivhaus" building designs), followed by materials with -100 EJ (dematerialization via digitalization and shared mobility and recycling) and mobility with -50 EJ (more public transport, shared mobility, and electrification of vehicles). {5.3.1.2}

Substantial increases in service levels to meet the twin objectives of development in the Global South and decent living standards for all, take back some of the energy savings but enhance wellbeing faster *(high confidence)*. {5.3.1.2, 5.4.5.5}

Low demand scenarios reduce both supply side capacity additions and the need for negative emissions technologies to reach emissions targets. ***(high confidence*)**. Primary energy demand in the LED scenario by 2050 is however with 279 (-232) EJ still 45% lower than in 2020 (511 EJ). {5.3.1, 5.3.3, Figure 5.1, 5.3.3.2}

Low-carbon service provisions that are informed by the Avoid-Shift-Improve (ASI) approach and targeted to achieve decent living standard for all can lower resource use and thus also leverage supply side transformations ***(high confidence)***. The sharing economy, digitalization, and the circular economy are emerging megatrends compatible with ASI strategies, with the circular economy tentatively more on the supply side, and the sharing economy and digitalization tentatively more on the demand side. {5.3.3, Table 5.2, Table 5.3, Table 5.4}

Current energy and GHG emission trends related to digitalization, the shared economy, and the circular economy contribute little, if at all, climate change mitigation (*high confidence*). Digitalization, as all-purpose technology, offers new services and efficiency improvements, but also realizes additional possibly large energy consumption and GHG emissions due to scale effects. Digitalization, automation and artificial intelligence has potential for a plethora of new products and applications that are efficient on their own but has scope for undesirable changes or absolute increases in demand for products and energy use. An important consideration in all ASI strategies is the potential for unintended rebound and run-away effects, which must be carefully avoided through various regulatory and behavioural measures. {5.3.2, 5.3.2.1, Figure 5.10, Figure 5.11}

Regulation and public policy are necessary to steer the digital economies towards effective climate change mitigation (*high confidence*). Combining efficiency gains with service provisioning systems that are minimally resource intensive, such as radically shared mobility opportunities, reduces GHG emissions by at least a third. Specific applications of digital services, such as telework, teleconferencing, and intelligent energy systems realizes mitigation potential by substituting other applications. For example, a modern smartphone requiring 5 watts of power can provide the same end user services (e.g., telephony, music, video, etc.) as previously associated with over 15 different end-use devices that collectively required 449 watts of power. Early and proactive public policies help avoiding excess energy use. {5.3.3.1}

Avoiding food waste reduces GHG emissions substantially ***(very high confidence)*****.** Consumers are the largest source of food waste; behavioural changes such as meal planning, use of leftovers, and avoidance of over-preparation can be important service-oriented solutions, while supermarkets can modify their supply chain and marketing, and improvements to expiration labels by regulators would reduce unnecessary disposal of unexpired items, resulting in a mitigation potential of 0.8-6.0 $GtCO_2$-eq yr^{-1} by 2050. {5.3.3.1}

Diet shifts to plant-based nutrition lead to healthier life and reduce GHG emissions (*very high confidence*). Estimated GHG emissions reductions associated with dietary shifts to low meat diets, plant based nutrition, vegetarian diets, or vegan diets range from 0.7-7.3, 4.3-6.4, and 7.8-8 $GtCO_2$-eq yr^{-1} by 2050, respectively {5.3.3.1, 5.4.4.4}. However, changes in meanings and agency tend to be important for such 'shift' and 'avoid' transition pathways because these involve substantial behavioural change that requires strong motivations and new beliefs. {5.4.5.1}

Spatial structures of service provisioning result in a factor 10 difference in GHG emissions of transport ***(high confidence*)****.** Improved urban planning and smart logistical systems help avoiding kilometres travelled and lead to fuel, and, hence, emissions savings, while delivering equivalent or improved service levels. Light-weighting vehicles, avoiding material input, also lead to significant emissions savings through improved fuel economy {5.3.2.1}. A balanced portfolio of avoid, shift, and improve policies brings the global transport sector emissions in line with global warming of not more than 1.5°C. {5.3.3.1, Chapter 10, 10.7}

Building designs help reduce energy waste ***(high confidence)***. Buildings designed to use daylight and lighting sensors, passive houses, thermal mass, and smart controllers help in avoiding demand for space conditioning services. Eliminating standby power losses can avoid energy wasted for no useful service in many appliances/devices. Smaller dwellings, shared housing, and building lifespan extension are all consistent with DLS can reduce overall demand for lighting and space conditioning services can reduce the overall demand for carbon-intensive building materials such as concrete and steel. {5.3.2.1}

Shifting to high intensity of service per product improve wellbeing *(high confidence)*. Shift strategies such as shifting from single-family to multi-family dwellings, shifting from passenger cars to rail or bus, shifting materials to reduce resource and emissions intensities e.g., low-carbon cement blends and shifting from conventional to additive manufacturing processes reduce materials requirements and improve end-use product performance {5.3.2.1}. Travel behaviour, business models, and especially public policy will be key components in determining how pooling and shared automated electric vehicles impacts unfold. {5.3.2.2.1}

In combination with pricing of energy use and GHG emissions, the circular economy supports climate mitigation *(high confidence)* . Relevant contribution to climate change mitigation at giga ton scale by the circular economy will remain out of scope, if decision makers and industry do not reduce primary inputs, either by restriction or taxation on GHG emissions and raw material extraction. {5.3.2.2.1, 5.3.2.2.3}

Current trends show that potential of demand-side solutions is not utilized; climate mitigation therefore requires transformative policies, business models and institutions to implement demand side solutions and overcome institutional, market, technological, and cultural and behavioural barriers *(very high confidence*). Individual component level change achieve little, due to reinforcing lock-ins in social, infrastructural, and cultural domains. Only coordinated change in several domains lead to the emergence of new low-carbon configurations. {5.4.5.1}

Demand side solutions require motivation and capacity for change *(high confidence)*. Capacity for change requires the availability and knowledge about change options and the resources to consider, initiate and maintain change. Correctly understanding the roles, goals, and needs of different actors, their perceptions and decision processes and the feedback between their actions is imperative in designing effective policies and decision support systems. {5.4.1, 5.4.5.1}

Behavioral change, not embedded in structural change, will contribute little to climate change mitigation *(high confidence)*. Motivation by individuals or households around the world to change energy consumption behaviour is low. Individual Motivation and capacity are impacted by different factors in different demographics and geographies. These factors go beyond traditional socio demographic and economic predictors and also consider psychological variables such as awareness, subjective norms, and perceived behavioural control. {5.4.1}

Decision making that does not follow standard rational model is prevalent in many energy-relevant contexts and require regulation beyond economic incentives *(high confidence)* . Individuals act in more roles than that of consumer when they make energy decisions, and the social environment, cultural practices, public knowledge, producer technologies and services all play influence decisions, too. To influence consumer demand, policymakers have an assortment of tools, including prohibitions, mandates, taxes, fees, subsidies, and "nudges", 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," such as wind or solar. {5.4.1.1, 5.4.2.3, 5.4.4.1}

Collective action by individuals as part of formal social movements or informal lifestyle movements underpins system change *(high confidence)*. Collective action and organization is crucial to shift the possibility space of public policy on climate change mitigation. In other instances, mitigation policies that allow the active participation of all stakeholders, result in building social trust, new coalitions and thus initiate a positive cycle in climate governance capacity and policies. {5.2.3, 5.4.1, 5.4.5.3}

Transition pathways require action by different actors at different stages *(high confidence)*. Transition pathways often start with experimental attempts by dedicating individuals and social norm settings in niche cultures. In adequate constellation, these groups can find entry points in the political process resulting in infrastructure reconfigurations or policies that support the further uptake of technologies or lifestyles. Agency of individuals as social change agents and narrators of meaning is central. {5.4.5.3}

Current effects of climate change are already threatening the viability of existing business practices *(high confidence)*. Lobby activism ('merchants of doubt'), protecting rent extracting business models, prevent political action. Concerns of job losses in particular industries are justified and public discourses and policies are required to preserve the livelihoods, respect, and dignity of all workers and employees involved. {5.4.5.3}

Middle actors play a crucial albeit underestimated role in establishing low-carbon professional standards and practices *(high confidence)*. Building managers, landlords, energy efficiency advisers, technology installers and car dealers, influence patterns of mobility and energy consumption by acting as 'middle actors' or 'intermediaries' in the provision of building or mobility services. {5.4.1, 5.4.5.3}

Mitigation policies that correspond to and communicate with the values people have are more likely to be successful *(high confidence)*. Values differ between cultures. Measures that support autonomy, energy security and safety, equity and environmental protection, and fairness may resonate well in many communities. {5.4.3}

Carbon pricing works the best if contextualized within the notions of fairness *(high confidence)*. A carbon levy earmarked for green infrastructures or as salient return of revenues corresponding to widely accepted notions of fairness increases political acceptability of carbon pricing. {5.4.6}

Greater contextualization and granularity in policy approaches is important to address the challenges of rapid transitions towards zero-carbon systems *(high confidence)*. Larger systems take more time to evolve, grow, and change compared to smaller ones**.** The creation of entirely new systems (diffusion) takes longer time than replacements of existing technologies/practices (substitution)**.** Late adopters tend to adopt faster than early pioneers{5.4.5.4}. Obstacles and feasibility barriers are high in early transition phases. Barriers decrease as a result of technical and social learning processes, network building, scale economies, cultural debates and institutional adjustments. {5.4.5.6, Table 5.6}

5.1 Introduction

The Sixth Assessment Report of the IPCC (AR6), for the first time, features a full chapter on demand, services and social aspects of mitigation. It builds on the AR4, which linked behaviour and lifestyle change to mitigating climate change (IPCC 2007a,b; Roy and Pal 2009), the Global Energy Assessment (Roy et al. 2012), and the AR5, which identified sectoral demand-side solutions across chapters (IPCC 2014a,b; Creutzig et al. 2016b). Since then the literature on the nature, scale, implementation and implications of demand-side solutions, and associated changes in lifestyles, social norms and well-being has been growing rapidly (5.4.1). The chapter's assessment of the social sciences, including psychology, sociology, and economics disciplines, reveals that social dynamics at different levels offer crucial entry points for acting on and mitigating climate change, with many options highlighting the political agency of individuals' scope for collective action.

5.1.1 Wellbeing for all

This chapter takes a human-scale perspective and investigates strategies to achieve wellbeing for all consistent with drastic cuts in GHG emissions. Wellbeing for all is a cornerstone of sustainable development (Princen 2003; Dasgupta and Dasgupta 2017) and underpins directly in half of the Sustainable Development Goals (SDGs). A focus on human wellbeing replaces GDP, which is an inadequate and sometimes misleading goal of socio-economic activities (Faber et al. 2012; Zimmerer 2012; Arrow et al. 2013; Dasgupta 2013; Griggs et al. 2013; Hobson 2013; Dasgupta 2014; Gabriel and Bond 2019; Hayward and Roy 2019). Human wellbeing is inclusive of procedures that give a voice to everyone. In turn, procedural inclusiveness is not only important on its own, but also to foster social acceptability, and to create the political space for mitigation solutions that work. Service provision that enables wellbeing to be delivered with low or no GHG emissions (and low energy use, material input) are of central dimension to this chapter (5.1.2). As a result, focusing on demand for services broadens the solution space beyond technological switches confined to the supply side of solutions that deliver identical or improved constituents of wellbeing, e.g., nutrition, shelter and mobility, at sometimes radically reduced energy and material input (Creutzig et al. 2018).

Human well-being is a description of the state of individuals' life situation in multiple dimensions that captures people's life circumstances. Human well-being is an 'abstraction used to refer to whatever is assessed in an evaluation of a person's life situation or being' in other words, is a description of the state of individuals' life situation (Mcgillivray and Clarke 2006). Constituents of well-being include health, happiness, meaningful work and social relationship, freedom and liberties, while determinants are the commodity inputs in the production of wellbeing such as food, shelter, water, access to knowledge and information (Dasgupta 2001). Well-being can be categorized either as "hedonic" or "eudaimonic". Hedonic well-being is related to a subjective state of human motivation, balancing pleasure over pain, and has gained influence in psychology assessing 'subjective well-being' such as happiness and life satisfaction, assuming that the individual is motivated to enhance personal freedom, self-preservation and enhancement (Sirgy 2012; Brand-Correa and Steinberger 2017; Ganglmair-Wooliscroft and Wooliscroft 2019; Lamb and Steinberger 2017). Eudaimonic well-being focuses on the individual in the broader context, associating happiness with virtue (Sirgy 2012) allowing for social institutions and political systems and considering their ability to enable individuals to flourish. Eudaimonic analysis supports numerous development approaches (Fanning and O'Neill 2019) such as the capabilities (Sen 1985), human needs (Doyal and Gough 1991) and models of psychosocial well-being (Ryan and Deci 2001).

In economics, welfare-evaluations are predominantly based on the preference approach. Preferences are typically assumed to be fixed, so that only changes in relative prices will reduce emissions. However, as decarbonisation is a societal transition, shifts in individuals' preferences will similarly contribute to climate change mitigation. Even if preferences are assumed to change in response to policy, it is nevertheless possible to evaluate policy, and demand-side solutions, by approaches to well-being/welfare that are based on deeper concepts of preferences across disciplines (von Weizsäcker 1971; Schipper 1989; Roy and Pal 2009; Fleurbaey and Tadenuma 2014; Dietrich and List 2016; Mattauch and Hepburn 2016). In cases of past societal transitions, such as smoking reduction, there is evidence that societies guided the processes of shifting preferences, and values changed along with changing relative prices (Nyborg and Rege 2003; Stuber et al. 2008). First evidence points to preference changes in consumption choices pertinent to decarbonisation (Grinblatt et al. 2008; Weinberger and Goetzke 2010) for mobility; (Costa and Johnson 2019), for diets; (Baranzini 2017), for solar panel uptake). If individuals' preferences and values change during a transition to the low-carbon economy, then this overturns conclusions on what count as adequate or even optimal policy responses to climate change mitigation in economics (Jacobsen et al. 2012; Schumacher 2015; Dasgupta et al. 2016; Daube and Ulph 2016; Ulph and Ulph 2018). In particular, if policy instruments, such as awareness campaigns, infrastructure development or education can change people's preferences, then policies or infrastructure provisions – socially constrained by deliberative decision making, which change both relative prices and preferences, are more valuable for mitigation than previously thought (Mattauch et al. 2018, 2016; Creutzig et al. 2016b).

The current socioeconomic system is based on high-carbon economic growth and resource use (Steffen et al. 2018). Several systematic review, reviewing more than 8000 individual papers, confirmed that the nexus between economic growth and energy use increases CO_2 emissions (Tiba and Omri 2017; Mardani et al. 2019). However, different patterns emerge in the causality of the energy-growth nexus; (i) energy consumption causes economic growth; (ii) growth causes energy consumption; (iii) bidirectional causality; and (iv) no significant causality (Ozturk 2010). In a systematic review Mardani et al.(2019) found that in most cases energy use and economic growth have a bidirectional causal effect, indicating that as economic growth increases, further CO_2 emissions are stimulated at higher levels; in turn, a reduction in GHG emissions may reduce economic growth. However, energy substitution and efficiency gains offer obvious opportunities to break the bidirectional dependency: decoupling can break the linkage between economic growth and carbon emissions (Shuai et al. 2019). Worldwide trends reveals that, at best only relative decoupling (resource use grows at a slower pace than GDP) was the norm during the twentieth century (Jackson 2009a; Krausmann et al. 2009; Ward et al. 2016), while absolute decoupling (when material use declines as GDP grows) is rare, observed only during recessions or periods of low or no economic growth (Haberl et al. 2019). Recent trends in OECD countries demonstrate the potential for absolute decoupling economic growth not only from territorial but also from consumption-based emissions (Le Quéré et al. 2019), albeit at scales insufficient with mitigation pathways (Chapter 2).

Failure to create a more sustainable development is attributed to the inability of the conventional development indicators to measure well-being. GDP is dominating the literature, assuming that welfare is still predominantly associated with increased levels of consumption of products and services (Roy et al. 2012). However, GDP only measures economic activity and neglects inequality and services delivered by current capital stocks (Haberl et al. 2019); it is therefore, a poor proxy for societal well-being (Ward et al. 2016). Instead, several new indices have emerged to measure well-being (i.e. Human Development Index, OECD better life initiative, QoL Index, Gallup Health, Well-Being Index, Gross National Happiness, Happy Planet Index) but finding a single measure represents a challenge due the lack of data (Sugiawan and Managi 2019). Recently, measures such as inclusive wealth (the sum of capital assets that form the productive base of an economy) are proposed as an indicator to replace GDP for measuring well-being (UNEP 2018; Dasgupta et al. 2015; Arrow et al. 2013)(Sugiawan and Managi

2019). Another measure for considering aspects of social progress beyond economic activity is the recently established social progress index (SPI), a composite index based on a dashboard of outcome-oriented indicators of fulfillment of basic human needs and foundations of well-being (Haberl et al. 2019) considering opportunities such as nutrition, shelter, water, safety, access to knowledge and information, health, education, freedom, rights and environmental quality. All of these considerations have been fully or partially reflected in the United Nation's Sustainable Development Goals (SDGs), politically agreed upon goals of human wellbeing and planetary stability for the year 2030. Hence, this chapter is oriented along the wellbeing dimensions as reflected in the SDGs framework.

Integrated assessment models (IAMs) evaluate the costs of mitigation options as a function of loss in sustained economic growth. Both the specific implementation of this cost evaluation as well as the general framework is incomplete. Specifically, the models insufficiently reflect the loss of economic growth induced by climate damages, thus underestimating the social costs of carbon (Moore and Diaz 2015). Generally, the use of GDP loss is an insufficient metric in reflecting wellbeing; for example, it counts specific climate solutions that achieve more wellbeing with less throughput as a burden to GDP. Thus IAMs, in their current state, are inadequate tools to evaluate demand-side solutions to climate change mitigation.

Demand-side solutions entail fewer environmental risks than many supply side technologies (von Stechow et al. 2016) and make destructive negative emission technologies, such as Bio-Energy with Carbon Capture and Storage (BECCS) irrelevant (Grubler et al. 2018) or at least less relevant (Van Vuuren et al. 2018). Well-designed demand for services scenarios are consistent with adequate levels of well-being for everyone (Rao and Baer 2012; Grubler et al. 2018) , with high and/or improved quality of life (Max-Neef 1995) and improved levels of happiness (Easterlin et al. 2010) and sustainable human development (Arrow et al. 2013; Dasgupta and Dasgupta 2017). Well-being focus emphasizes equity and universal need satisfaction, compatible with SDG progress (Lamb and Steinberger 2017). Interrogating demand for services from the well-being perspective also opens new avenues for potential decoupling (Brand-Correa and Steinberger 2017). Demand-side solutions may also support near-time goals towards climate change mitigation and reduce the need for politically challenging high global carbon prices (Méjean et al. 2019). In the IPCC's SR1.5C (IPCC 2018a), four stylized scenarios have explored possible pathways towards stabilizing global warming at 1.5°C (SPM SR.15 Figure 3a (IPCC 2018b),; Figure 5.1). One of these scenarios, LED-19, investigates the scope of demand-side solutions (Figure 5.1). The comparison of scenarios reveals that such a low-energy demand pathways reduces the substitution of technologies in energy supply by a factor of two to three, and that it eliminates the need for technologies with high uncertainty, such as BECCS.

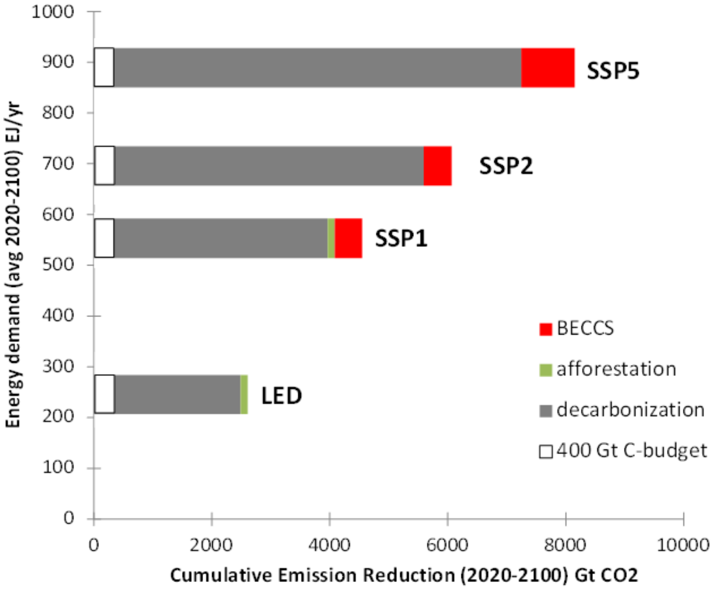


Figure 5.1 Dependence of the size of the mitigation effort to reach a 1.5°C climate target (cumulative GtCO$_2$ emission reduction 2020-2100 by option) as a function of the level of energy demand (average global final energy demand 2020-2100 in EJ yr^{-1}) in baseline and corresponding 1.5°C scenarios (1.9 W m^{-2} radiative forcing change) based on the IPCC Special Report on 1.5°C global warming (data obtained from the scenario explorer database, LED baseline emission data obtained from authors). An illustrative remaining carbon budget consistent with a 1.5°C target of 400 GtCO$_2$ post 2020 also shown (Rogelj et al. 2019)

5.1.2 Service for human wellbeing

The core tenet is the concept of services and service delivery systems. The service concept recognizes that the traditional economic conceptualization of "demand" as bundles of goods (fuels, material goods, etc.) exchanged with consumers via market transactions (gasoline for a car, grain for food, a cell phone, etc.) is an intermediary, rather than "final" step for the satisfaction of social needs. People "demand" the services (mobility, nutrition, communication, etc.) using the economic goods to further human well-being (Nakićenović et al. 1996b; Johansson et al. 2012; Creutzig et al. 2018). Service delivery systems are (alternative) combinations of products, end-use devices (technologies), infrastructure and forms of (market and non-market) institutions to provide particular services. For instance, the service of personal mobility (access to activities) can be provided alternatively by electric or gasoline powered privately owned vehicles, but also by shared vehicles, or by soft-mobility modes (walking and cycling), or by means of public transport (electric metros, or diesel buses), or even alternative urban form or telecommuting. Services can contribute directly to human well-being (shelter, comfort, better health, nutrition) or are themselves intermediary (e.g. goods transport, ton-kms), required "upstream" in form of materials and infrastructures for the provision of direct services.

Criteria for better life and fuller satisfaction of human needs differ between places, and countries and world regions. Some countries are likely to require more energy to satisfy all services, while other countries may improve their quality of life with shifting service provisioning systems, possibly reducing concurrent energy demand. Some literature suggests that conspicuous consumption and luxury emissions need differential treatment from 'survival emissions' (Roy and Pal 2009; Kobayashi 2004). This difference is manifested in the discrepancy between global north and global south (Bell 2019) (Hayward and Roy 2019) reflecting a differentiation between highly privileged and substantially underprivileged communities irrespective of their respective geographical boundaries. Fostering societies that are local, inclusive, peaceful, equitable and even frugal is increasingly seen as a main goal for societies (Boschetti et al. 2016). Energy sufficiency, or voluntary curtailment of energy consumption, motivated by the desire to live in more equitable societies, becomes a social and political priority (Hanemann et al. 2011; Vadovics and Živčič 2019). This considerations adds to a narrative of inclusive, just-consumption (Hayward and Roy 2019), which emphasizes the possibility of a virtuous circle of self-reinforcing system transformation based on better service provisioning for all. This chapter takes the plurality of needs of people, of requirements for improved well-being, and contextual differences between places into account and aims to characterize the richness and diversity of corresponding solutions.

5.1.3 Demand-side mitigation strategies: Avoid-Shift-Improve

Demand-side solutions for mitigating climate change include strategies targeting technology choices, consumption, behaviours, lifestyles, coupled production-consumption infrastructures and systems, service provision, and associated socio-technical transitions. Sectoral approaches emphasize the potential of diet shift (Bajželj et al. 2014; Smith et al. 2014), transport infrastructure design (Sims et al. 2014), compact urban forms (Seto et al. 2014), energy- and materials- efficient manufacturing, new product design (Fischedick et al. 2014), energy-efficient buildings (Lucon et al. 2014). 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 process (Poortinga et al. 2019; Mills and Schleich 2012; Niamir et al. 2020; Bamberg et al. 2007); 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. 2013); normative economics focuses on enabling conditions for sustainable human development, sociologists emphasize every-day practices, structural issues, and socio-economic inequality; anthropologists address the role of culture in energy consumption; urban planners take the role of infrastructures as an entry point; and studies in technological innovation consider socio-technical transitions and the norms, rules and pace of adoption that support dominant technologies. This chapter touches upon multiple components of the systemic change and relates the demand for GHG-emission intensive products and services across the key concepts of agency, structure, and meaning (Sovacool and Hess 2017). This involves the potential of individuals to change consumption patterns, and to act collectively driving institutional change (agency), the redesign of infrastructures 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).

The avoid, shift, improve (ASI) framework help examining the role of service-related mitigation options, originally arising from the need to assess the staging and combinations of interrelated mitigation options in the provision of transportation services (Hidalsdgo & Huizenga, 2013). In the context of transportation services, ASI seeks to mitigate emissions through avoidance of as much transport service demand as possible (e.g., telework to eliminate commutes, mixed-use urban zoning to shorten commute distances), shifting remaining demand to more efficient modes (e.g., bus rapid transit replacing passenger vehicles), and by improving the carbon intensity of modes utilized (e.g., electric buses powered by renewable electricity) (Creutzig et al. 2016a).

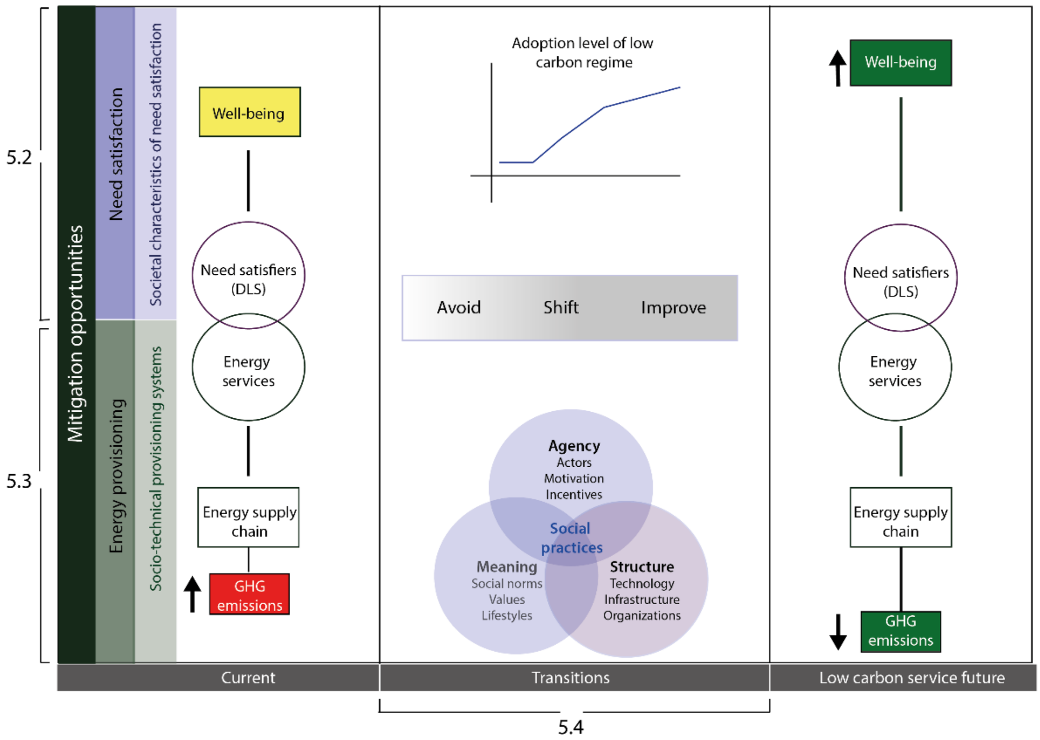


Figure 5.2 Main concepts and chapter overview. Currently service provisioning systems are organized around high energy, material, and land-use inputs and associated high levels of GHG emissions and provide satisfiers, like food, mobility, and jobs at adequate levels in some countries that underlie a certain level of wellbeing varying between individuals, countries and cultures. Demand-side and service-oriented solutions are successful, when alternative service-provision systems require zero or very-low GHG emissions but produce higher-level of well-beings for everyone. Section 2 assesses and motivates the goal of wellbeing for service provisioning systems; Section 3 assesses the state of GHG emissions associated with service provisioning systems and the potential to restructure these systems to reduce GHG emissions; and Section 4 assesses avoid/shift/improve policies, and the role of agency/structure/meaning in dynamically explicit transitioning pathways

This chapter frames peoples demand for services to enhance wellbeing to ensure well living and good life, connects with products, and social aspects of inclusive collective good of climate change mitigation (Figure 5.2). Mapping demand for services to various product lines and process of delivery broadens the mitigation option space. It allows to identify service and product demands that can be avoided, shifted or reduced by whom and where and the underlying difficulties, struggles and opportunities. This chapter aims to provide measures and metrics that help assessing these solutions and thus put service focused demand-side solutions to climate change mitigation on stronger footing.

This chapter is structured into three parts. First, concepts of equity and wellbeing, the current within and between country diversity in levels of wellbeing and why these concepts are relevant for delineating demand-side service-oriented solutions to climate change mitigation (5.2). Second, how service demand orientation help to generate quantitative estimates of the demand-side solution space, contribution of novel economic frameworks for service delivery, including the megatrends like digitization and shared economy, the circular economy digitalization (5.3). Third, focus is on people who act as agents of change, and how alignment of people, institutions, and policies enable a transition to low-energy demand and other climate change mitigation solutions. Also explains the role of agents across different scales (5.4.1, 5.4.2), their role in energy transitions (5.4.3), and synthesizes insights from case studies, and underlying policy requirements, into an overall transition framework (5.4.4, 5.4.5). Novel estimates of GHG emission reductions by lifestyle changes, redesigned infrastructures, and shifting social norms and cultures are included. Service-oriented framework for evaluation of GHG emission reduction of this chapter is complementary to sectoral chapters (6-11) in this assessment report. Framework of transitioning based on insights from different social science disciplines and contexts emphasizes that not only market and regulatory mechanisms and policies but also infrastructures and social norms need alignment for successful transitioning to societies with high wellbeing but characterized by low GHG emissions with potential for sustaining human development while doing no harm to others.

5.1.4 Bibliometric overview of the literature

A bibliometric overview of the literature found 77,177 academic peer-reviewed papers associated with this chapter. This literature was identified by three classes of search queries: 1) 14 queries coding the government-provided keywords, always in combination with climate change mitigation; 2) 23 queries of various research teams aiming to perform a systematic review into a particular subtopic associated with this chapter; and 3) 13 additional queries chosen to fill potential gaps left by the other queries. Individual queries were iterated to ensure that the rate of false positives is low. A large part of the literature is highly redundant and/or includes little quantitative or qualitative data of relevance to this chapter. For example, a systematic review on economic growth and decoupling identified more than 11,500 papers treating this topic, but only 834 of those, i.e. 7%, were including relevant data. In another systematic review, assessing quantitative estimates of consumption-based solutions, only 0.8% of papers were considered after consistency criteria were enforced. Out of the 77177 papers about 1-10%, i.e. between 700 and 7000 papers, belong to the relevant ones to consider. In addition, several hundred false negatives must also be considered, which is done by authors, expert solicitation and with contributing authors addressing identified gaps.

The amount of papers on demand and services in the context of climate change mitigation is growing exponentially. A topical analysis, clustering jointly occurring keywords found: A) A clustering along sectoral topics like i) buildings, ii) heating, iii) vehicle-transport, iv) mobility, v) waste, vi) urban, vii) water, viii) tourism, ix) energy supply, x) fuels, xi) agriculture, and xii) forest; B) a few method-oriented clusters, dominated by decomposition analysis; C) wider ranging topics, like economic growth, GDP, and adaptation. Issues like shared economy and digitalization were also present but due to their relatively recent emergence and resulting low share in the overall literature, they were not displayed in topic models.

The landscape map of the literature (Figure 5.4) displays topical relationships. Data-based modelling (mostly of economic growth), behavioural and development issues are central and connect to many other topics. The Southern area is dominated by land-based topics, the North-Western area by urban issues and governance, and the North-Eastern area by technical analysis on more granular scale. China is the only location appearing in topic models reflecting its outsize quantitative consideration in the literature. Topics like work, green (digital) behaviour, wind energy, and forests are disconnected from the core of the literature. Even though the chapter is oriented around social science issues, the engineering and nature science disciplines occupy each two times larger proportions of the literature than the social sciences, and ten times more than the humanities. However, many engineering studies were redundant; the proportion of social science studies and humanity papers making a contribution to this chapter was comparatively high.

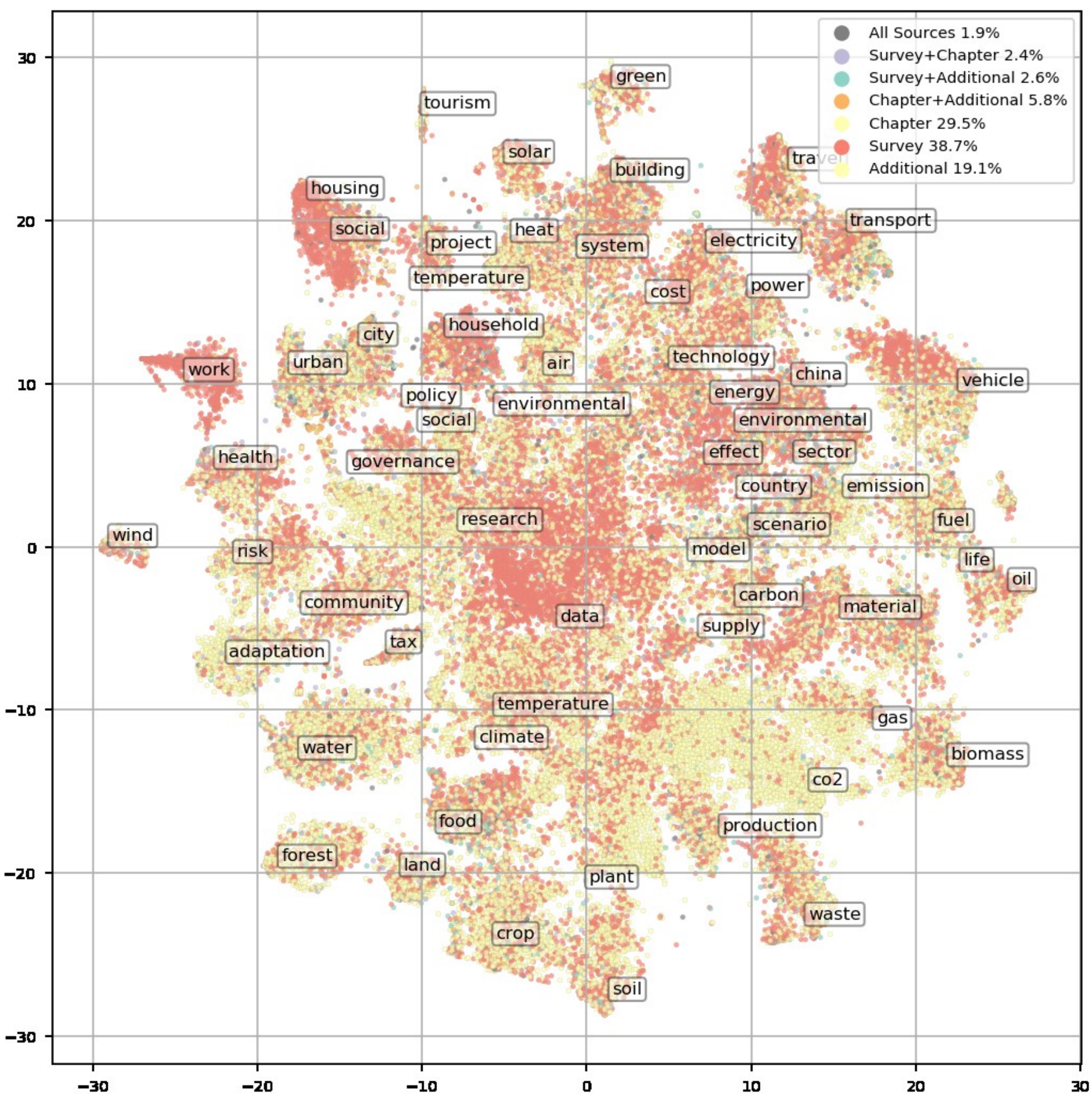


Figure 5.3 Topical map of 77, 177 peer-reviewed papers identified by 50 distinct search queries on topics mandated by governments, and on topics deemed of importance by the chapter team and outside experts

5.2 Wellbeing and sustainable development, and mitigation

Limiting climate change risks is fundamental to collective wellbeing (Yamin et al. 2005; Nelson et al. 2013; Gough 2017; Pecl et al. 2017; Tschakert et al. 2017). Inequities violate widely shared values of social justice, reduce trust and political engagement, and thus compromise overarching goal of climate change mitigation, and wellbeing as associated with climate change mitigation. There is *high agreement in the literature* that alienation or distrust weakens collective governance and fragments political approach towards climate action (Smit and Pilifosova 2001; Adger et al. 2003; Smith and Mayer 2018; Fairbrother et al. 2019; Kulin and Johansson Sevä 2019; Liao et al. 2019; Smith and Howe 2015; Alvaredo et al. 2018; ISSC et al. 2016; Hammar and Jagers 2007; Van Vossole 2012; Bulkeley and

Newell 2015; Hayward and Roy 2019). Mitigation options have varying degrees of synergies and trade-offs with wider societal goals and the SDGs (Creutzig et al. 2017; Gomez-Echeverri 2018; Campagnolo and Davide 2019; Roy et al. 2018a). An appropriate, context-specific mix of options facilitated by policies can deliver both higher wellbeing and reduced disparity in access to basic needs for services concurrently with climate mitigation (Thomas and Twyman 2005; Mearns and Norton 2009; Klinsky and Winkler 2014; Lamb et al. 2014; Lamb and Steinberger 2017). Hence, nurturing equitable human wellbeing through provision of decent living for all and climate change mitigation actions go hand in hand (OECD 2019a; ISSC et al. 2016). To fully explore such synergistic mitigation actions this chapter relies on the framework of 'Decent Living Standards'(DLS) for all (see 5.2.1; Box 5.1; Table 5.1 Direct services. Illustrative examples of direct services that provide for human wellbeing (as exemplified by the respective SDGs), quantitative indicators proposed in the literature and recent values) (Rao and Min 2018a; Rao et al. 2019a).

5.2.1 Services and demand for services to meet decent living standard for all

Sustainable consumption and production revolve around 'doing more and better with less' and thereby 'increasing net welfare gains from economic activities by reducing resource use, degradation and pollution along the whole lifecycle, while increasing quality of life' (UNEP 2010). Although energy is required for delivering human development by supporting access to basic needs (Lamb and Rao 2015; Lamb and Steinberger 2017), a reduction in primary energy, if associated with the maintenance or improvement of services, can not only ensure better environmental quality but also directly enhance wellbeing (Roy et al. 2012). It is the services provided by energy rather than energy use *per se* that deliver benefits for well-being (Kalt et al. 2019): people value illumination not electricity, mobility not transport fuels. Considering service needs for wellbeing and how to deliver them equitably allows for more flexibility in considering various ways to "avoid, shift, and improve" service provision – via technological and socio-cultural advances – rather than projecting current energy demand into the future. Thus energy services constitute the end of the energy value-chain offering an important lens to analyze the relationship between energy systems and human well-being (Walker, Simcock, and Day 2016; Fell 2017; Brand-Correa et al. 2018).

At the interpersonal and community level, cultural specificities, infrastructure differences, norms, and relational behaviors differ. For example, demand for space heating and cooling depends on building materials and designs, urban planning, vegetation, clothing and social norms as well as geography and outside temperatures (Brand-Correa et al. 2018). Social interactions and normative values play a crucial role in determining energy demand. The challenge for societies is how to rapidly decouple human wellbeing from energy use, or at least from high-emissions forms of energy use (Jackson 2009b), and in this sense, provision of services associated with low-energy demand is a key component of current and future efforts to reduce carbon emissions.

Development targeted to basic needs entail less carbon-intensive development than GDP-focused growth (Rao et al. 2014). There is high agreement in the literature that GDP is an inadequate measure of welfare, especially when environmental and climate considerations are included (Costanza 1999). GDP is an aggregate measure, it reflects neither distributional issues nor heterogeneity in wellbeing outcomes (van den Bergh 2009; Stiglitz et al. 2018; Aitken 2019; Stiglitz et al. 2009). GDP was never intended to measure welfare, and does a poor job of this (Islam and Clarke 2002; Fleurbaey 2009; Fleurbaey and Blanchet 2013; Kubiszewski et al. 2013; van den Bergh and Antal 2014; Giannetti et al. 2015; Jones and Klenow 2016; Schmelzer 2016; Aitken 2019).

The relationship between climate change mitigation and well-being can be viewed in two ways. The first is as the energy provisioning systems, which allows for the analysis of socio-technical characteristics (e.g. infrastructure, lock-in) of the particular energy service provisioning options in a specific society. The second is as societal characteristics of needs satisfaction, that allow for the analysis of social and cultural characteristics (e.g. values, norms) and economic and political institutions in relation to the particular human needs that society has (Day et al. 2016; Brand-Correa and Steinberger 2017). This requires differentiated action among social groups and leads to analysis from two perspectives: human needs and energy use. The energy services provisioning opens up avenues of efficiency and possibilities for decoupling energy services demand and primary energy supply, while needs satisfaction leads to the analysis of the factors influencing the energy demand associated with the achievement of well-being (Brand-Correa and Steinberger 2017).

Box 5.1: Definitions and Indicators

Demand-side approaches to climate mitigation rely on several key concepts whose definitions vary across disciplines. This chapter adopts the following semantic distinctions:

Equal distribution or “Equality” implies allocating the same amount of resources to all – fair allocation. Equitable distribution or “Equity” means allocating resources according to the level of need, to produce fair outcomes, since unequal starting-points require social policy to improve the circumstances of the most vulnerable (Klasen 2018; Alvaredo et al. 2018).

Decent Living Standard for all (DLS) is a set of basic service requirements that includes adequate nutrition, shelter, hygiene, clothing, healthcare, mobility, education, communication and information access (Frye and et al. 2018; Rao and Min 2018a). Determinants of “Wellbeing” encompasses DLS but also social interaction and factors which vary in relative importance in different contexts (Dasgupta 2001; Roy et al. 2012; Gough 2017).

The “Carbon Footprint” (global emissions impact of consumption) and the “Carbon Gini Index” and related “Carbon Lorenz Curve” (measures of emissions inequality) echo income distribution patterns. They are useful in tracking relative overconsumption and other inequities (Duro and Padilla 2006; Kahrl and Roland-Holst 2007; Groot 2010; Teng et al. 2011).

Carbon budgets usually do not focus on equity in relation to historical emissions (Jiahua 2008) (Jiahua and Ying 2010; Kanitkar et al. 2010; Jayaraman et al. 2012; Gignac and Matthews 2015; Kartha et al. 2018).

The emergence of literature on alternative indicator for human wellbeing is vast (Van Der Slycken and Bleys 2019; Zabala 2019; Fleurbaey 2009). Proposals have included the Index of Sustainable Economic Welfare (Lawn 2003, 2005; Brennan 2008; Beça and Santos 2010, 2014; O’Mahony et al. 2018), the Genuine Progress Indicator (Lawn 2003, 2005; Kubiszewski et al. 2013), the National Welfare Index (Held et al. 2018; Gran et al. 2019), the Human Development Index (UNDP 1990, 2010), the ecological footprint (Wackernagel et al. 1999; Walther et al. 2005; Dietz et al. 2007; Hoekstra and Wiedmann 2014; Fang et al. 2015; Mikkelson 2019), wellbeing indicators (Bryce et al. 2016; Disabato et al. 2016; Mcgillivray and Clarke 2006; Lamb and Steinberger 2017), sufficiency, or leading a life of moderation and prudence (Figge et al. 2014; Schäpke and Rauschmayer 2014; Muller 2009; Harvey 1996; Goodman 2009; Roy et al. 2012; Hayward and Roy 2019; Steinberger and Roberts 2010), and many others (Mair et al. 2018; Hayden and Wilson 2017).

Because of data limitations, which can make cross-country comparisons difficult, health-based indicators and in particular life expectancy (Lamb et al. 2014) have sometimes been proposed as quick and practical ways to compare local or national situations, climate impacts, and policy effects (Decancq et al. 2009; Burstein et al. 2019). Specific wellbeing metrics (Lamb and Steinberger 2017) are valuable in emphasizing the constituents of what is needed for a good life in different dimensions, making the metrics directly tangible at the individual level. The SDGs overlap in many ways with such indicators, and the data needed to assess progress in meeting the SDGs is also useful for quantifying wellbeing. For the purposes of this chapter, indicators directly relating GHG emissions to wellbeing for all are particularly relevant. Given the need for accelerated reduction in emissions to meet the Paris targets, defining a 'level of sufficiency' to meet adequately various needs 'for all,' considering fundamental service outcomes such as health, nutrition and housing, is an important focus (Lamb et al. 2014). [see 5.3.3.1 for more examples].

In this chapter, we use the 'Decent Living Standard' (DLS) as a metric for equitable service provision alongside emissions reductions. DLS 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; Rao and Baer 2012; Frye 2013; Saramet et al. 2009; Brand-Correa and Steinberger 2017; Rao and Min 2018a) (see also Chapter 9.1). The DLS goes beyond existing multidimensional poverty indicators by addressing living conditions and social participation, and offers a normative basis to assess environmental impacts and climate change (Rao and Min 2018a). It is based on human needs theory, which argues that vital dimensions of well-being correlate with consumption expenditures, but only up to a threshold (Frank 2010; Stiglitz 2012; Oishi et al. 2018; Xie et al. 2018; Wilkinson and Pickett 2009, 2019). It is also closely related to eudaimonic wellbeing approaches focused on realizing human potential, not just seeking pleasure and avoiding pain (Lamb and Steinberger 2017). Since vital dimensions of wellbeing correlate with consumption, but only up to a threshold, a mitigation strategy that protects minimum levels of service delivery for DLS, but critically views excessive consumption, can sustain wellbeing while generating emissions reductions. Such relational dynamics are relevant both within and between countries, due to variances in income levels, lifestyle choice (also see 5.4.4) geography, resource assets and local contexts. Provisioning for human needs is recognized as participatory and interrelational; transformative mitigation potential can be found in social as well as technological change (Hayward and Roy 2019; Lamb and Steinberger 2017).

For climate mitigation analysis, an important advantage of using DLS as a socio-economic benchmark is that it views human welfare not in relation to consumption but rather in terms of services which together help meet human needs (e.g. nutrition, shelter, health, etc.), recognizing that these service needs may be met in many different ways (with different emissions implications) depending on local contexts, cultures, geography, available technologies, social preferences, and other factors. They may be supplied to individuals or groups /communities, both through formal markets and/or 'informally', by collaborative work for example, or gifts or unpaid work – in coordinated ways that are locally-appropriate, designed and implemented in accordance with overlapping local needs. The 'bottom line', in this framework, is that to enhance participation in climate response actions, all members of society need to have access to the basic services which underpin decent living standards. This necessarily overlaps with the applicability and implementability of the transformative changes required to move towards a 1.5°C threshold (IPCC 2018b; Lamb and Steinberger 2017) involving use of resources and energy in supply chains, physical infrastructures, and different forms of social provisioning -- the demand side of climate mitigation (Lamb and Rao 2015; Roy et al. 2012; Creutzig et al. 2018).

Such an approach begins with questions such as: Which goods and services are required for decent living standards? What energy resources are required to provide these goods and services across groups/regions? What is the magnitude of inequality in terms of access to services and emissions, and what implications does this have for climate mitigation and public policy? What different policy / climate mitigation strategies are feasible in terms of behavior and lifestyle shifts? How demand is met in providing DLS for all thus becomes the main policy focus and a key driver of incentive structures.

The services which make up DLS include adequate nutrition (food and cooking services), shelter, hygiene and sanitation, lighting, thermal comfort, communication, and mobility (Rao et al. 2019a). Table 5.1 Direct services. Illustrative examples of direct services that provide for human wellbeing (as exemplified by the respective SDGs), quantitative indicators proposed in the literature and recent valuesshows inputs and indicators for these, along with global average service levels. This table is based on a growing literature (Foxon and Steinberger 2013; Hubacek et al. 2017; Rao and Pachauri 2017; Rao and Min 2018a), and indicates how diverse service provision strategies could help attain two-way synergies between mitigation and wellbeing. Such strategies, ranging from building designs that facilitate passive solar heating, to radically shared mobility, and to integration of workplaces with housing, can produce cascades of resource and energy-saving types of service provision that also help meet DLS for all, in both Annex-I and non-Annex-I communities (for more see 5.3, Chapter 9, 9.4).

Table 5.1 Direct services. Illustrative examples of direct services that provide for human wellbeing (as exemplified by the respective SDGs), quantitative indicators proposed in the literature and recent values

	DLS (Dimensions)	SDGs	Service Indicator	Global Average/ capita	Typical Inputs
Direct services	Food	SDG 2 Zero hunger	Calorie food	2909 [2]	Food
	Cooking	SDG 6 Clean water and Sanitation	Liters	?	Water
		SDG 7 Affordable and Clean energy	MJ	?	Energy (cooking fuels) Devices (stoves)
	Hygiene (Hot water)	SDG 3 Good health and wellbeing	M^3k (kelvin)	229 [1]	Water, energy
	Sanitation	SDG 6 Clean water and Sanitation	Liters	?	Toilets, water use
	Shelter	SDG 11 Sustainable cities and communities	M^2 living area	23 [2]	Building
	Thermal comforts in building	SDG 7 Affordable and Clean energy	MJ m^{-2} (heating)	21 [2]	Boilers, Energy
			MJ m^{-2} (cooling)	1 [2]	AC units, Energy
			MJ m^{-2} (appliances)	12 [2]	Appliances, Energy
	Lighting	SDG 7 Affordable and Clean energy	Million lumen-hrs	9 [2]	Lamps, Energy
	Mobility	SDG 1 No poverty			
		SDG 8 Decent work and economic growth	Passenger-Km	6927 [2]	Vehicles, Energy
	Communication	SDG 11 Sustainable cities and communities	Giga bytes	43 [1]	ICT, Energy, All communication
			Devices (mobile phones)	1	(HH+Public+Comm)

[1] 2005 values from (Cullen and Allwood 2010)

[2] 2020 values from (Grubler et al. 2018)

[3] 2020 values from (Rao et al., 2019)

5.2.2 Heterogeneity and inequities in access to energy and DLS services

No single grand approach to demand-side mitigation can possibly be appropriate, since there are many different contexts, socio-cultural practices, customs, political configurations, geographic circumstances, and institutions that shape and prioritize options for change. Consumption patterns across nations show striking differences, with wide variation in energy and emissions outcomes (Schipper 1989; Roy and Pal 2009). Importantly, even today in some parts of the world, additional energy consumption is required to satisfy basic needs and achieve decent standards of living; while in other parts of the world, avoiding specific patterns of energy use can improve wellbeing. Country-scale analysis camouflages differences across socio-economic status and sociological groups within countries. The maps in Figure 5.4 showing variations in DLS elements provide a starting-point for comparative global analysis.

At present, the 'energy-poor' – more than three billion people, nearly one-third of the world's population – have little or no access to energy for clean cooking. One to 1.2 billion lack energy for cleaning, sanitation and water supply, lighting, and basic livelihood tasks (Sovacool and Drupady 2016; Rao and Pachauri 2017). The most gravely energy-poor are women who live in sub-Saharan Africa and developing Asia, whose socially-determined responsibilities for food, water, and care are highly labour-intensive and made more intense by climate change (Guruswamy 2016; Wester et al., 2019). Achieving DSL and the SDGs, so that billions of people can escape drudgery, requires that the energy-poor obtain better access to sustainable energy to supply their basic needs (Birol 2014; Gonzalez 2016; Arto et al. 2016). Increasing energy access and equity also helps to break political deadlocks, reduce deforestation, lengthen human life expectancy, reduce hunger, provide water, improve health and education access and the lives of women and children, and contribute to environmental sustainability (Roberts and Parks 2007; Sovacool and Drupady 2016). This will free billions of people for more productive economic and social contributions and more meaningful lives (Nagel 2015; Black 2016). Meanwhile, about half of the energy used in the world is consumed by the richest 10% of people, most of whom live in developed countries, especially when one includes the energy embodied in the goods they purchase from other countries (their carbon footprint) (Wolfram et al. 2016; Arto et al. 2016). As a result of this inequality, the lowest global emitters (the poorest 10% in the poorest countries) in 2013 emitted about 0.1 tCO_2 cap^{-1} , whereas the highest global emitters (the top 1% in the richest countries) emitted about 200-300 tCO_2 cap^{-1} (World Bank 2019).

Heterogeneity in energy access and emissions can be seen from different approaches: spatial, urban-rural, geographic, by countries or regions, temporal or intergenerational, societal, by gender, etc. (Wood and Roelich 2019). In the climate discourse, comparisons among countries and regions (rich and poor, developed or developing) have predominated over other approaches, in many cases due to the dominance of national-level statistics and analysis of policies, exposure to environmental degradation, and emissions contributions. Globally, there are differences in the amount of energy that societies require to provide the basic needs for everyone. The per capita energy requirement to provide a decent standard of living has been calculated at 30 GJ to 40 GJ (Lamb and Steinberger 2017), while other studies place it in an order of magnitude from 10 GJ to 100 GJ (Steckel et al. 2013; Lamb and Rao 2015); but this depends on the context and how services are provided (Brand-Correa et al. 2018). Recent DLS estimates for Brazil, South Africa, and India are in the range between 15 and 25 GJ cap^{-1}. Figure 5.4 shows the wide variation across world regions in people's access to the basic material prerequisites for meeting DSL. Heterogeneity in access to and availability of services for human well-being can be seen specially in mobility, food and housing dimensions, which dominate the energy needs. For example, in Brazil, India and South Africa, mobility (51-60%), food production and preparation (21-27%) and housing (5-12%) dominate total energy needs (Rao et al. 2019b).

There *is high agreement* in the literature that through equitable resource distribution, high levels of human development can be provided at moderate energy and carbon levels (Steinberger and Roberts 2010) by reducing overconsumption by the global rich (Annecke 2002; de Zoysa 2011; Ehrlich and

Ehrlich 2013; Spangenberg 2014; Toroitich and Kerber 2014; Dario Kenner 2015; Toth and Szigeti 2016; Smil 2017; Otto et al. 2019). For example, at similar levels of human development, per capita energy demand in the US was 63% higher than in Germany (Arto et al. 2016). Human well-being is socially-based and has a large relational component (Yellowfly 1992; Ball and Chernova 2008; Easterlin et al. 2010; McCubbin et al. 2013; Schneider 2016; White 2017; Lamb and Steinberger 2017; D'Ambrosio and Frick 2012; Stone et al. 2018; Wang et al. 2019; Tu and Hsee 2018; Shields 2016). Once subsistence needs are met, relative well-being is much more significant for human happiness than absolute consumption levels (Frank 2010; Stiglitz 2012; Oishi et al. 2018, Reyes-Garcia 2015, Xie et al. 2018; Wilkinson and Pickett 2009, 2019), and the higher the income inequality, the more people compare themselves with their neighbours (Luttmer 2005; Cheung and Lucas 2016). Income standards for wellbeing comparisons are now largely global rather than national (Diener et al. 2013). Recent research shows that in emerging economies such as India, Brazil and South Africa, the energy demand required to provide everyone with a decent standard of living is far less than the current world average energy demand (Rao et al. 2019a). Priority can be placed on ways of providing the services, which make up the DLS using low-carbon/renewable energy and materials with low carbon footprints (Campagnolo and Davide 2019).

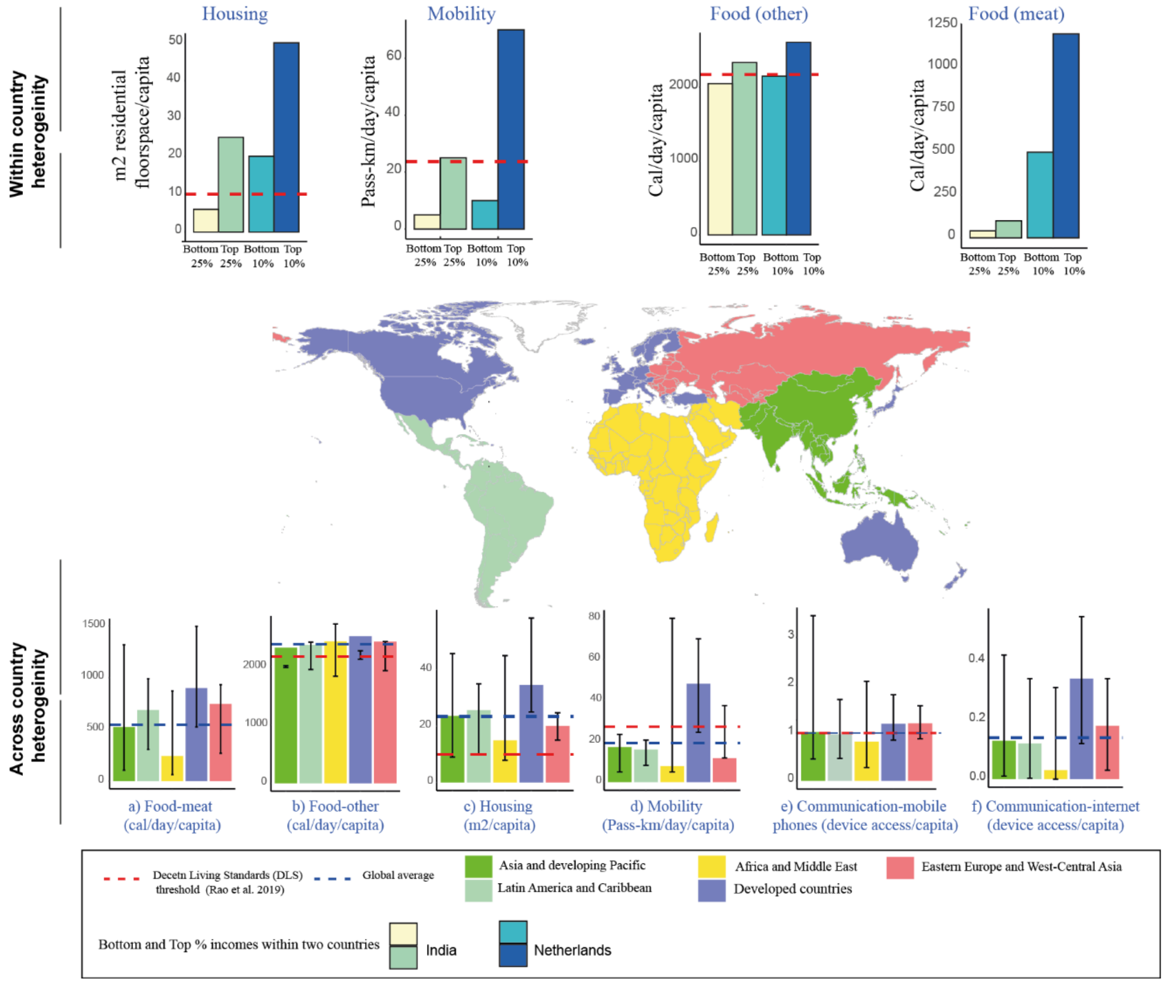


Figure 5.4 Heterogeneity in access to and availability of services for human well-being within and across countries. Within-country differences in service levels are shown as a function of income differences for the Netherlands (bottom and top 10% of incomes) and India (bottom and top 25% of incomes) (Grubler et al. 2012c and data update 2016). Across–country differences appear in panel (a) food-meat, (b) food other, (c) housing, (d) mobility, (e) communication – mobile phones, and (f) high speed internet access. Values are shown for 5 world regions based on WG III AR6 Regional breakdown. Variation in service

levels across countries within a region are shown as error bars (black). Values proposed as decent standard of living threshold (Rao et al. 2019a) are shown as red dashed lines. Global average values are shown as blue dashed lines

A more granular analysis of household energy consumption differentiated according to household consumption expenditure quintiles and quartiles, reveals that the lowest two quintiles in countries with average annual income below 15,000 USD cap^{-1} lack final energy required to attain decent living standards (20-50 GJ cap^{-1}); 77% of people consume less than 30 GJ $yr^{-1} cap^{-1}$ and 38% consume less than 10 GJ yr^{-1} cap^{-1}. In contrast, the richest half of consumer in all countries consumes final energy above DLS levels, sometimes by an order of magnitude (Figure 5.6; Oswald et al. 2020). Many energy-intensive goods have high price elasticity (>1.0). Highly unequally distributed energy consumption is concentrated in the transport sector, ranging from vehicle purchase to fuels, and most unequally in package holidays and aviation (Oswald et al. 2020).

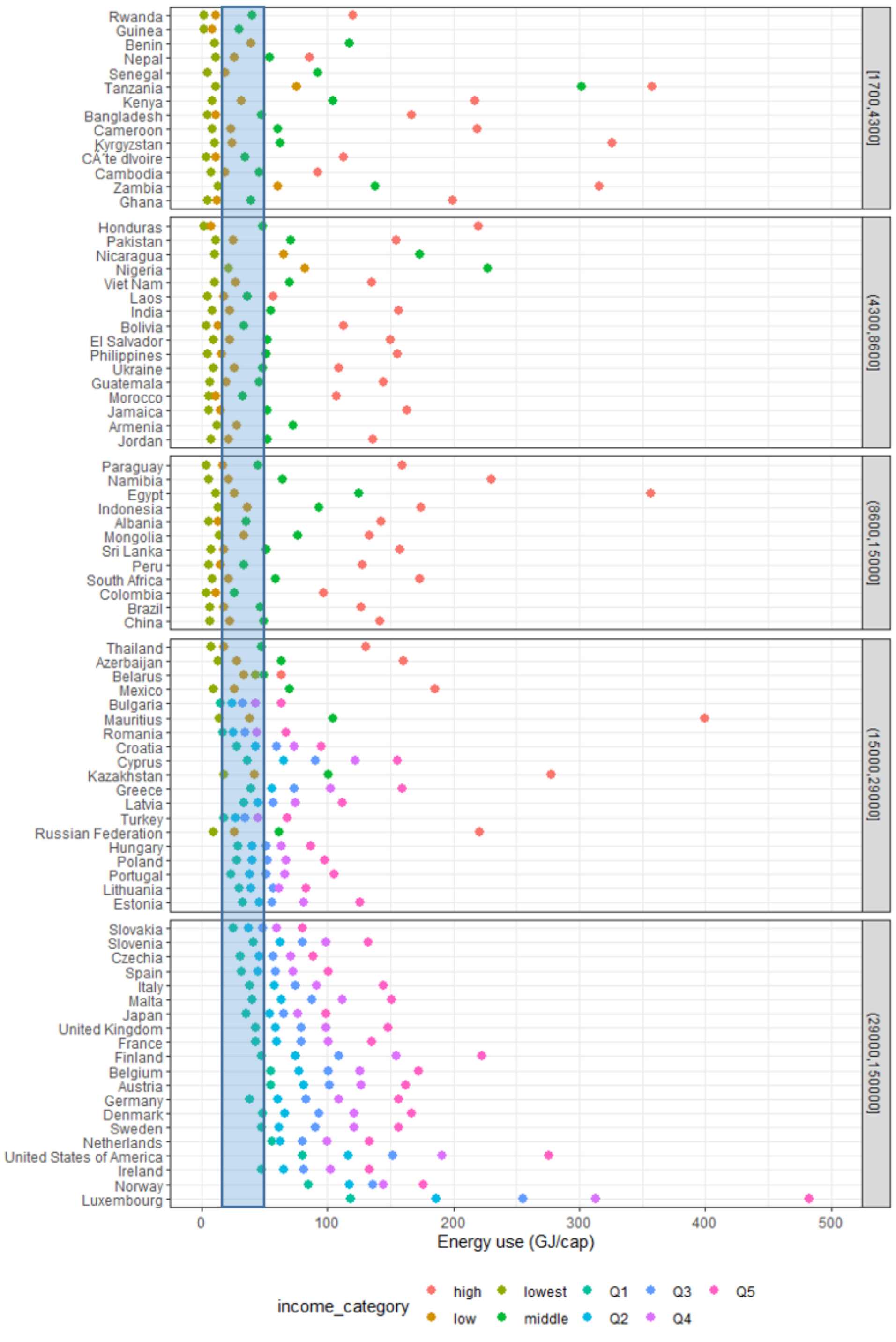


Figure 5.5 Energy use per capita of countries in 5 groups of countries ranked by monetary expenditure in USD per capita per year, and displayed for each country for four or five different income groups. The energy required for decent living standards (20-50 GJ cap^{-1}) is indicated in the blue column. Data based on Oswald et al. 2020

The lifestyle and behaviour framework [more in Section 5.4] is useful in analyzing carbon emissions for mitigation policy purposes (Jorgenson et al. 2019; Creutzig et al. 2018). For example, in the case of lifestyles, household energy consumption (heating, cooking and cooling) comprises half of the average footprint in Alberta, Canada and the highest income quintile has household carbon footprints 2.2 times greater than the lowest (Kennedy et al. 2014). In the case of behaviour, a study found that upgrades in Mexican households had no detectable impact on electricity use or thermal comfort for behavioural reasons such as maintaining their windows open on hot days, which nullify the thermal benefits of roof and wall insulation. This underscores the need to incorporate human behaviour into engineering models of energy use because energy-efficient upgrades *per se* do not always affect energy use or thermal comfort (Davis et al. 2020). In the case of the food sector for example, reducing the consumption of red and processed meat during dinner and of soft and alcoholic drinks throughout the day leads to lower dietary GHG emissions of people in the Netherlands while having health benefits (van de Kamp et al. 2018). US consumers wasted 422 g (95% CI: 409–434 gm) of food person^{-1} day^{-1} during the period 2007–2014, which represents over 800 kcal (795–840 kcal) person^{-1} day^{-1} , representing about 29% of total daily energy intake (Conrad et al. 2018). Literature is in high agreement that equity in wellbeing can be attained with less than current energy use in various service provision systems by focusing on either infrastructure, education for behaviour change towards thermal comfort rather than heating and cooling, waste reduction, healthy calorie intake through dietary choice.

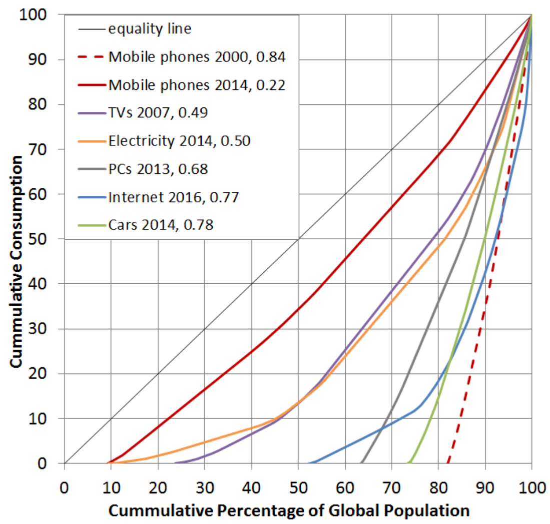
Business-as-usual (BAU) projections for achieving equitable levels of service provision typically project large increases in global GHG emissions and demand for key resources (Blomsma and Brennan 2017) (OECD 2019a), with attention typically focused on increasing passenger mobility (road and air) and associated infrastructure needs, increasing freight (Murray et al. 2017), increasing demand for cooling (International Energy Agency 2018), and shifts to carbon-intensive high-meat diets (OECD 2018). A useful framing concept is the so-called carbon footprint, a metric that is rooted in consumption-oriented emissions accounting theory (Davis and Caldeira 2010), and which assigns the life cycle emissions associated with an activity directly to the consuming entity. Its utility lies in quantifying the total emissions associated with provision of specific services (e.g., food, transport, housing, clothing, leisure) and in comparing those emissions across available service-provision options, regions and socioeconomic strata. In low-income nations—which can exhibit per-capita carbon footprints 30 times lower than wealthy nations (Hertwich and Peters 2009)—emissions are predominantly domestic and driven by provision of essential services (shelter, low-meat diets, clothing). In wealthy nations, expanded services such as private road transport, frequent air travel, private jet ownership, meat-intensive diets, entertainment and leisure increase the size and global reach of the carbon footprint considerably (Weber and Matthews 2008a,b; Druckman and Jackson 2009; Hertwich and Peters 2009; Roy and Pal 2009; Hubacek et al. 2017). For example, BAU carbon footprints increase with income and expenditure levels. In contrast, mitigation efforts that are based on consumption focus on the 1 billion top emitters, which does not conflict with alleviating the poverty of low-emitters (Chakravarty et al. 2009a). Wealth redistribution thus simultaneously advances equity, wellbeing, and mitigation goals.

There are large differences in carbon footprints between the poor and the rich. Per capita carbon footprints average 1.6 tonne day^{-1} for the lowest income category, then quickly increase to 4.9 and 9.8 t for the two middle-income categories and finally to an average of 17.9 tonne for the highest income category. Global CO_2 emissions remain concentrated: the top 10% of emitters contribute about 35-45% of the total, while the bottom 50% contribute just 13-15% of global emissions (Chancel and Piketty 2015; Hubacek et al. 2017). The poorest 50% of the world's population are responsible for only about 10% of total lifetime consumption emissions (Chancel and Piketty 2015). Inversely, about half of the energy used in the world is consumed by the richest 10% of people, most of whom live in developed countries, especially when one includes the energy embodied in the goods they purchase from other countries (carbon footprint) (Wolfram et al. 2016; Arto et al. 2016).

Box 5.2 STARTS HERE

Box 5.2 Inequalities in access to and levels of service provision

Access to technologies, infrastructures and products and the service they provide are essential for raising global living standards and improving human well-being (Alkire and Santos 2014; Rao and Min 2018a). Yet access to and levels of service delivery are distributed extremely inequitably. How fast such inequalities can be reduced by granular end-use technologies is illustrated by the cell phone (mobile phone subscriptions) comparing the situation in 2000 with 2014 in which it changed from the most inequitably distributed technology, to the one with almost universal access.



Technology/Infrastructure	Gini	Year	Population (w/o access)	
			bn	%
Mobile phone subscriptions	0.877	2000	3.9	78.6
Mobile phone subscriptions	0.221	2014	0.6	9.2
TVs	0.492	2007	1.2	27.7
Electricity (kWh)	0.503	2014	0.5	9.4
Internet bandwidth (bits/sec)	0.774	2016	3.0	52.2
Cars	0.780	2014	4.2	73.3
PCs	0.866	2005	4	78.7

Box 5.2, Figure 1: International Lorenz Curves and Gini coefficients for the share of population without access to SDG-related end-use technology and infrastructure services. Source: adapted from (Zimm 2019)]

Several of the United Nations' Sustainable Development Goals (SDGs) (United Nations 2015) deal with providing access to technologies and service infrastructures to the share of population so far excluded, showing that the UN 2030 Agenda has adopted a multidimensional perspective on poverty. Multi-dimensional poverty indices go beyond income and focus on tracking the delivery of access to basic services to the poorest shares of population, both in developing countries (Fulton et al. 2009; Alkire and Santos 2014; Alkire and Robles 2017; Rao and Min 2018a)[1], Social Progress Indicator (SPI)[2], Individual Deprivation Measure[3]), as well as in developed countries (Townsend 1979; Aaberge and Brandolini 2014; Eurostat 2018). At the same time, the SDGs, foremost SDG 10 on reducing inequalities within and among countries, promote a more equitable world, both in terms of inter- as well as intra-national equality.

Access to various end-use technologies and infrastructure services features directly in the SDG targets or among the indicators used to track their progress (United Nations Economic and Social Council 2017; United Nations 2015): Basic services in households (SDG 1.4.1), Improved water source (SDG 6.1.1); Improved sanitation (SDG 6.1.2); Electricity (SDG 7.1.1); Internet - fixed broadband subscriptions (SDG 17.6.2); Internet - proportion of population (SDG 17.8.1). Transport (cars, mopeds or bicycles) and media technologies (mobile phones, TVs, radios, PCs, Internet) can be seen as proxies for access to mobility and communication crucial to participate in society and the economy (Smith et al. 2015). In

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[1] Multi-dimensional Poverty Index, http://ophi.org.uk/

[2] Social Progress Imperative, www.socialprogressimperative.org

[3] Individual Deprivation Measure, http://www.individualdeprivationmeasure.org/

addition, SDG 10 is a more conventional income-based inequality goal, referring to income inequality (SDG 10.1), social, economic and political inclusion of all (SDG 10.2.), and equal opportunities and reduced inequalities of outcome (SDG 10.3).

Box 5.2 ENDS HERE

Per capita disparities in carbon footprints decline as countries become richer, but the average carbon footprint increases along with income even though carbon intensity tends to decline: that is, lower-carbon consumption expenditures (such as healthcare or education) become a larger share of the consumption mix as income rises (Jorgenson et al. 2019). The top 10% of emitters live on all continents, and one third of them are from non-Annex-I countries (Pan et al. 2019). Estimates also show that within-country inequality in CO_2-eq emissions explains more and more of the global dispersion of CO_2-eq emissions. For example, in 1998, one third of global CO_2-eq emissions inequality was accounted for by inequality within countries (Chancel and Piketty 2015). By 2009, within-country inequality made up 50% of the global disparity in CO_2-eq emissions. The higher the income level, the more disproportionate the carbon footprint (Figure 5.6) It is thus crucial to focus on high-emitting individuals and groups, rather than only those who live in high-emitting countries (Chakravarty et al. 2009b).

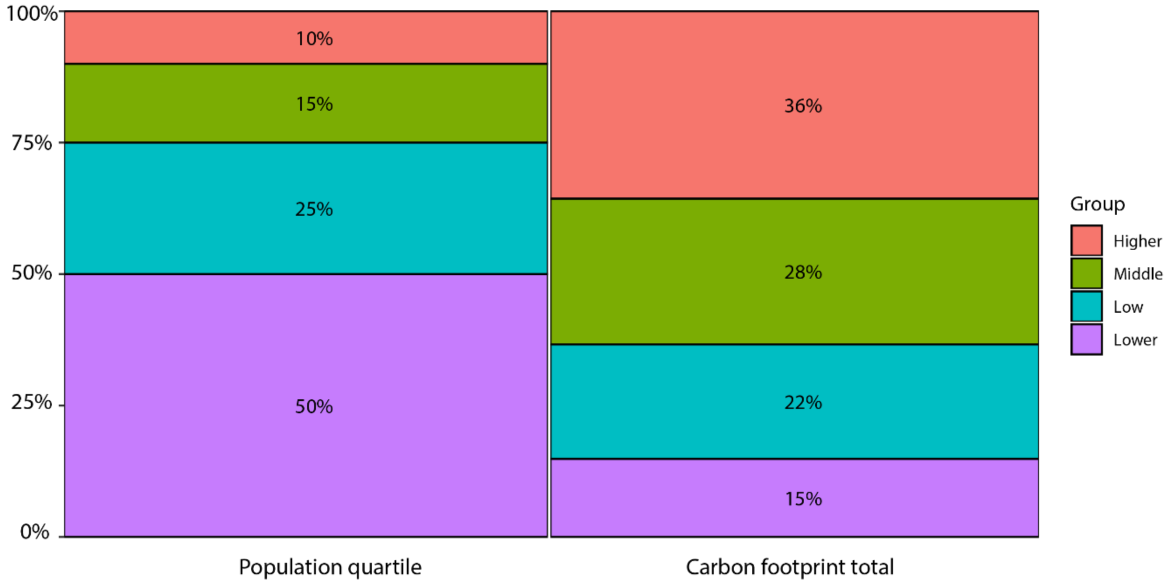


Figure 5.6 Shares of population and associated carbon emissions, Data from (Hubacek et al. 2017)

Though low-income countries have historically contributed fewer GHG emissions, and most of their citizens continue to have a small per capita carbon footprint, they suffer the earliest and the most from harmful shifts in the environment. The poorest in particular are profoundly reliant on agriculture and forests for food and income, and thus on the economic sectors that are most sensitive to climate change and most vulnerable to land degradation (Adams and Luchsinger 2009). The huge gap between Annex I and non-Annex-I countries both in terms of emissions responsibilities and impacts has constantly marked international climate change negotiations (Adger 2010; Lindner et al. 2010; Hayward and Roy 2019), with policy makers from some Annex I countries arguing that all countries need to reduce emissions, while decision makers from other countries emphasize the need to increase (preferably low-emissions) energy use for development (Kameyama 2004; Lenschow et al. 2005; Adams and

Luchsinger 2009; Guruswamy 2016). As more countries and people attain higher levels of development, their energy demands will almost certainly increase in step with their improved standards of living (Arto et al. 2016). However, these additional emissions, even in the most radical equity scenarios, would represent less than 8% of all emissions, and could be reduced further by the transfer of low-carbon technologies to developing countries (Rao and Min 2018b). Global income inequality has been declining since 1990 mainly due to rising incomes in India, China and some other countries -- which is good for development, but does increase overall emissions. To mobilize the benefits of increasing global equity, development-related energy needs must be supplied using renewable, low-carbon energy sources (Ahuja and Tatsutani 2009; Keho 2016). Co-benefits of this include reduced air pollution, and local energy production and control (Klasen 2018; Campagnolo and Davide 2019). Reflecting current trends, the share of people living in countries with a Human Development Index (HDI) of less than 0.55 decreased from 60% to 12% between 1990 and 2014, and by 2014 more than half the world's population lived in countries with a HDI greater than 0.7, compared to 24% in 1990 (UNDP 2015). Considering energy needs in terms of end-use services rather than by energy use alone (based on current technologies and demand patterns) allows for these needs to be addressed directly, creatively and collectively, using a range of locally-appropriate methods to address inequalities in consumption.

The SDG framework offers an opportunity for differentiated pathways that meet common responsibilities. Countries that lack basic services such as electricity access and public healthcare can focus on achieving SDGs directly related to wellbeing (such as SDG 1-7), while countries with high GHG emissions and carbon footprints can focus action on decarbonizing their economies and keeping within planetary boundaries (SDG 12-15), while also continuing to improve wellbeing related SDGs, such as SDG 3. Importantly, the physical foundation of human development and DLS can be achieved with moderate energy use and GHG emissions, consistent with high levels of life expectancy as a proxy for well-being (O'Neill et al. 2018; Steinberger and Roberts 2010). As acknowledged by the United Nations Framework Convention on Climate Change (UNFCCC 2011), a pathway of development and low emissions is possible for everyone if there is equity.

Box 5.3 The informal sector and climate mitigation

GDP leaves out the informal economy and unpaid work, which represent large portions of socio-economic activities, including much of the work done by women worldwide, with wide variations among countries. The informal economy accounts for an estimated 61% of global employment in the world; 90% in developing countries, 67% in emerging countries, and 18% in developed countries (Berik 2018). It is valued at roughly 30% of the size of each country's GDP in Portugal, Australia, Japan, China, New Zealand, India, and Russia (Durán Heras 2012; Narayan 2017). The significance of the informal economy, and its wide variations across the globe, have important climate implications for climate mitigation actions. Due to the importance of the informal sector, the participation of local people is crucially important in developing context-relevant, appropriate climate policies. Governance practices which ignore or repress informal activities may alienate large segments of the population, harm wellbeing, and hamper climate action. Along with the increased consumption of goods and services by the poor that is consistent with development and progress toward the SDGs, emissions may rise in some regions and among the lowest-income population groups, while emissions also are likely to decline in other regions and groups as low-emissions service-provision substitutes are developed and adopted.

All along the CO_2-per-capita spectrum, better public information and understanding of the CO_2-equivalent emissions implied by one's own and others' consumption patterns have the potential to unleash great creativity for meeting human service needs fairly and with lower emissions (Darier and Schüle 1999; Sterman and Sweeney 2002; Lorenzoni et al. 2007; Billett 2010; Marres 2011; Zapico Lamela et al. 2011; Polonsky et al. 2012; (Jonsson et al. 2015)) and strengthen public policies (Loiter et al. 1999; Stokes and Warshaw 2017; Zhou et al. 2019). The importance of the informal economy, especially in low-income countries, also opens many possibilities for new approaches to DSL service provision along with climate resilience (Rynikiewicz and Chetaille 2006; Javaid et al.; Backstränd et al. 2010; Porio 2011; Kriegler et al. 2014; Taylor and Peter 2014; Brown and McGranahan 2016; Chu 2016; Boran 2019; Hugo and du Plessis 2019; Satterthwaite et al. 2018). There is scope for large improvements in low-emission, locally-appropriate service provision by facilitating the work of informal-sector service providers and their access to low-energy technologies (while taking care not to additionally burden the unpaid and marginalized) through such means as education, participatory governance, government policies to assist the informal sector, social services, healthcare, credit provision, and removing harmful policies and regulatory silos. Examples of informal-sector contributions to mitigation include digital banking in Africa; mobility in India using recycled motors and collective transport; food production, food service provision, and reduction of food waste in Latin America (e.g. soup kitchens in Brazil, community kitchens in Lima, Peru); informal materials recycling, space heating and cooling, illumination (Hordijk 2000; Baldez 2003; Maumbe 2006; Gutberlet 2008; Chaturvedi and Gidwani 2010; Nandy et al. 2015; Rouse and Verhoef 2016; Ackah 2017).

5.2.3 Equity matters in climate change mitigation governance

More equal societies have better climate policies. Positive feedbacks link income equality, socio-economic equity, well-being for all, public trust, strong governance, and climate mitigation. Studies from several disciplines trace these linkages and show how their synergies emerge in mutually reinforcing ways. DLS are more likely to be met, and social well-being tends to be greater, in societies with more equitable income distribution. Not just energy and material consumption, but also the social components of well-being such as community cohesion, social capital, and trust, are higher in more equitable societies (Delhey and Dragolov 2014; Roser et al. 2019; Schneider 2016). Beyond basic levels of DLS, increased material consumption is not closely correlated with development indicators (Steinberger and Roberts 2010); high consumption and emissions levels (which often accompany inequality) are generally decoupled from happiness, especially in higher-income countries (Frank 2010; Oishi et al. 2018; Xie et al. 2018; Wang et al. 2019; Schneider 2016). High life satisfaction, although not emotional well-being, does appear to have an income or consumption-related component (Kahneman et al. 2006; Kahneman and Deaton 2010; O'Neill et al. 2018). Relatively slight increases in energy consumption and carbon emissions produce great increases in human development and well-being in non-Annex-I countries, and the amount of energy needed for a high global level of human development is dropping (Steinberger and Roberts 2010). More equitable societies are also more economically efficient societies (Stiglitz 2012; Singer 2018; Wilkinson and Pickett 2009).

Job creation, retraining for new jobs, local production of livelihood necessities, social provisioning, and other positive steps toward climate mitigation and adaptation are all associated with more equitable and resilient societies (Okvat and Zautra 2011; Bentley 2014; Klinsky et al. 2016; Roy et al. 2018a). Mental health problems, stress, "solastalgia" or distress caused by environmental change (Albrecht et al. 2007; Galway et al. 2019), social and inter-generational frictions related to climate, regressive international policies (e.g. on migration), and other negative symptoms of climate change-related stress are less prevalent in societies where DLS for all are met and prioritized (Fritze et al. 2008; Berry et al. 2010; Tschakert and Tutu 2010; McNamara and Westoby 2011; Cunsolo and Ellis 2018; Hayes et al. 2018; Manning and Clayton 2018) and are thus consistent with SDGs.

More equitable societies use energy more efficiently and control carbon emissions more efficiently. They waste less. Higher income inequality is associated with higher carbon emissions, at least in Annex I countries (Grunewald et al. 2017a); although in some non-Annex-I countries, higher income inequality may in fact reduce per capita emissions, mainly because it pushes some people out of the carbon economy and forces them to lead carbon-neutral lives and rely on biomass (Klasen 2018). Not having access to energy sources to help meet human needs implies drudgery and anti-development. Reducing inequality in high-income countries will help to reduce emissions (Klasen 2018). Even in non-Annex-I countries, livelihood improvements may not cause increases in emissions (Reusser et al. 2013). Worsening income inequality has been associated with higher global emissions in the period 1990-2019

(Ravallion et al. 1997; McGee and Greiner 2018; Diffenbaugh and Burke 2019; Rao and Min 2018b). From 1985 to 2011, for a group of 35 Annex I countries, higher income inequality was linked to a tighter connection between economic growth and CO_2 emissions, while decreasing income inequality reduced the association between economic growth and CO_2 emissions (McGee and Greiner 2018). Since income equality has worsened over recent decades in most Annex I countries (Piketty and Saez 2014), this may relate to political reluctance in some jurisdictions to implement strong climate policies such as carbon taxes. Climate change may also be contributing to global and local income inequality (Diffenbaugh and Burke 2019). Policies to assist the renewable energy transition have added potential benefits for income equality, besides contributing to greater energy access for the poor.

Higher female political participation, controlled for other factors, lead to higher stringency in climate policies, and results in lower GHG emissions (Mavisakalyan and Tarverdi 2019).

Conspicuous consumption by the wealthy is the cause of a large proportion of emissions in all countries, related to expenditures on such things as air travel, tourism, large private vehicles and large homes (Roy and Pal 2009; Gore 2015; Jorgenson et al. 2017; Roy et al. 2012; Hubacek et al. 2017). Global and intergenerational climate inequities impact people's well-being, which affects their consumption patterns and political actions (Gori-Maia 2013; Clayton et al. 2015; Pizzigati 2018; Albrecht et al. 2007; Fritze et al. 2008). Consumption reductions, both voluntary and policy-induced, can have positive and double-dividend effects on efficiency as well as reductions in energy and materials use (Harriss and Shui 2010; Spangenberg and Lorek 2019; Figge et al. 2014). Gender equity also is correlated with lower per capita CO_2-eq emissions (Ergas and York 2012).

Less waste, better emissions control and more effective carbon policies lead to better governance and stronger democracies. Institutions work more fairly, with more public trust. Equitable income, wealth distribution, and tax policies make democracies stronger (Jordahl 2011; Steijn and Lancee 2011; Stiglitz 2012; You 2012; Yamamura 2014; Levin-Waldman 2012). More equal societies display higher trust, which is a key requirement for successful implementation of climate policies (Rothstein and Teorell 2008; Klenert et al. 2018). The provisioning context of human needs is participatory, so transformative mitigation potential arises from social as well as technological change (Lamb and Steinberger 2017). Since many dimensions of wellbeing and 'basic needs' are social not individual in character (Schneider 2016), and since over-consumption is also a social construct, extending wellbeing and DLS analysis to emissions also involves understanding individual situations in social contexts. This includes building supports for collective strategies to reduce emissions (Chan et al. 2019)– going far beyond individual consumer choice. Consumer preferences driving demand, moreover, are themselves mutable.

A rich interdisciplinary literature exists on what causes norms and preferences to differ among groups of people and to change over time. Education and awareness about climate change, especially its complexity from a dynamic systems perspective, is a big factor (Chen and Li-Hua 2011; Bakaki and Bernauer 2017; Keenan et al. 2016; Knight 2016; Derkzen et al. 2017; Adenle et al. 2015; Bernauer et al. 2016) and personal connections with the land and with other species which may be threatened by climate change affect people's preferences (Shoyama et al. 2013). Uncertainty and risk aversion, in combination with personal experiences of dangerous extreme weather events, play a part (Dessai et al. 2004; Leiserowitz 2006; Viscusi and Zeckhauser 2006; Riddel 2014; Morton et al. 2017). Generational change is a driver of changing preferences and behaviours related to climate, with young people tending to want stronger climate action since their lives will be more affected (Conner et al. 2016; Wynes and Nicholas 2017; Ferguson 2018; Bandura and Cherry 2019). Social-ecological innovation also offers a framework for understanding this, along with local innovations and resilience (Kok et al. 2002; Bergman et al. 2010; Rodima-Taylor et al. 2012; Klasen 2018). Religion and ideology are also factors (Shao 2017). Most people prefer mitigation over adaptation, and those with longer-term orientations are more supportive of climate change policies (Tompkins et al. 2008; Alló and Loureiro 2014; Derkzen et al. 2017; Adenle et al. 2015). Sub-national governments, more sensitive to grassroots views, are undertaking mitigation actions with huge potential (Lutsey and Sperling 2008). Civil society organizations have changed climate politics by focusing on climate justice, which creates space for broader political alliances both within and among countries (Rosewarne et al. 2014; Allan and Hadden 2017). In some studies, people have shown willingness to pay for climate mitigation, even when their incomes drop as a result, if they feel responsible for causing it and/or realize that those most impacted have less ability to pay – a very unusual result for economic studies (Layton and Brown 2000; Lange et al. 2007; Cai et al. 2010; Gampfer 2014; Mildenberger and Leiserowitz 2017). In the U.S., while higher-income people (the top quintile by income) tend to be more liberal politically than others, the very wealthiest 0.01% (those above 40 million USD in net worth) appear to be much more conservative than others, deviating significantly from the views of most U.S. citizens (Page et al. 2013).

Activist climate movements are changing policies as well as normative values. Environmental justice and climate justice activists worldwide have called attention to the links between economic and environmental inequities, collected and publicized data about this, and pushed for change (Schlosberg and Collins 2014; Jafry et al. 2019; Goodman 2009). Youth climate activists, and Indigenous leaders, are also exerting growing political influence (White 2011; Powless 2012; Curnow and Gross 2016; United Nations 2015; Grady-Benson and Sarathy 2016; Claeys and Delgado Pugley 2017, White 2011; Petheram et al. 2015; Helferty and Clarke 2009). Indigenous resurgence not only strengthens environmental movements in many countries, but also changes social norms by raising awareness about Indigenous governance systems which preserved sustainable lifeways over thousands of years (Wildcat 2014; Chanza and De Wit 2016; Whyte 2017, 2018). Their advocacy and movements are creating growing pressure for emissions reductions globally, and for wiser, longer-term governance perspectives.

Populism, non-empirical decision-making, and politics of fear are less prevalent under conditions of more income equality (Chevigny 2003; O'Connor 2017; Myrick and Evans Comfort 2019) (Bryson and Rauwolf 2016). In societies where women have more economic equity, their votes push political decision-making in the direction of environmental / sustainable development policies, less high-emission militarization, and more emphasis on equity and social policies (Ergas and York 2012; Crawford 2019; Bryan et al. 2018; Resurrecciõn 2013; UNEP 2013; Glemarec et al.). Innovations and restructuring of governance institutions to meet new conditions are easier when diversity and equity are recognized as important values (Okereke 2018; Lazarus and van Asselt 2018; Di Gregorio et al. 2019; Sturm 2007); thus, equitable societies are better-governed. This includes recognition of the value of traditional ecological knowledge, Indigenous governance traditions, decentralization, and appropriate technologies (Goldthau 2014; Martin et al. 2018; Lange et al. 2007; Whyte 2017). Potential for climate-related conflicts is reduced in more democratic, participatory, and open societies (Barnett 2003; Mearns and Norton 2009; Sovacool et al. 2015; Hunsberger et al. 2017; Inderberg et al. 2015).

Better governance, and the expectation of equitable policies, mean that mitigation advances faster in more equitable societies. Better education, health care, valuing of social diversity, and reduced poverty – characteristics of more equal societies – all lead to resilience, innovation, and readiness to adopt progressive and locally-appropriate mitigation policies, whether high-tech or low-tech, centralized or decentralized (Martin 2016; Chu 2015; Cloutier et al. 2015; Vandeweerdt et al. 2016; Tanner et al. 2009; Turnheim et al. 2018; Lorenz 2013). There is less policy lock-in in more equitable societies (Seto et al. 2016). More equitable societies which provide DLS for all can devote attention and resources to mitigation (Dubash 2013; Rafaty 2018; Richards 2003). International communication, networking, and global connections among citizens are more prevalent in more equitable societies, and these help spread promising mitigation approaches (Scheffran et al. 2012). Climate-related injustices are addressed where equity is assumed important (Klinsky and Winkler 2014). Income inequality correlates with higher emissions levels in Annex I countries (Golley and Meng 2012; Grunewald et al. 2012; Sager 2017; Klasen 2018; Liu et al. 2019), Jorgenson et al. 2017; Chancel and Piketty 2015). Correspondingly, for Annex I countries where there is high income inequality, pro-poor growth measures are associated with reduced emissions (Grunewald et al. 2017b).

These positive feedbacks, part of a continuous interactive and self-reinforcing multidimensional process, are shown in Figure 5.7.

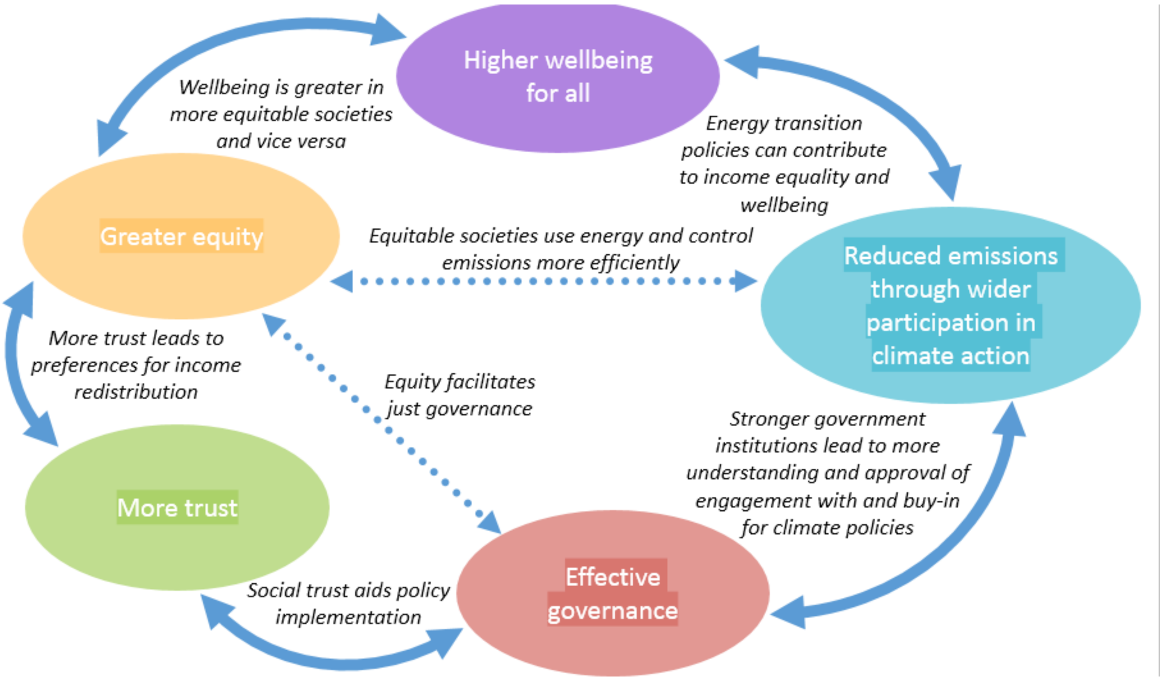


Figure 5.7 Positive feedbacks among wellbeing, equity, trust, governance and mitigation

Gender equity improves climate action along similar lines. Women's carbon footprints are about 6-28% lower than men's (with high variation across countries), mostly based on their lower meat consumption and lower vehicle use (Räty and Carlsson-Kanyama 2010; Ahmad et al. 2017; Medina and Toledo-Bruno 2016; Barnett et al. 2012; Räty and Carlsson-Kanyama 2009; Fernström Nåtby and Rönnerfalk 2018). This means that pay equity and increased economic power for women have mitigation implications; gender-based income redistribution in the form of pay equity for women could reduce emissions if the redistribution is revenue-neutral (Terry 2009; Dengler and Strunk 2018). Carbon emissions are lower per capita in countries where women have more political 'voice', controlling for GDP per capita and a range of other factors (Ergas and York 2012). Nearly all climate change deniers are men (McCright and Dunlap 2011; Anshelm and Hultman 2014; Jylhä et al. 2016; Nagel 2015), and women are more likely to be environmental activists, support stronger environmental and climate policies (Stein 2004; McCright and Xiao 2014) – further underscoring the synergies between equity and mitigation. The contributions of women, racialized people, and Indigenous people who are socially positioned as those first and most affected by climate change -- and therefore experts on appropriate climate responses -- are substantial (Wickramasinghe 2015; Pearse 2017; Dankelman and Jansen 2010; Black 2016), which provides strong incentives for equitable power, participation, and agency in climate policy-making (Collins 2019).

In summary, there is high confidence in literature that addressing inequities in DLS raises not only overall wellbeing but also improves the governance and policies of climate change mitigation. The most pressing DLS service shortfalls, as shown in Figure 5.4, lie in the areas of nutrition, mobility, and communication. These gaps in regions like Africa and the Middle East are accompanied by current level of service provision in the Annex I countries at much higher than DLS levels for the same three service categories. The lowest population quartile by income worldwide faces glaring shortfalls in housing, mobility, and nutrition. Meeting these service needs using low-emissions energy sources is a top priority. Reducing emissions associated with high levels of consumption and material throughput by those far above DLS levels is no less a priority, due to the overall volume and impact of that consumption. Focusing on low-emission service provision to first meet DLS for all, and then to improve well-being beyond DLS for all, allows the synergies among equity, trust, improved governance, well-being, and mitigation to grow. The mitigation responses in demand side through service provision have wide potential for diversity in action (details are in Section 5.3) around Avoid, shift and improve depending on regional context.

5.3 Mapping the opportunity space

The accelerated transition to low energy and resource demand pathways at the same time providing human wellbeing for all requires additional novel ways of identifying systemic inefficiencies and evaluating solutions. These need to be supported by robust metrics, analysis frameworks, and quantitative evidence to guide decisions needed for technology investment, social acceptability and policy design. To identify such pathways, this section first reviews two key concepts for evaluating the efficiency of service provision systems: resource cascades and exergy. 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 (Section 5.2) and higher wellbeing levels, typically focusing on end-use conversion and service delivery improvements as the most influential opportunities for system-wide waste reductions.

It then reviews the role of three megatrends that is transforming delivery of the services in innovative ways —digitalization, the sharing economy, and the circular economy. This section makes an assessment highlighting the potential risks of rebound effects, and even accelerated consumption; it also scopes for proactive and vigilant policies to harness their potential for future energy and resource demand reductions, and, conversely, avoid undesirable outcomes. Next, it summarizes the avoid/shift/improve (ASI) concept and uses it to provide a simple categorization of measures aimed at eliminating waste in current systems of service provision and thereby creating better ones. Finally, it reviews the state of modelling low energy and resource demand pathways in long-term climate mitigation scenarios--recognizing the importance of such scenarios for illuminating technology and policy pathways for more efficient service provision—and summarizes the mitigation potentials estimated from relevant scenarios to date.

5.3.1 Technical tools to identify ASI options

Service delivery systems to satisfy service needs (e.g., illumination, nutrition, thermal comfort, etc.) comprise a series of interlinked processes to convert primary resources (e.g. coal, minerals) into useable products (e.g. electricity, copper wires, lamps, light bulbs). It is useful to differentiate between conversion and processing steps “upstream” of end-users (mines, power plants, manufacturing facilities) and “downstream”, i.e. those associated with end-users, including service levels, and wellbeing benefits (Kalt et al. 2019). Illustrative examples of such resource processing systems steps and associated conversion losses drawn from the literature are shown in Figure 5.8 for energy (direct energy conversion efficiencies (De Stercke 2014; Nakićenović et al. 1993)), water use in food production systems (water use efficiency and embodied water losses in food delivery and consumption (Lundqvist et al. 2008; Sadras et al. 2011)), and materials (Ayres and Simonis 1994; Fischer-Kowalski et al. 2011) using the example of steel manufacturing, use and recycling at the global level (Allwood and Cullen 2012). Invariably, conversion losses along the entire service delivery systems are substantial, ranging from 83% (water) to 86% (energy) and 87%(steel) of primary resource inputs. In other words, only between 14 to 17% of the harnessed primary resources remain at the level of ultimate service delivery. A substantial part of these losses happens at the level of end-use in final service delivery (where losses account for 47 to 60 percentage points of aggregate systems losses for steel and energy respectively, and for 23% in the case of water embodied in food, i.e. in food waste). The efficiency of service delivery (for a detailed discussion cf. Brand-Correa (Brand-Correa and Steinberger 2017)) has usually both a technological component (efficiency of end-use devices such as cars, light bulbs) and a behavioural component (i.e. how efficiently end-use devices are used, e.g. load factors). Using the example of mobility where service levels are usually expressed by passenger-km, the service delivery efficiency is thus a function of the fuel efficiency of the vehicle and its drivetrain (typically only about 20%-25% for internal combustion engines, but close to 100% for electric motors) plus how many passengers the vehicle actually transports (load factor, typically as low as 20%-25%, i.e. one passenger per vehicle that could seat 4-5), i.e. an aggregate end-use efficiency of between 4-6% only.

To harness additional gain in efficiency by shifting the focus in service delivery systems to the end-user can translates into large "upstream" resource reductions. For each unit of improvement at the end-use point of the service delivery system (examples shown in Figure 5.8), primary resource inputs are reduced between a factor of 6 to 7 units (water, steel, energy). For example, reducing energy needs for final service delivery equivalent to 1 EJ, reduces primary energy needs by some 7 EJ. This is hence a leverage point to waste less, while maintaining or improving services (as motivated in 5.2.1).

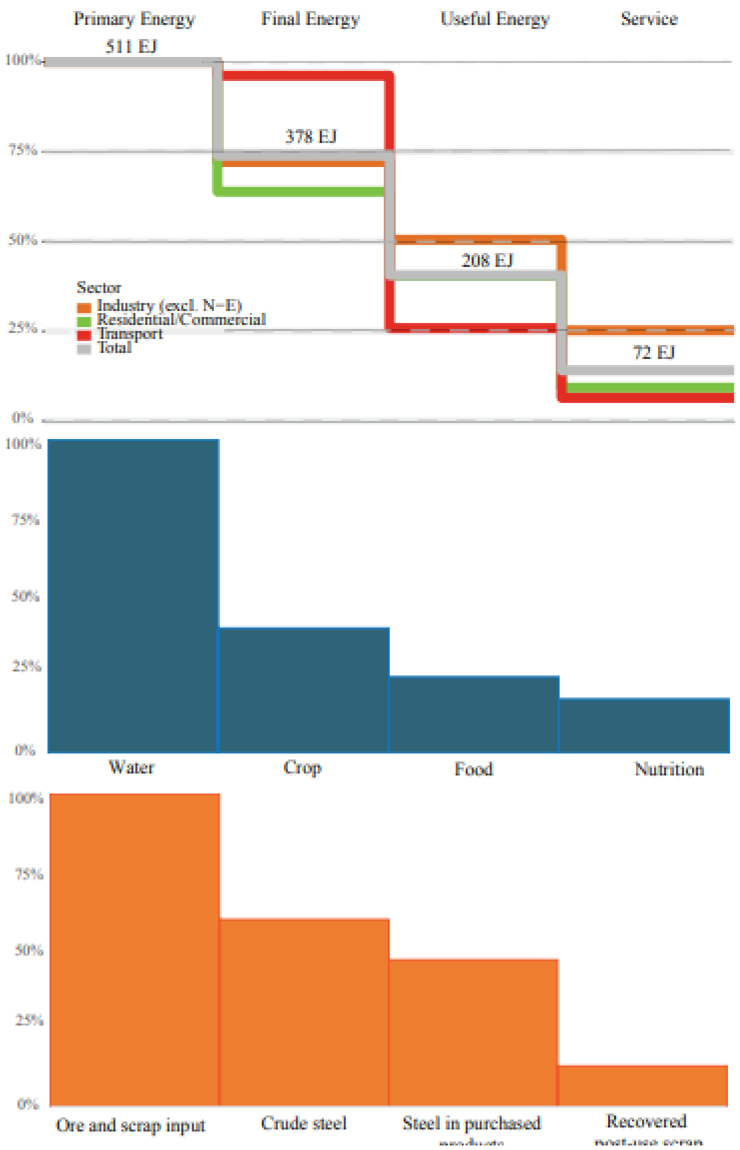


Figure 5.8 Resource processing steps and efficiency cascades (in percent of primary resource inputs [vertical axis] remaining at respective step until ultimate service delivery) for illustrative global service delivery systems for energy (top panel, disaggregated into three sectorial service types and the aggregate total), food (middle panel, water use in agriculture and food processing, delivery and use), and materials (bottom panel, example steel). The aggregate efficiencies of service delivery chains is with 13-17% low. Source: (TWI2050 2018)

5.3.1.1 Efficiency of service delivery systems: Exergy analysis and efficiencies

The stage-wise direct efficiencies discussed in the previous section are simple indicators, straightforward to measure. However, they do not capture quality considerations in this simple material and energy input-output balances. Also, technological, economic, or thermodynamic limits to conversion efficiencies are not taken into account, as the balance equations imply an upper bound of 100% resource efficiency, which may not be attainable. To overcome these shortcomings 'Exergy analysis' originated in the analysis of energy conversion processes and systems (Ahern 1980; Ford et al. 1975), for recent reviews cf. Shabgard and Faghri (2019) for energy, and Hernandez & Cullen (2019) for materials). Exergy (see also Glossary), also referred to as "availability", describes the ability of a particular energy flow to do useful work and thus takes quality explicitly into account. The ability (and versatility) of a kWh electricity to do useful work in the form of thermal, mechanical, or illumination work is very high, whereas the exergy of ton of biomass to do useful work is low, basically limited to the delivery of low-temperature heat via combustion, reflected in so-called exergy quality factors (Nakićenović et al. 1996a). In addition, efficiencies in exergy analysis are always calculated in comparison to a thermodynamic limit (usually determined from temperature or enthalpy gradients via the Carnot formula (Ahern 1980), thus giving a more accurate representation of realized efficiencies and improvement potentials.

The literature on exergy analysis is vast and comprises many sectors and systems ranging from industrial process efficiencies (Utlu and Hepbasli 2007; Özdoĝan and Arikol 1995; Carmona et al. 2019; Chowdhury et al. 2019b), entire supply chains (e.g. electricity generation (Felício et al. 2019)), analysis of national and global energy systems, e.g. for Canada (Rosen 1992), Brazil (Schaeffer and Wirtshafter 1992) and its Sao Paulo State (Mosquim et al. 2018), India (Jadhao et al. 2019), the USA (Ayres 1989) or entire global and regional energy systems (Grubler et al. 2012c; Nakićenović et al. 1996a), human settlements ranging from pre-industrial villages in Mexico (that have the lowest exergy efficiency due to lack of access to modern technologies and high-quality energy carriers (Masera and Dutt 1991)), to rural domestic sectors (e.g. Bangladesh, cf. Chowdhury et al. (2019a)) to cities (Causone et al. 2018) (for a review see (Grubler et al. 2012a)). Recently also historical time series for energy and exergy balances have become available (De Stercke 2014) and uncertainty analysis document the uncertainties underlying the construction of service-oriented energy and exergy balances (Paoli et al. 2018).

The comparison of realized systems efficiencies to the thermodynamically possible maximum provides an analytical algorithm to extend exergy analysis to the delivery of services, where a current configuration of service delivery (e.g. an inefficient car with one passenger) is compared to an ideal configuration without changing the basic service or technology used in delivering it (e.g. a commercially available fuel-efficient car with four passengers, increasing the service-to-product ratio (Fischedick et al. 2014)). The application of exergy efficiencies to service delivery systems was first introduced by (Nakićenović et al. 1996b), further elaborated in (Grubler et al. 2012b), and more recently has also been proposed as a general framework for societal exergy accounting (Sousa et al. 2017) and in the field of ecological economics (Warr and Ayres 2012; Jenkins and Hopkins 2019). As such exergy analysis does not only provide a rigorous analytical framework to extend the conventional resource accounting to explicitly consider service delivery systems and their efficiencies but also allows to aggregate otherwise non-commensurable services and activities into a common metric (service exergy delivered). Such aggregation is not possible with conventional indicators such as service-related energy intensities (GJ m^{-2}, GJ passenger-km^{-1}) or is only possible when aggregating different services and activities via their aggregate energy inputs rather than by their service exergy delivered, which can be misleading as overemphasizing those activities that are least efficient (and hence have high energy inputs), over those that are more efficient (and require less energy inputs) but deliver comparable service outputs (and human wellbeing impacts).

Despite some degree of variability in calculated exergy efficiencies due to differences in method, systems boundaries, and specifics of systems analysed, the literature (for systemic reviews see (Grubler et al. 2012c; Nakićenović et al. 1996b; Sousa et al. 2017) provides a robust evidence that exergy efficiencies are invariably low, particularly for those components at the end-use and service delivery back end of service provisioning systems, and also substantially lower than those revealed by direct input-output resource accounting as discussed in the previous section above. Illustrative exergy efficiencies of entire national or global service delivery systems range from 2.5% (USA, (Ayres 1989)) to 5% (OECD average, (Grubler et al. 2012c)) and 10% (global, Nebojša Nakićenović, Grubler, et al., 1996) respectively. Studies that adopt more restricted systems boundaries either leaving out upstream resource processing/conversion or conversely end-use and service provision, show typical exergetic efficiencies between 15% (city of Geneva, cf. (Grubler et al. 2012b)) to below 25% (Japan, Italy, and Brazil, albeit with incomplete systems coverage that miss important conversion losses, cf. the review in (Nakićenović et al. 1996b).

There is high agreement in the literature that from an exergy analysis perspective, the leverage effect for improvements in end-use service delivery through behavioural, technological, and market organizational innovations is larger than the factor 6-7 identified in the previous section. Indicative potentials for improvements revealed by exergy analysis range from a factor 10 to 20 with the highest improvement potentials at the end-user and service provisioning levels (*high confidence*).

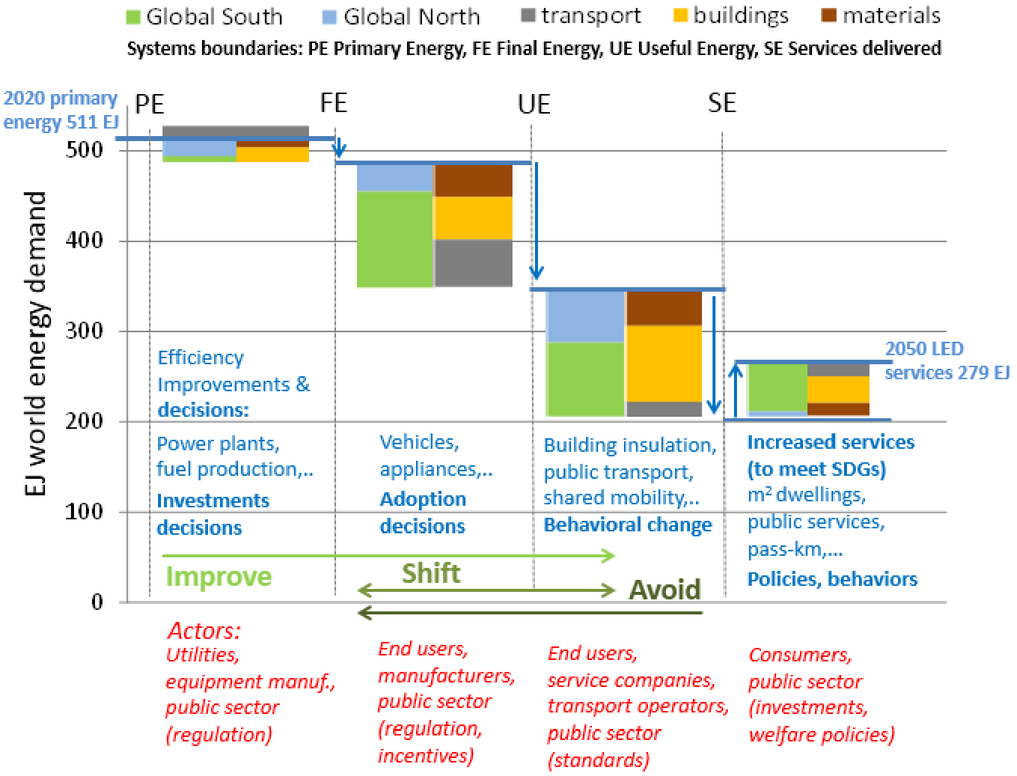


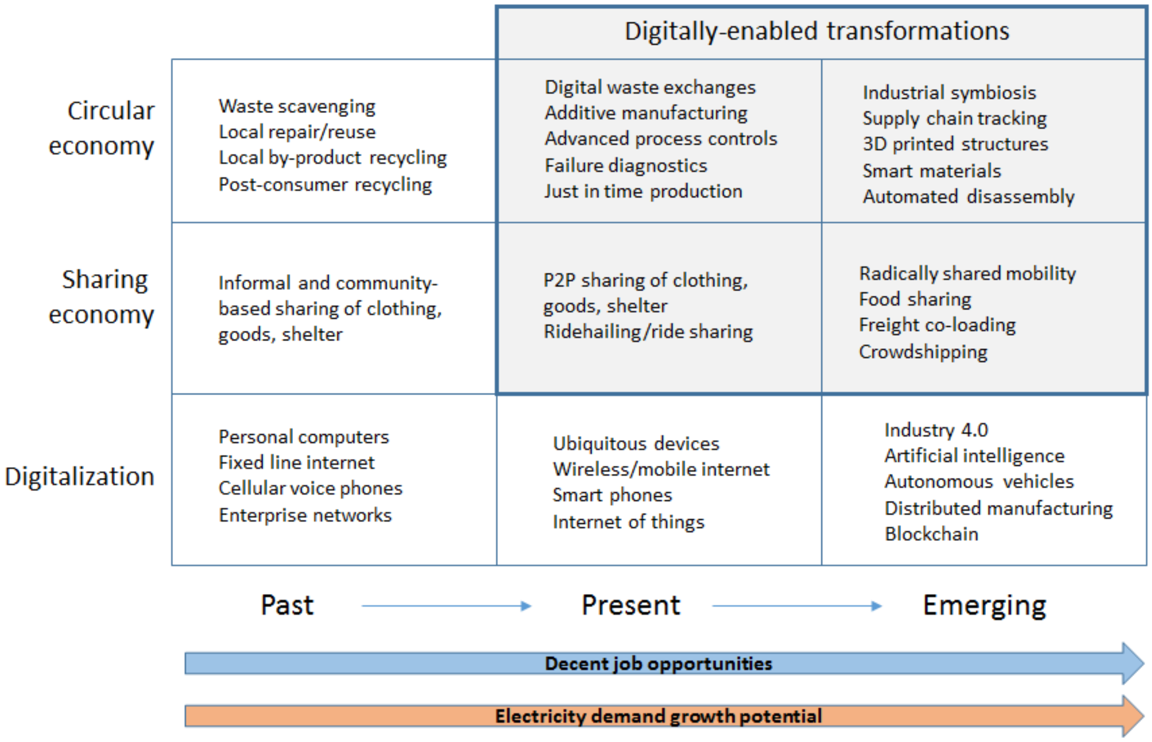
Figure 5.9 Realized energy efficiency improvements by region and by end-use type between 2020 and 2050 in an illustrative Low Energy Demand scenario (in EJ). Data: Figure 5.8 and (Grubler et al. 2018). Efficiency improvements are decomposed by respective steps in the conversion chain from primary energy to final, and useful energy, and to service delivery and disaggregated by region (Global North, Global South) and end-use type (buildings, transport, materials). Improvements are dominated by improved efficiency in service delivery (153 EJ) and by more efficient end-use energy conversion (134 EJ). Improvements in service efficiency in transport shown here are conservative in this scenario but could be substantially higher with the full adoption of integrated urban shared mobility schemes. Increases in energy use due to increases in service levels and systems effects of transport electrification (grey bars on top of first pair of bar charts) that counterbalance some of the efficiency improvements are also shown. Examples of options for efficiency improvements and decision involved (blue text), the relative weight of generic demand-side strategies (improve, shift, avoid; green text), as well as prototype actors involved (red text) are also illustrated

5.3.1.2 Efficiency Potentials Realizable by 2050

How much of these vast efficiency improvement potentials can be realized? Figure 5.9 illustrates realizable efficiency improvement potentials by 2050 in comparison to 2020 (see Figure 5.8 above for comparison and conceptual definitions) decomposed by region and also by type of end-use using a (highly ambitious) Low Energy Demand scenario (Grubler et al., 2018) as an example. There aggregate efficiency from primary energy to service delivery improves from 14% in 2020 to 41% in 2050, equivalent to 334 EJ, i.e. two thirds (66%) of 2020 primary energy use. Efficiency improvements are largest at the end-user stage: -153 EJ in service delivery (e.g. higher service delivery efficiencies via more public transport and shared mobility, more efficient buildings, dematerialization via digital service provision, etc.) and -134 EJ in end-use energy conversion (more efficient [e.g. electric] vehicles, appliances, etc.), whereas efficiency improvements in energy supply, are comparatively modest (-23 EJ –without systems interdependencies). By type of use, efficiency gains are the largest for buildings (including appliances): -160 EJ (pervasive adoption of "Passivhaus" building designs), followed by materials with -100 EJ (dematerialization via digitalization and shared mobility and recycling) and mobility with -50 EJ (more public transport, shared mobility, and electrification of vehicles). These efficiency gains are countered by activity increases and the impacts of system interdependencies. Realized efficiency improvements are therefore somewhat lower than suggested by the simple comparison to 2020 (334 EJ). Systems interdependencies (e.g. more efficient electric vehicles improve efficiency at end-use conversion, but lower the efficiency of energy supply (more conversion losses at power plants), as well as substantial increases in service levels to meet the twin objectives of development in the Global South and "decent living standards" for all, "take back" some of the energy savings. Primary energy demand in the LED scenario by 2050 is however with 279 (-232) EJ still 45% lower than in 2020 (511 EJ) Figure 5.9.

5.3.2 Megatrends

The sharing economy, the circular economy, and digitalization are all essentially emerging and contested concepts (Gallie 1955) that have the common goal of increasing convenience for users and rendering economic systems more resource-efficient, but which exhibit variability in the literature on their definitions and system boundaries. Historically, both sharing and circular economies have been commonplace in developing countries, where reuse, repair, and waste savaging and recycling comprise the core of informal economies facilitated by human interventions (Pacheco et al. 2012). Digitalization is now propelling sharing and circular economy concepts in developed and developing countries alike, and the three megatrends are highly interrelated Figure 5.10. For example, many sharing economy concepts rely on corporate or, to lesser degree, non-profit digital platforms that enable efficient information and opportunity sharing, thus making it part of the digitalization trend. Parts of the sharing economy are also included in some circular economy approaches, as shared resource use renders utilization of material more efficient. Digital approaches to material management also support the circular economy, while other aspects, such a material substitution (wood instead of cement in building construction) are distinct from digitalization strategies. Digitalization aims more broadly to deliver services in more efficient, timely, intelligent, and less resource-intensive (i.e., by moving bits and not atoms) ways, though the use of increasingly interconnected physical and digital systems in many facets of economies.



	Past	Present	Emerging
Circular economy	Waste scavenging Local repair/reuse Local by-product recycling Post-consumer recycling	Digital waste exchanges Additive manufacturing Advanced process controls Failure diagnostics Just in time production	Industrial symbiosis Supply chain tracking 3D printed structures Smart materials Automated disassembly
Sharing economy	Informal and community-based sharing of clothing, goods, shelter	P2P sharing of clothing, goods, shelter Ridehailing/ride sharing	Radically shared mobility Food sharing Freight co-loading Crowdshipping
Digitalization	Personal computers Fixed line internet Cellular voice phones Enterprise networks	Ubiquitous devices Wireless/mobile internet Smart phones Internet of things	Industry 4.0 Artificial intelligence Autonomous vehicles Distributed manufacturing Blockchain

Figure 5.10 The growing nexus between digitalization, the sharing economy, and the circular economy. While these trends started mostly independently, rapid digitalization is creating new synergistic opportunities with potential to improve the quality of jobs, particularly in developing economies. Widespread digitalization also introduces risks of growing electricity use, which is a pressing policy concern

5.3.2.1 Digitalization

Digitalization has been described as “the increasing interaction and convergence between the digital and physical worlds” (IEA 2017a). While digitalization trends have been underway for decades, the more recent advent of ubiquitous connected consumer devices such as mobile phones (Grubler et al. 2018), rapid expansions of global internet infrastructure and access (World Bank 2014), and steep cost reductions and performance improvements in computing devices, ubiquitous sensors, and digital communication technologies has accelerated the pace at which the physical and digital worlds are converging (Koomey et al. 2011; IEA 2017a).

Digitalization in a broader sense involves (1) the all-embracing interconnectedness of things, systems, processes, persons and organizations; (2) the increasing cognitive capabilities of digital technology; (3) the growing autonomy of digitalized systems such as robots, vehicles and institutional decision-making systems; (4) the spread of virtual spaces and virtualized technical services; and (5), as a result of all this, an unprecedented knowledge explosion in many scientific areas and disciplines (WBGU 2019; TWI2050 2019).

The long-term sustainability implications of digitalization hinge on three factors: (1) the direct energy demands of connected devices and the digital infrastructures (i.e., data centres and communication networks) that provide the necessary computing, storage, and communication services; (2) the systems-level energy and resource efficiencies gained through the provision of digital services; and (3) the magnitude of potential rebound effects or induced energy demands that might unleash unintended and unsustainable demand growth, such as autonomous vehicles inducing more frequent and longer journeys due to reduced travel costs (Wadud et al. 2016). Additionally, how wellbeing for all is addressed through disruptive digital innovations also is an additional concern. Besides basic mobile telephone service for communication digital innovation have been primarily geared to population groups with high purchasing power, and too little to the needs of poor and vulnerable people.

Estimating the digitalization's direct energy demand has historically been hampered by lack of consistent global data on IT device stocks, their power consumption characteristics, and usage patterns, for both consumer devices and the data centres and networks behind them. As a result, quantitative estimates vary widely, with literature values suggesting that consumer devices, data centres, and data networks account for anywhere from 5% to 12% of global electricity use (Malmodin and Lundén 2018; Cook et al. 2014; Gelenbe and Caseau 2015). Forward-looking projections have typically relied on extrapolations based on growing demand for devices and internet services, leading to stark predictions that direct energy demand may rise to 20- 30% of global electricity demand within the next decade (Belkhir and Elmeligi 2018; Jones 2018; Andrae and Edler 2015). However, such extrapolations can overlook strong countervailing effects of rapid efficiency gains in IT devices and network infrastructures that are occurring in parallel. For example, in the United States—the world's largest data centre market—efficiency improvements delivered a plateau in national data centre energy use since 2010, despite rapid increases in demand for U.S. data centre services (Shehabi et al. 2018). Yet there is evidence that rapid efficiency improvements might be outpaced by rising demand for digital services, particularly as data-intensive technologies such as artificial intelligence, smart and connected energy systems, distributed manufacturing systems, and autonomous vehicles promise to increase demand for data services even further in the future (TWI2050 2019). As digitalization grows, an important policy objective is therefore to invest in data collection and monitoring systems to guide technology and policy investment decisions for addressing potential direct energy demand growth (IEA 2017a).

The systems-level energy and resource efficiencies gained through the provision of digital services could play an important role in dealing with climate change and other environmental challenges (Elliot 2011; Melville 2010; Watson et al. 2012; Gholami et al. 2013; Añón Higón et al. 2017). There are numerous studies focusing on specific applications of digital services and their estimated mitigation potentials, such as the emissions savings related to telework (Kitou and Horvath 2003), streaming media (Shehabi et al. 2014; Weber et al. 2010), autonomous vehicles (Greenblatt and Saxena 2015), and intelligent energy systems (Koomey et al. 2013), which are often attributable to substantial substitution effects. For example, a modern smartphone requiring 5 watts of power can provide the same end-user services (e.g., telephony, music, video, etc.) as previously associated with over 15 different end-use devices that collectively required 449 watts of power (Grubler et al. 2018). In the United States, an estimated 25% reduction in national energy demand (compared to business as usual) might be achieved due to productivity improvements from digitally-enabled services (Skip Laitner 2010).

Only one study has comprehensively estimated the mitigation potential of digitalization and ICT service delivery at the global level, estimating that ICT can enable a 20% reduction of global CO_2-eq emissions—or 12 $GtCO_2$-eq—by 2030 (GeSI 2015; Accenture 2015). More than three-quarters of this estimated mitigation wedge was attributed to "smart" systems enabled by widespread digitalization of manufacturing systems, agriculture, buildings, energy systems, and logistics. Notably, digitalization of mobility (i.e., the combination of smart logistics, traffic control and optimization, connected private transportation and e-services) represented the largest sector for GHG emissions savings, at 24% of the 2030 mitigation potential.

Despite the efficiency potential of digitalization, there exist substantial risks of rebound effects and induced energy demand. Digitalization, automation and artificial intelligence, as general-purpose technologies, may lead to a plethora of new products and applications that are likely to be efficient on their own but that may also lead to undesirable changes or absolute increases in demand for products. For example, last-mile delivery in logistics is both expensive and cumbersome. Battery-powered drones enable a delivery of goods at similar life-cycle emissions to delivery vans (Stolaroff et al. 2018). At the same time, drone delivery is cheaper in terms of time (immediate delivery) and monetary costs (automation saves the highest cost component: personnel) (e.g., (Sudbury and Hutchinson 2016)). As a result, demand for package delivery may increase rapidly. Similarly, automated vehicles reduce the costs of time, parking, and personnel, and therefore may dramatically increase vehicle mileage (Cohen and Cavoli 2019; Wadud et al. 2016). On-demand electric scooters offer mobility access preferable to passenger cars, but replace trips otherwise taken on public transit and can come with significant additional energy requirements for night time system rebalancing (Hollingsworth et al. 2019). The energy requirements of cryptocurrencies is also a growing concern, although considerable uncertainty exists surrounding the energy use of their underlying blockchain infrastructure (Vranken 2017; Stoll et al. 2019; de Vries 2018; Masanet et al. 2019). Efficiency gains enabled by digitalization, in terms of reduced marginal GHG emissions or energy use per service unit may be overcompensated by activity/scale effects Figure 5.11.

Maximizing the mitigation potential of digitalization trends involve diligent monitoring and proactive management of both direct and indirect demand effects, to ensure that a proper balance is maintained. Direct energy demand can be managed through continued investments in and incentives for energy-efficient data centres, networks, and end-use devices (Masanet et al. 2011; IEA 2017a; Avgerinou et al. 2017). Shifts to renewable power are a particularly important strategy being undertaken by large data centre operators (Cook et al. 2014), which might be adopted across the digital device spectrum as a proactive mitigation strategy where data demands outpace feasible efficiency gains, which may be approaching limits within the next decade (Koomey et al. 2011). Ensuring efficiency benefits of digital services while avoiding potential rebound effects and demand surges will require extensive data collection and monitoring systems to ensure that net mitigation benefits are realized and unintended consequences can be identified early and properly managed (IEA 2017a). In this regard, the role of early and proactive public policies to avoid excess energy use may be critical (WBGU 2019; TWI2050 2019).

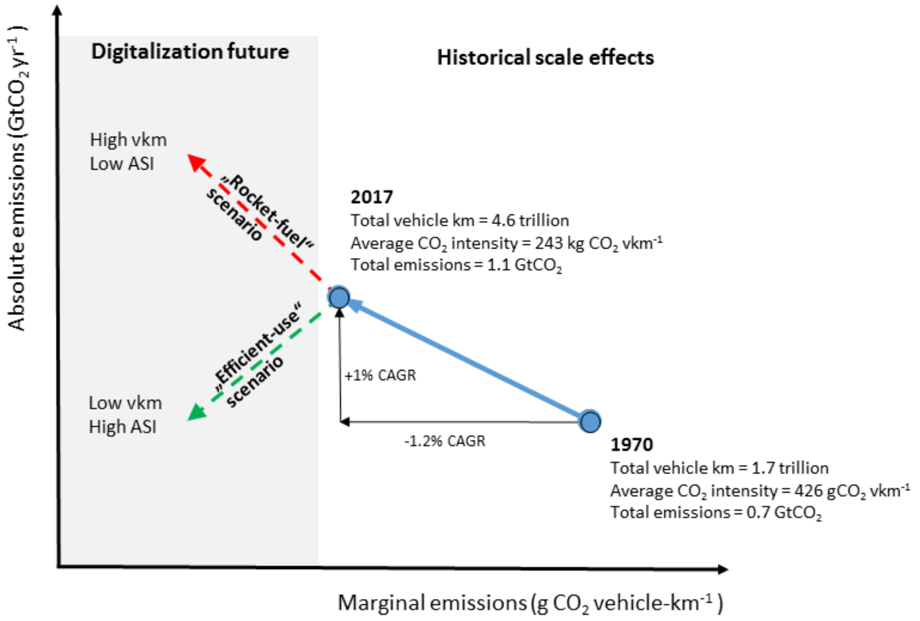


Figure 5.11 Digitalization and the shared economy make mobility systems more efficient but scale effects lead to increasing GHG emissions. Historical examples show that more efficient technologies reduce GHG emission marginally, but increase emissions by scale effects. A similar trajectory appears likely for digitalization in the absence of strong policies aimed at energy demand mitigation. For example, as a general-purpose technology, artificial intelligence opens up a plethora of new business opportunities and technologies that together may further scale-up emissions

5.3.2.2 The sharing economy

Opportunities to increase service per product includes peer-to-peer based sharing of goods and services such as housing, mobility, and tools. The sharing economy focuses on sharing underutilized products/assets in ways that promotes flexibility and convenience, often via gig economy/ online platforms. General conclusions on the sharing economy as a framework for climate change mitigation are challenging and are better broken down to specific subsystems (Mi and Coffman 2019). 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 2014; 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) 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; Schor 2014; Frenken and Schor 2017; Parente et al. 2018; Möhlmann 2015; Belk 2014).

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 of room sharing hosts pay their rent and utility bills by sharing their living spaces. Environmental motivations are important particularly for mobility and ridesharing (Böcker and Meelen 2017). Food sharing involve 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 are still edible but contain defects in size, colour, shape and size; the so-called market for "ugly food" (Richards and Hamilton 2018). Other popular meal sharing initiatives are EatWith, Meal Sharing, Traveling Spoon, in which hosts offer affordable food and a closer look into local life to tourists. 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).

5.3.2.2.1 Shared mobility

Shared mobility is characterized by the sharing of an asset (e.g. a bicycle, e-scooter, vehicle), and the use of technology (i.e. apps and the Internet) to connect users and providers. It succeeded by identifying market inefficiencies and transferring control over transactions to consumers. Shared mobility reduces GHG emissions if it substitutes for more GHG intensive travel (usually private car travel) (Martin and Shaheen 2011; Shaheen and Cohen 2019; Shaheen and Chan 2016; Santos et al. 2018; Axsen and Sovacool 2019), and especially if it changes consumer behaviour in the long run "by shifting personal transportation choices from ownership to demand-fulfilment" (Mi and Coffman 2019).

Shared mobility is categorized into four models (Santos et al. 2018): P2P platform where individuals can rent the vehicle when not in use (Ballús-Armet et al. 2014); short term rental managed and owned by a provider (Enoch and Taylor 2006; Schaefers et al. 2016; Bardhi and Eckhardt 2012); Uber-like service (Wallsten 2015; Angrist et al. 2017); and ride pooling where private vehicles shared by passengers to a common destination (Shaheen and Cohen 2019; Liyanage et al. 2019). The latest model – ride pooling – is promising in terms of congestion and per capita CO_2 emissions reductions, however is challenging in terms of waiting and travel time, comfort, and convenience, relative to private cars (Santos et al. 2018; Shaheen and Cohen 2019). The other models often yield profits to private parties, but remain mostly unrelated to reduction in CO_2 emissions (Santos et al. 2018).

The current state of shared mobility looks dismal or at least questionable (Fishman et al. 2014; Ricci 2015; Zhang et al. 2019; Zhang and Mi 2018; Mi and Coffman 2019; Martin 2016) (Creutzig et al. 2019). Transport entrepeneurs and government officials often conflate 'smart' and "shared' vehicle with 'sustainable' mobility, an intellectual shortcut not withstanding scrutiny (Noy and Givoni 2018). Surveys demonstrate that users take free-floating car sharing instead of public transit, rather than to replace their private car (Herrmann et al. 2014). If substitution effects and deadheading are accounted for, flexible moto-cycle sharing in Djakarta is at best neutral to overall GHG emissions (Suatmadi et al. 2019). Around 22% of all trips travelled with Uber and Lyft would have been travelled by transit, 12% would have walked or biked, and another 12% of induced demand or passengers that would not have travelled at all (Henao and Marshall 2019). Such developments would likely increase residential energy demand, commuting distances and the conversion rate of bio-productive land into low-density residential areas.

Positive effects is realized directly in bike sharing due to its very low marginal transport emissions. For example, in 2016, bike sharing in Shanghai reduced CO emissions by 25ktCO_2 with additional benefits to air quality (Zhang and Mi 2018). However, also bike-sharing can increase emissions from motor vehicle usage when inventory management is not optimized during maintenance, collection, and redistribution of dock-less bikes (Fishman et al. 2014; Zhang et al. 2019; Mi and Coffman 2019).

Shared mobility scenarios demonstrate that GHG emission reduction is substantial when mobility systems and digitalization is regulated. Some studies model that ride pooling with electric cars (6 to 16 seatings) (shift and improve), cuts GHG emissions by one-third (International Transport Forum 2016), and 63-82% per mile compared to a privately owned hybrid vehicle in 2030, 87 to 94% lower than a privately owned, gasoline-powered vehicle in 2014 (Greenblatt and Saxena 2015). This also realizes 95% reduction in space required for public parking; total vehicle kilometres travelled would be 37% lower than the present day, although each vehicle would travel ten times the total distance of current vehicles (International Transport Forum 2016). Studies of Berlin and Lisbon demonstrate that sharing strategies could reduce the number of cars by more than 90%, also saving valuable street space for human-scale activity (Bischoff and Maciejewski 2016; Martinez and Viegas 2017; Creutzig et al. 2019). The impacts will also depend on sharing levels – concurrent or sequential – and the future modal split among public transit, automated electric vehicles fleets, and shared or pooled rides. It is possible that shared automated electric vehicles fleets could become widely used without many shared rides, and single or even zero occupant vehicles will continue to dominate the majority of vehicle trips. It is also feasible that shared rides could become more common, if automation makes route deviation more efficient, more cost-effective, and more convenient, increasing total travel substantially (Wadud et al. 2016) ("rocket-fuel" scenario in Figure 5.11). Car sharing with automated vehicles could even worsen congestion and emissions by generating additional travel demand (Rubin et al. 2016). Travel time in autonomous vehicles can be used for other activities but driving and travel costs are expected to decrease, which most likely will induce additional demand for auto travel (Moeckel and Lewis 2017) and could even create incentives for further urban sprawl. More generally, increased efficiency generated by big data and smart algorithms may generate rebound effects in demand and potentially compromise the public benefits of their efficiency promise (Gossart 2015).

In the Global South, shared mobility and ride pooling is often the norm. Here the challenge is to improve service quality to keep users in shared mobility and public transport (see the case of Kolkata in 5.4.4.3). A key barrier in cities like Nairobi is the lack of public involvement of users and sustainability experts in designing transport systems, leaving planning to transport engineers, and thus preventing inclusive shared mobility system design (Klopp 2012).

Altogether, travel behaviour, business models, and especially public policy will be key components in determining how pooling and shared automated electric vehicles impacts unfold (Shaheen and Cohen 2019). Urban-scale governance of smart mobility that prioritizes public transit and the use of public spaces for human activities, manages the data as a digital sustainable commons, and Central Information Officer, as installed in Tel Aviv, manages the social and environmental risks of smart mobility and realize its benefits (Creutzig et al. 2019). Pricing of energy use and GHG emissions will be helpful to achieve these goals ("efficient-use" scenario in Figure 5.11). The governance of shared mobility is complicated, as it involves many actors, and is key to realize wider benefits of shared mobility (Akyelken et al. 2018).

5.3.2.2.2 Shared accommodation

Housing is responsible for 25% of aggregated environmental impacts from household consumption in the European Union (EU) with additional pressures added by the hotel industry. The EU average annual environmental impact related to housing person^{-1} yr^{-1} is 2.62 tCO_2-eq (Lavagna et al. 2018). As an alternative, several ways of accommodation are now emerging, in which accommodation is offered to, or shared with, travellers by private people organized by business-driven or non-profit online platforms. Accommodation sharing includes P2P, ICT-enabled, short-term renting, swapping, borrowing or lending of existing privately-owned idling lodging facilities (Möhlmann 2015; Voytenko Palgan et al. 2017).

Shared accommodation service is linked with negative sustainability effects, such as rebound effects caused by increased travel frequency (Tussyadiah and Pesonen 2016). This is particularly a problem if apartments are removed from the long-term rental markets, thus indirectly inducing constructions, with substantial GHG emissions on their own. Other studies show that if a host shares their accommodation with a guest, the use of some resources, such as heating and lighting, is shared, thereby leading to more efficient resource use per capita (Chenoweth 2009; Voytenko Palgan et al. 2017).

5.3.2.2.3 Comparative table on sharing economy strategies

Sharing economy initiatives play a central role in enabling individuals to share underutilised products. In addition, different strategies present different mitigation potential. However, negative rebounds effects may occur by changing consuming patterns, e.g., if savings from sharing housing are used to finance air travel. Table 5.2 Comparative table on sharing economy strategies and their relative mitigation potentialshows that P2P trading and shared mobility has higher total mitigation potential compared to shared accommodation, all depending on stringent public policy that reigns in run-away consumption effects. The overall literature remains limited.

Table 5.2 Comparative table on sharing economy strategies and their relative mitigation potential. Mitigation potential is conditional on corresponding public policy and/or regulation

Strategy	**Sector / Industry**	**Relative potential** [i]	**Total CO_2-eq potential** [ii]	**Rebound** [iii]	**Notes** *(baseline for reduction, scope, cause for rebound)*	**Source**
P2P sharing	Accommodation	-	0.4–0.8 Mt yr^{-1} [b]	0.2–0.3 Mt	a: Average demand per user; b: Scenario analysis for Germany	(Ludmann 2019)
		<<1% [b]	0.16 Mt [b]	0.15–0.20 Mt yr^{-1} (90–125%)	- Annual emission savings in 2030, EU28 - Rebound mostly due to increased travel demand - Rebounds have the potential to overcompensate savings, i.e. leading to a net negative effect	(Rademaekers et al. 2017)
	Mobility	<1% [b]	1.5–7.5 Mt yr^{-1} [b]	0.2 Mt yr^{-1} (13%)	- Annual emission savings in 2030, EU28	(Rademaekers et al. 2017)
		34% [b]	625 Mt [b]	957 Mt (52%)	- Global reductions of urban mobility emissions, compared to 'current ambition' scenario for 2050 - Rebounds assume loose regulations leading to 18% net increase.	(ITF 2019)
		1–6% [b]	1.2–5.9 Mt [b]	0.3–2.2 Mt (25–37%)	- Counterfactual scenarios for mobility emissions in Germany - Car- and ride-sharing results combined	(Ludmann 2019)
		8–13% [a]	0.335–0.425 Mt cap^{-1} yr^{-1} [a]	160 kg cap^{-1} yr^{-1} (40–50%)	- Counterfactual scenarios for Dutch personal mobility demand - Rebound due to change in mode of transport	(Nijland et al. 2015)
		6–45% [a]	0.130–0.980 Mt household^{-1} yr^{-1} [a]	0.814–3 Mt household^{-1} yr^{-1}	- Households in Denmark, Finland, Iceland, Norway, Sweden - Rebound estimated	(Skjelvik et al. 2017)

	Appliances/ Tools	<<1% [b]	0.3 Mt yr^{-1} [b]	0.18–0.26 Mt (60–90%)	- Consider sharing of common household tools - Annual emission savings in 2030, EU28	(Rademaekers et al. 2017)
P2P trading	Smartphones	86% [a]	0.08 Mt $phone^{-1}$	0.026 Mt/phone (30%)	- Savings from reusing a smartphone compared to buying a new one in the US - Rebound for money spent on average goods in the US	(Makov and Font Vivanco 2018)
	Food	-	154–163 Mt [b]	9.07–108.8 Mt [b]	- Savings from trade of discarded food in London - Rebound effects from increased mobility demand for picking up goods	(Makov et al. 2019)
	Textiles	1–12% [b]	0–1.3 Mt [b]	<1%	- Counterfactual scenarios for clothing emissions in Germany - Rebound partly neglected	(Ludmann 2019)

[i] Gross effect, i.e. excluding rebound effects
[ii] Savings, i.e. lower emissions compared to some sort of baseline
[iii] Reduction of the saving effect. E.g. 100% means all savings are lost due to additional emissions.
[a] Theoretical and technical potential, e.g. comparing two technologies
[b] Systemic potential, e.g. counterfactual study, considering market penetration, etc.
[c] Calculation based on source
P2P: Peer-to-peer, i.e. connecting users directly by means of internet-based communication platforms

Shared economy solutions relate to the “Avoid” and “Shift” strategies (5.1.3; 5.3.3.1). They provide similar or improved services for wellbeing (mobility, shelter) at reduced energy and resource input, when public policy reigns run-away effects.

5.3.2.3 The circular economy

Old and traditional linear throughput flow model dominates the overall wasteful development path causing serious environmental harm due to overconsumption of resources. Circular economy (CE) embodies a multitude of schools of thought with roots and relations to a number of related concepts (Blomsma and Brennan 2017; Murray et al. 2017), including cradle to cradle (McDonough and Braungart 2002), performance economy (Stahel 2016), biomimicry (Benyus 1997) and industrial ecology (Saavedra et al. 2018). A systematic literature review identified 114 definitions of the CE (Kirchherr et al. 2017). One of the most comprehensive models is suggested by the Netherlands Environmental Assessment Agency (Potting et al. 2018), which defines ten strategies for circularity: Refuse (R0), Rethink (R1), Reduce (R2), Reuse (R3), Repair (R4), Refurbish (R5), Remanufacture (R6), Repurpose (R7), Recycle (R8), Recover energy (R9). The key message is that planning a product and integrating its lifecycle demands less resources and energy, which in turn may more economic as well than conventional recycling of materials as low-grade raw materials. Thus, CE maximizes the time resources spends within the inner circles (Korhonen et al. 2018).

In line with the principles of SDG12, responsible consumption and production, the essence of building CE is to retain as much value as possible from products and components when they reach the end of their useful life (Linder and Williander 2017; Lewandowski 2016; Lieder and Rashid 2016; Stahel 2016). This requires an integrated approach during the design phase that, for example, extends product usage and ensures recyclability after use (de Coninck et al. 2018). While traditional improve strategies tend to focus on direct energy and carbon efficiency, service-oriented strategies focus on reducing lifecycle emissions through harnessing the leverage effect. The development of closed-loop models in service-oriented business can increase resource and energy efficiency, reducing emissions and achieve climate change mitigation goals on national, regional, and global levels (Johannsdottir 2014; Korhonen et al. 2018). Key examples include remanufacturing of consumer products to extend lifespans while maintaining adequate service levels (Klausner et al. 1998), reuse of building components to reduce demand for virgin materials and construction processes (Shanks et al. 2019), and improved recycling to reduce resource pressures (IEA 2019a, 2017b).

Among the many schools of thought on the CE and climate change mitigation two different trends can be distinguished. First, there are publications, many of them non peer-reviewed, that eulogize the perceived benefits of the CE, but in many cases step short of providing a quantitative assessment. Promotion of CE from this perspective has been criticized as a greenwashing attempt by industry and manufacturers, using the concept to avoid serious regulation (Isenhour 2019). Second there are more methodologically sound publication, mostly originating in the industrial economy discipline, but sometimes investigating only limited aspects of the CE. Conclusions also differ with diverging definitions of the CE.

There are two key concerns relating to the usefulness of the CE concept. First, many proposals and pamphlets on the CE insufficiently reflect on thermodynamic constraints that limit the potential of recycling or ignore the considerable amount of energy needed so reuse materials (Cullen 2017). Second, demand for materials and resources will likely outpace efficiency gains in supply chains, becoming a key driver of GHG emissions and other environmental problems, rendering the CE alone an insufficient strategy to reduce emissions (Bengtsson et al. 2018). In fact, the empirical literature points out that only 6.5% of all processed materials (4 Gt yr^{-1}) globally originate from recycled sources (Haas et al. 2015). The low degree of circularity is explained by the high proportion of processed materials (44%) used to provide energy thus not available for recycling; and the high rate of net additions to stocks of 17 Gt yr^{-1}. Hence, strategies targeting end-of-pipe materials are limited; instead, a significant reduction of societal stock growth, and decisive eco-design is suggested to advance the CE (Haas et al. 2015). One initiative focusing on waste diversion of IT waste is the Computer Reconditioning Centre in Belo Horizonte, Brazil. Since 2008, the program has diverted from local landfills around 165 tonnes of post-use electronics by restoring IT Products (e.g. CPUs, monitors, printers). In addition, the program offers digital inclusion to local communities and more ten thousand citizens have been trained in basic computer skills, environmental education, and computer remanufacturing (MCTIC 2019). Its success has fostered seven new centres around the country.

A report estimates that the CE can contribute to more than 6 $GtCO_2$ emission reductions from 2016 to 2030, including strategies such as car sharing (thus strongly overlapping with shared mobility (see 5.3.2.2.1 and 5.3.2.2.3)) and material substitution in buildings (Blok et al. 2016). Reform of the tax system towards GHG emissions and the extraction of raw materials substituting taxes on labour is key precondition to achieve such a potential. Otherwise rebound effect will take back high share of marginal CE efforts. 50% reduction of GHG emissions in industrial processes, including the production of goods in steel, cement, plastic, paper, and aluminium from 2010 until 2050 are impossible to attain only with reuse and radical product innovation strategies, but will need to also rely on the reduction of primary input (Allwood et al. 2010).

CE strategies correspond to the “Avoid” strategy (5.1.3; 5.3.3.1). CE strategies in industrial settings improve wellbeing mostly indirectly, via the reduction of environmental harm and climate impact. They also save monetary resources of consumers by reducing the need for consumption.

In summary, the definition of CE is contested, and in many cases, there is considerable overlap both with the sharing economy and digitalization. CE concepts that extend the lifetime of products and increase the fraction of recycling are useful but are both thermodynamically limited and will remain relatively small in scale as long as demand of primary materials continue to grow, and scale effects dominate. Relevant contribution to climate change mitigation at Giga ton scale by the CE will remain out of scope, if decision makers and industry do not reduce primary inputs, either by restriction or taxation on GHG emissions and raw material extraction. The comparative Table 5.3 Comparative table on circular economy strategies and their relative mitigation potentialshows that total CO_2 reduction potential is higher in recycling of materials in buildings sector followed by passenger car sector. However, circular economy initiatives, which have a lower per-unit production impacts, without a clear systemic analysis may increase level of production and reduce their benefits.

Table 5.3 Comparative table on circular economy strategies and their relative mitigation potential

Strategy	**Sector / Industry**	**Relative potential** [i]	**Total CO_2-eq potential** [ii]	**Rebound**	**Notes** *(baseline for reduction, scope, cause for rebound)*	**Source**
Supply chain management	Chemicals	30–70% [a]	-	-	- Compared to current technology	(Genovese et al. 2017)
Remanufacturing	Engines	69% [a]	-	-	- Current technology	(Hertwich et al. 2019; Liu et al. 2013)
Recycling	Passenger cars	1%–2% [b]	1266–1429 Mt	-	- Cumulative 2016–2060 savings for G7, CN, IN in a counterfactual scenario analysis of life-cycle car emissions	(Hertwich et al. 2020)
	Buildings	3%–15% [b]	2768–2949 Mt	-	- Cumulative 2016–2060 savings for G7, CN, IN in a counterfactual scenario analysis of lifecycle building emissions	(Hertwich et al. 2020)
	Plastics	-	30–70 Mt (CN, 2030)	-	- Scenario analysis for increasing recycling rates	(Liu et al. 2018b)
	Heavy industry	34% [b]	178 Mt [b]	-	- Savings in EU's heavy industry in 2050 - Considering recycling, product design, and closed-loop recycling	(Material Economics Sverige AB 2018)
Business models	Heavy industry	12% [b]	62 Mt [b]	-	- Savings in EU's heavy industry in 2050 - Considering sharing, design, remanufacturing	(Material Economics Sverige AB 2018)
Reuse	Passenger cars	0%–1% [b]	193–575 Mt	-	- Cumulative 2016–2060 savings for G7, CN, IN in a counterfactual scenario analysis of life-cycle car emissions	(Hertwich et al. 2020)
	Buildings	0%–3% [b]	382–463 Mt	-	- Cumulative 2016–2060 savings for G7, CN, IN in a counterfactual scenario analysis of lifecycle building emissions	(Hertwich et al. 2020)
	Steel	80% [a]	-	-	- Current technology	(Dunant et al. 2017; Hertwich 2019)
	Smartphones	86% [a]	0.08 Mt $phone^{-1}$	0.026 Mt $phone^{-1}$ (30%)	- Savings from reusing a smartphone compared to buying a new one in the US - Rebound for money spent on average goods in the US	(Makov and Font Vivanco 2018)

Repurpose	Food	-	154–163 Mt [b]	9.07–108.8 Mt [b]	- Savings from trade of discarded food in London - Rebound effects from increased mobility demand for picking up goods	(Makov et al. 2019)
[i] Gross effect, i.e. excluding rebound effects [ii] Savings, i.e. lower emissions compared to some sort of baseline [iii] Reduction of the saving effect. E.g. 100% means all savings are lost due to additional emissions. [a] Theoretical and technical potential, e.g. comparing two technologies [b] Systemic potential, e.g. counterfactual study, considering market penetration, etc. [c] Calculation based on source P2P: Peer-to-peer, i.e. connecting users directly by means of internet-based communication platforms						

5.3.3 Service, solutions, and scenarios

The preceding sections have provided examples of how improved service provision efficiencies can lead to substantial emissions reductions. Organizing these under the ASI framework, provides efficient service-oriented opportunities across all demand sectors, as summarized in

Table 5.3 Comparative table on circular economy strategies and their relative mitigation potential(Creutzig et al. 2018). The sharing economy, digitalization, and the circular economy all can contribute to ASI strategies, with the circular economy tentatively more on the supply side, and the sharing economy and digitalization tentatively more on the demand side. These new service delivery models go beyond sectoral boundaries (IPCC sector chapter boundaries explained in Chapter 12) and take advantage of technological innovations, design concepts, and innovative forms of cooperation cutting across sectors to contribute to systemic changes worldwide. Some of these changes can be realized in the short term, such as energy access, while others may take a longer period such as radical and systemic eco-innovations in order to transform current linear patterns of production and consumption into sustainable systems. It is important to understand benefits and distributional impacts of these systemic changes. This section presents emissions decompositions which highlight the major avoid, shift, and improve levers for decarbonizing key services necessary for decent standards of living worldwide, summarizes some novel strategies for deep demand reductions, and reviews long-term scenario results that explicitly considered ASI strategies for demand reduction.

5.3.3.1 Integration of service provision solutions with A-S-I framework

Assessment of service-related mitigation options within the ASI framework is aided by further decomposition of emissions intensities into explanatory contributing parameters, which depend on the type of service delivered. Table 5.4 summarizes resource, energy, and emissions intensities commonly used in the literature for this purpose by type of service (Cuenot et al. 2010; Lucon et al. 2014; Fischedick et al. 2014). The concepts of service provision adequacy (Arrow et al. 2004; Samadi et al. 2017) and service provision efficiency are also relevant dimensions of such analyses. The former is aimed at establishing the extents to which consumption levels exceed (e.g., high-calorie diets contributing to health issues (Roy et al. 2012); excessive food waste) or fall short of (e.g., malnourishment) service level sufficiency (e.g., recommended calories) and the latter encompassing variability that may occur in chosen service provision solutions (e.g., effect of occupancy on the energy intensity of public transit passenger-km travelled (Figueroa et al. 2013)). Hereafter, literature findings related to service-oriented solutions are discussed in the context of the Table 5.4 Avoid-Shift-Improve options in different sectors and services. Many options, such as urban form and infrastructures are systemic, and influence several sectors simultaneously. Source: adapted from (Creutzig et al. 2018) framework.

Table 5.4 Avoid-Shift-Improve options in different sectors and services. Many options, such as urban form and infrastructures are systemic, and influence several sectors simultaneously. Source: adapted from (Creutzig et al. 2018)

Service	Emission decomposition	Avoid	Shift	Improve
Mobility **[passenger-km]**	kg CO_2 = (passenger km)*(MJ pkm^{-1})*(kg CO_2 MJ^{-1})	**Innovative mobility to reduce passenger-km:** Integrate transport & land use planning Smart logistics Tele-working Compact cities	**Increased options for mobility MJ pkm^{-1}:** Modal shifts: from car to cycling, walking, or public transit from air travel to high speed rail	**Innovation in equipment design MJ pkm^{-1} and CO_2-eq MJ^{-1}:** Lightweight vehicles Hydrogen vehicles Electric vehicles Eco-driving
Shelter **[Square meters]**	kg CO_2 = (square meters)*(tons material m^{-2})*(kg CO_2 ton material^{-1})	**Innovative dwellings Reduce square meters:** Smaller dwellings Shared common spaces Multigenerational housing	**Material efficient housing m^{-2}:** Less material-intensive dwelling designs Shift from single-family to multi-family dwellings	**Low emission dwelling design kgCO_2 ton^{-1} material:** Use wood as material Use low-carbon production processes and materials for cement and steel Use CCS
Thermal comfort **[indoor temperature]**	kg CO_2 = (Δ°C x m^3 to warm or cool) (MJ m^{-3})*(kg CO_2 MJ^{-1})	**Choice of Healthy indoor temperature Δ°C x m^3:** Reduce m^2 as above Change temperature set-points Change dressing code Change working times	**Design options to Reduce MJ $\Delta{}^{\circ}C^{-1}$ x m^3:** Architectural design (shading, natural ventilation, etc.)	**New technologies to Reduce MJ/ Δ°C x m^3 and kgCO_2/MJ:** Solar thermal devices Improved insulation Heat pumps District heating
Goods **[units]**	kg CO_2 = units * (kg material/unit)*(kg CO_2 kg material^{-1})	**More service per product:** Consume less Long lasting fabric, appliances Sharing economy	**Innovative product design kg material unit^{-1}:** Materials efficient product designs	**Choice of new materials kg CO_2 kg material^{-1}:** Use of low carbon materials New manufacturing processes and equipment use
Food **[Calories consumed]**	kg CO_2 = (calories consumed)*(calories produced calories consumed^{-1})*(kg CO_2 calorie produced^{-1})	**Reduce sick and morbid days by calorie choice calories produced/calories consumed:** Keep calories in line with daily needs and health guidelines	**Add more variety in food plate to Reduce kg CO_2 cal^{-1} produced** Dietary shifts from ruminant meat to other protein sources	**Reduce kg CO_2 cal^{-1} produced:** Improved agricultural practices Locally-sourced food Energy efficient food processing

		Reduce waste in supply chain and after purchase		
Lighting **[lumens]**	kg CO_2 = lumens*(kWh lumen^{-1})*(kg CO2 kWh^{-1})	**Increase natural lumen demand:** Daylighting Occupancy sensors Lighting controls	**Adopt new innovation kWh lumens^{-1}:** Shift to LED lamps	**Demand innovation in power supply kg CO_2 kWh^{-1}:** Low-carbon electricity provision

Opportunities for avoiding excess provision of services, or avoiding excess demand for services themselves, exist across multiple service categories. Avoidance of food wastage — which accounts for around 8% of total annual GHG emissions (FAO 2014), while millions suffer from hunger and malnutrition — is a prime example. A key challenge in meeting global nutrition services is therefore to avoid food waste while simultaneously raising nutrition levels to equitable standards globally. Literature results indicate that consumers are the largest source of food waste, and that behavioural changes such as meal planning, use of leftovers, and avoidance of over-preparation can be important service-oriented solutions (Gunders et al. 2017; Schanes et al. 2018), while improvements to expiration labels by regulators would reduce unnecessary disposal of unexpired items (Wilson et al. 2017b). The mitigation potential of food waste reductions globally has been estimated at 0.8-6.0 $GtCO_2$-eq yr^{-1} by 2050 (Smith et al. 2014; Olsson et al. 2019). Coupling food waste reductions with dietary shifts can further reduce energy, land, and resource demand in upstream food provision systems, leading to substantial GHG emissions benefits. Estimated GHG emissions reductions associated with dietary shifts to low meat diets, vegetarian diets, or vegan diets range from 0.7-7.3, 4.3-6.4, and 7.8-8 $GtCO_2$-eq yr^{-1} by 2050, respectively (Olsson et al. 2019).

In the transport sector, avoid-shift-improve opportunities exist at myriad levels, comprehensively summarized in Bongardt et al (2013). Modeling based on a plethora of bottom-up insights and options reveals that a balanced portfolio of avoid, shift, and improve policies brings the global transport sector emissions in line with global warming of not more than 1.5°C (Gota et al. 2019). For example, telework may be a significant lever for avoiding road transport associated with daily commutes, achievable through digitalization, but its savings depend heavily on the modes, distances, and types of office use avoided (Kitou and Horvath 2003) and whether additional travel is induced due to greater available time (Mokhtarian 2002). More robustly, avoiding kilometres travelled through improved urban planning and smart logistical systems can lead to fuel, and, hence, emissions savings (IEA 2016, 2017a; Creutzig et al. 2015a). At the vehicle level, light weighting strategies (Fischedick et al. 2014), avoiding inputs of carbon-intensive materials into vehicle manufacturing, can also lead to significant emissions savings through improved fuel economy (Das et al. 2016; Hertwich et al. 2019; IEA 2019a). For details see Chapter 10.

In the buildings sector, avoidance strategies can occur at the end use or individual building operation level. End use technologies/strategies such as the use of daylighting (Bodart and De Herde 2002) and lighting sensors can avoid demand for lumens from artificial light, while passive houses, thermal mass, and smart controllers can avoid demand for space conditioning services. Eliminating standby power losses can avoid energy wasted for no useful service in many appliances/devices, which may reduce household electricity use by up to 10% (Roy et al. 2012). At the building level, smaller dwellings can reduce overall demand for lighting and space conditioning services, while smaller dwellings, shared housing, and building lifespan extension can all reduce the overall demand for carbon-intensive building materials such as concrete and steel (IEA 2019a; Material Economics Sverige AB 2018; Hertwich et al. 2019). Emerging strategies for materials efficiency, such as 3D printing of buildings to reduce construction waste or to optimize the geometries and minimize the materials content of structural elements, may also play a key role (Favier et al. 2019). Several scenarios estimate an 'avoid' potential in the building sector, reducing waste in superfluous floor space, heating and IT equipment, and energy use, by between 10 and 30%, in one case even by 50% (Chapter 9, 9.4).

Service efficiency strategies are also emerging to avoid materials demand at the product level, including dematerialization strategies for various forms of packaging (Worrell and Van Sluisveld 2013) and the concept of "products as services," in which product systems are designed and maintained for long lifespans to provide a marketable service (Oliva and Kallenberg 2003), thereby reducing the number of products sold and tons of materials needed to provide the same service to consumers. Successful examples of this approach have been documented for carpets (Stubbs and Cocklin 2008), copiers (Roy 2000), kitchens (Liedtke et al. 1998), and more (Roy 2000).

Shift strategies unique to the service-oriented perspective generally involve meeting service demands at much lower life-cycle energy, emissions, and resource intensities (Roy and Pal 2009), through such strategies as shifting from single-family to multi-family dwellings (reducing the materials intensity per unit floor area (De Wolf et al. 2015), shifting from passenger cars to rail or bus (reducing fuel, vehicle manufacturing, and infrastructure requirements (Chester and Horvath 2009), shifting materials to reduce resource and emissions intensities (e.g., low-carbon cement blends (Scrivener and Gartner 2018)) and shifting from conventional to additive manufacturing processes to reduce materials requirements and improve end-use product performance (Huang et al. 2016, 2017).

An important consideration in all ASI strategies is the potential for unintended rebound effects (Sorrell et al. 2009), which must be carefully avoided through various regulatory and behavioural measures (Santarius et al. 2016). For example, extending the lifespan of energy inefficient products may lead to net increases in emissions (Gutowski et al. 2011), whereas automated car sharing may reduce the number of cars manufactured at the expense of increased demand for passenger kilometres due to lower travel opportunity cost (Wadud et al. 2016) (see also 5.3.2).

5.3.3.2 Low demand scenarios

Long-term mitigation scenarios play a crucial role in climate policy design in near term, by illuminating transition pathways, interactions between supply-side and demand-side interventions, their timing, and the scale of required investments needed to achieve mitigation goals (see Chapter 3). Historically, most long-term mitigation scenarios have taken technology-centric approaches with heavy reliance on supply-side solutions and the use of negative emissions technologies, particularly in 1.5°C scenarios (Rogelj et al. 2018). Comparatively less attention has been paid to deep demand-side reductions incorporating lifestyle change and the cascade effects (Please see 5.3.1) associated with ASI strategies, primarily due to limited past representation of such service-oriented interventions in long-term IAMs and energy systems models (ESMs) (Napp et al. 2019; Grubler et al. 2018; van de Ven et al. 2018). While there is ample evidence of savings from sector- or issue-specific studies (see Section 5.3.3), the dominant narrative has so far been on the integrated view provided by IAMs and ESMs to evaluate combinations of ASI and efficiency strategies, and their interaction effects, alongside supply-side and negative emissions options (van den Berg et al. 2019; Samadi et al. 2017; Van Vuuren et al. 2018).

In response to 1.5°C ambitions, and a growing desire to identify participatory pathways with less reliance on negative emissions technologies with high uncertainty, several recent IAM and ESM mitigation scenarios have explored the role of deep demand-side energy and resource use reductions potentials at global and regional levels. Table 5.5 summarizes long-term scenarios that aimed to minimize service-level energy and resource demand as a central mitigation tenet, to specifically evaluate the role of behavioural change and ASI strategies, and/or to achieve a carbon budget with limited/no negative emissions technologies. From assessment of this emerging body of literature, several general observations arise.

First, behavioural changes within transition pathways offer Gigaton-scale CO_2 savings potential at the global level, and therefore represent a substantial overlooked strategy in traditional mitigation scenarios.

Two lifestyle change scenarios conducted with the IMAGE IAM suggested that low-cost behaviour changes such heating and cooling set-point adjustments, shorter showers, reduced appliance use, shifts to public transit, less meat intensive diets, and improved recycling can deliver an additional 1.7 Gt and 3 $GtCO_2$ savings in 2050, beyond the savings achieved in traditional technology-centric mitigation scenarios for the 2ºC and 1.5ºC ambitions, respectively (van Sluisveld et al. 2016; Van Vuuren et al. 2018). In its Sustainable Development Scenario, the IEA's behavioural change and resource efficiency wedges deliver around 3 $GtCO_2$-eq reduction in 2050, combined savings that exceed those of Solar PV that same year (IEA 2019b). In Europe, a GCAM scenario evaluating combined lifestyle changes such as teleworking, travel avoidance, dietary shifts, food waste reductions, and recycling reduced cumulative EU-27 CO_2 emissions 2011-2050 by up to 16% compared to an SSP2 baseline (van de Ven et al. 2018). A global transport scenario suggests that transport sector emission can decline from 18$GtCO_2$-eq in business-to-usual to 2 $GtCO_2$-eq if avoid-shift-improve strategies are deployed (Gota et al. 2019), a value considerably below the estimates provided in IAM scenarios that have no resolution in ASI strategies (compare with Chapter 10, Figure 10.18).
Second, pursuant to the ASI principle, deep demand reductions require parallel pursuit of behavioural change and advanced energy efficient technology deployment; neither is sufficient on its own. The LED scenario combines behavioural and technological change consistent with numerous ASI strategies that leverage digitalization, sharing, and circular economy megatrends to deliver decent living standards while reducing global final energy demand in 2050 to 245 EJ (Grubler et al. 2018). This value is 40% lower than final energy demand in 2018 (IEA 2019b), and a lower 2050 outcome than other IAM/ESM scenarios with primarily technology-centric mitigation approaches (IEA 2017b; Teske et al. 2015). In the IEA's B2DS scenario, avoid/shift in the transport sector accounts for around 2 $GtCO_2$-eq yr^{-1} in 2060, whereas parallel vehicle efficiency improvements increase the overall mitigation wedge to 5.5 $GtCO_2$-eq yr^{-1} in 2060 (IEA 2017b).

Third, low demand scenarios reduce both supply side capacity additions and the need for negative emissions technologies to reach emissions targets. Of the scenarios listed in Table 5.5, two (LED-MESSAGE and RegChange-IMAGE) reach 2050 emissions targets with no negative emission technologies (Grubler et al. 2018; van Sluisveld et al. 2018), whereas others report significant reductions in reliance on bioenergy with carbon capture and storage (BECCS) compared to traditional technology-centric mitigation pathways (Liu et al. 2018a; Napp et al. 2019; Van Vuuren et al. 2018).

Fourth, the costs of reaching mitigation targets are generally lower when incorporating ASI strategies for deep energy and resource demand reductions. The TIAM-Grantham low demand scenarios displayed reduction in mitigation costs (0.87–2.4% of GDP), while achieving even lower cumulative emissions to 2100 (228 to ~475 $GtCO_2$) than its central demand scenario (741 to 1066 $GtCO_2$), which had a cost range of (2.4–4.1% of GDP) (Napp et al. 2019). The GAMS behavioural change scenario concluded that domestic emission savings would contribute to reduce the costs of achieving the internationally agreed climate goal of the EU by 13.5% to 30% (van de Ven et al. 2018). The AIMS lifestyle case indicated that mitigation costs, expressed as global GDP loss, would be 14% lower than the SSP2 reference scenario in 2100, for both 2ºC and 1.5ºC mitigation targets (Liu et al. 2018a).

There remain several important limitations within most IAMs and ESMs regarding ASI strategy analysis, which once addressed will expand and improve long-term mitigation scenarios (van den Berg et al. 2019). These include broader inclusion of mitigation costs for behavioural interventions (van Sluisveld et al. 2016), incorporation of rebound effects from avoided spending (van de Ven et al. 2018), improved representation of materials cycle to assess resource cascades (Pauliuk et al. 2017), broader coverage of behavioural change (Samadi et al. 2017) and institutional, political, social, entrepreneurial, and cultural factors (van Sluisveld et al. 2018).

Table 5.5 Summary with long-term scenarios that aimed to minimize service-level energy and resource demand

Global scenarios										
				Focused demand reduction element(s)				**Mitigation potential**[iii]		
#	**Scenario [Temp]**	**IAM/ ESM**	**Final energy**	**Scope**	**Sectors** [i]	**Key demand reduction measures considered (A, S, I)** [ii]	**Baseline scenario**	**CO_2 (Gt)**	**Final energy**	**Primary energy**
a	Lifestyle change scenario [2ºC]	IMAGE		Whole scenario	R, T, I	A: Set points, smaller houses, reduced shower times, wash temperatures, standby loss, reduced car travel, reduced plastics S: from cars to bikes, rail I: improved plastic recycling	2ºC technology-centric scenario in 2050	1.7		
b	Sustainable Development Scenario [1.8ºC]	WEM	398 EJ in 2040	Behavioral change wedge and resource efficiency wedge	T, I	A: shift from cars to mass transit, building lifespan extension, materials efficient construction, product reuse I: improved recycling	Stated policies in 2050	3		
c	Beyond 2 Degrees Scenario [1.75ºC]	ETP-TIMES	385 EJ in 2050	Transport avoid/shift wedge and material efficiency wedge	T, I	A: shorter car trips, optimized truck routing and utilization S: shifts from cars to mass transit I: plastics and metal recycling, production yield improvements	Stated policies in 2060	2.5		
d	Lifestyle change scenario [1.5ºC]	IMAGE		Whole scenario	R, C, T, I	A: Set points, reduced appliance use S: from cars to mass transit, less meat intensive diets, cultured meat I: best available technologies across sectors	1.5ºC technology-centric scenario in 2050	3		175 EJ

e	Low Energy Demand Scenario [1.5ºC]	MESSAGE	245 EJ in 2050	Whole scenario	R, C, T, I, F	A: device integration, telework, shared mobility, material efficiency, dematerialization, reduced paper S: multi-purpose dwellings, healthier diets I: best available technologies across sectors	Final energy in 2020		165 EJ	
f	Advanced Energy [R]evolution		279 EJ in 2050	Whole scenario	R, C, T, I	S: shifts from cars to mass transit I: best available technologies across sectors	Stated policies in 2050		221 EJ	
g	Limited BECCS – lifestyle change [1.5ºC]	IMAGE		Whole scenario	R, C, T, F	A: Set points, reduced appliance use S: from cars to mass transit, less meat intensive diets, cultured meat I: best available technologies across sectors	SSP2 in 2050	58		400 EJ
h	Lifestyle scenario [1.5ºC]	AIM	425 EJ in 2100	Whole scenario	T, I, F	A: reduced transport services demand, reduced demand for industrial goods S: less meat-intensive diets	SSP2 in 2100		125 EJ	
i	Transport scenario [1.5ºC]	Bottom-up construction		Whole scenario	T	A: multiple options S: multiple options I: multiple options		89% vs BAU: 16GtCO$_2$		
Regional scenarios										
j	Urban mitigation wedge		540 EJ in global cities in 2050	Whole scenario	R, C, T	A: reduced transport demand S: mixed-use developments I: vehicle efficiency, building codes and retrofits	Current trends to 2050		180 EJ	

k	France 2072 collective society	TIMES-Fr	4.2 EJ in France in 2072	Whole scenario	R, T	A: less travel by car and plane, longer building and device lifespans, less spending S: shared housing, shifts from cars to walking, biking, mass transit	Final energy in 2014		1.7 EJ	
l	EU-27 lifestyle change – enthusiastic profile	GCAM		Whole scenario	R, T, F	A: telework, avoid short flights, closer holidays, food waste reduction, car sharing, set points S: vegan diet, shifts to cycling and public transit I: eco-driving, composting, paper, metal, plastic, and glass recycling	SSP2, cumulative emissions 2011-2050	16%		
m	Europe broader regime change scenario	IMAGE	35 EJ in EU in 2050	Whole scenario	R, T	A: reduced passenger and air travel, smaller dwellings, fewer appliances, reduced shower times, set points, avoid standby losses S: car sharing, shifts to public transit I: best available technologies	SSP2 in 2050		10 EJ	

Sources: a (van Sluisveld et al. 2016), b (IEA 2019b), c (IEA 2017b), d (Van Vuuren et al. 2018), e (Grubler et al. 2018), f (Teske et al. 2015), g (Esmeijer et al. 2018), h (Liu et al. 2018a), i (Creutzig et al. 2015b), j (Millot et al. 2018), k (van de Ven et al. 2018), l (van Sluisveld et al. 2018)

i. R = residential; C = commercial, T = transport, I = industry, F = food,
ii. A= avoid; S = shift, I = improve
iii. Relative to indicated baseline scenario value in stated year

5.4 Transition toward high wellbeing and low-carbon demand societies

To characterize the dynamics of a transition from the current global high-carbon, consumption, and continuous GDP-growth oriented economy to a low-carbon, energy-services, and wellbeing and equity oriented economy (Section 5.2), we distinguish between elements of agency, structure, and meaning (Sovacool and Hess 2017). There is *very high confidence* in the literature that the interactions between forces of agency, structure and meaning are driving a low-carbon transition, as described in by several integrative frameworks, including social practice theory (Røpke 2009; Shove and Walker 2014), the energy cultures framework (Stephenson et al. 2015; Jürisoo et al. 2019), and socio-technical transitions theory (McMeekin and Southerton 2012; Geels et al. 2017a). *Agency* describes the capacity to act independently. It includes actors with roles for the desired demand-side transition, their motivations, and their capacities for change. *Structure* refers to recurrent patterned arrangements that influence or limit human actions and can be further divided into infrastructure, rules, and organizations. *Meaning* refers to the cognitive, discursive, and normative systems that orient action of actors and can be further subdivided into lifestyles, norms, and shared beliefs. As shown in Figure 5.12, the elements of agency, structure, and meaning combine to create social practices which in turn modify those elements in dynamic ways, creating social change over time.

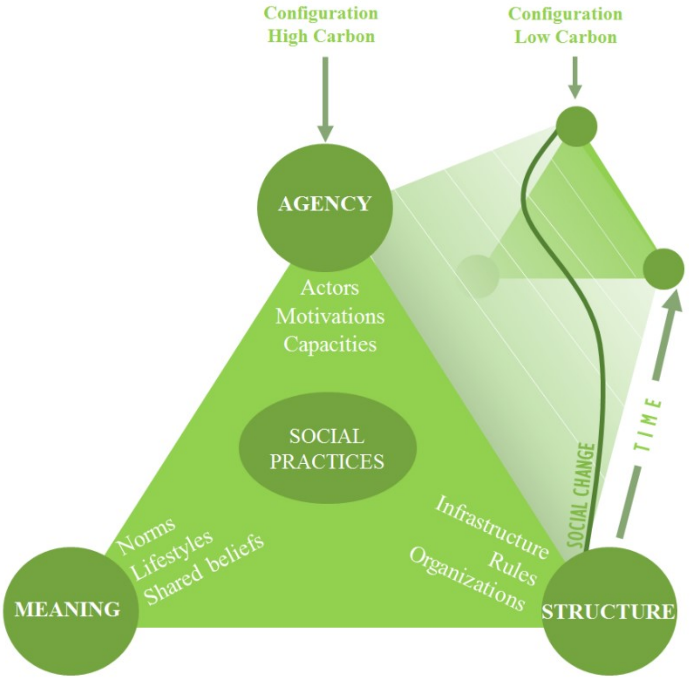


Figure 5.12 Forces that interact in the dynamics of transitioning from current "High-Carbon Supply-Side Driven World" to a future "Low-Carbon Supply- and Demand-Side Driven World"

5.4.1 Agency

In the demand-side mitigation options space, agency is expressed by actors who differ in motivations and goals, and in their capacities for change as shaped by different physical, social, historical, and cultural contexts. Actors include (a) individuals and households whose personal decisions and actions (as consumers, prosumers, citizens) impact products/services/energy demand; (b) collective action as expressed in civil society, NGOs, and social movements; and (c) the private sector in the form of business firms, the financial sector, and professional organizations, who shape and incentivize technological and social innovation and the behaviour of professional actors (Roy et al. 2012). Decisions or action that directly or indirectly reduce energy demand can be motivated by market- and non-market forces, and can be either legally vs. socially vs. ethically binding.

It has long been thought useful to conceive of consumers as "rational actors," attentive to incentives, including all relevant costs and benefits (Becker 2013). If the price of certain goods increases, people will buy less of them. Under this framework, moral commitments, and social norms, may or may not matter (Becker and Murphy 2000). If they do, it is because violations of a social norm operate as a kind of "tax", leading a consumers to take steps to avoid such violations. The large point is that demand-side behaviour is above all reflection of what consumers perceive as costs and benefits. If, for example, consumers believe that it is in their interest to engage in consumption patterns that lead to a high-carbon economy, then a high-carbon economy is much more likely. A transition to a low-carbon economy will require a significant shift in incentives.

This understanding of consumer behaviour has clear implications for policy – suggesting, for example, that appropriate taxes or subsidies can lead to major reductions in greenhouse gas emissions. But it misses important features of human judgment and decisionmaking (Kahneman 2011; Thaler 2015), with relevant implications for environmental policy (Sunstein and Reisch 2014; Creutzig et al. 2016b). 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 incentives depends on whether those incentives are salient (Gabaix and Laibson 2018). Some characteristics of activities and products are "shrouded," even though they matter to consumer's wellbeing, and consumer may not pay a great deal of attention to them. In addition, norms matter, and can greatly affect behaviour (Lessig 1995).

To influence consumer demand, policymakers have an assortment of tools, including prohibitions, mandates, taxes, fees, subsidies, and "nudges" (Thaler and Sunstein 2009), defined to include such choice-preserving interventions as information, warnings, reminders, uses of social norms, and default rules, such as automatic enrolment in "green energy," such as 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 wellbeing 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 these 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 influence and feedback processes (Stern 2016; Niamir et al. 2018, 2019) 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) (*high confidence*).

There has been continuous advancement in the way demand side choice processes are viewed and modelled in the IPCC and energy and carbon mitigation policy community. From AR1 to AR4, rational decision making as defined by microeconomics was the implicit assumption, where individual agents maximize self-focused expected utility and are homogeneous, the only consequential variations of *homo economicus* being in wealth, risk attitude, and time discount rate (Persky 1995). AR5 (Kunreuther et al. 2014) introduced a broader range of goals (material goals, self- and other-regarding social goals, and psychological goals) and a broader range of decision processes (calculation-based, but also affect-based, and role- and rule-based processes), but its perspective on decisions and action was individual- and agency-focused and thus did not explicitly address the role of structural, cultural, and institutional constraints and the influence of physical and social context (Thaler and Sunstein 2003).

AR5 (Kunreuther et. al 2014) reviewed how experts and the general population differed in their responses to risky and uncertain climate information and the importance for experts/scientists/policy makers to understand and predict the public's reaction in order to communicate climate risks and uncertainties effectively. Its perspective focused on the 'deficits' of boundedly-rational individuals and ways to 'aid' their decisions (Kunreuther and Weber 2014), taking a 'top-down' view of change and implementation, with some negative implications as discussed in Section 5.4.3 (Wolsink 2007). Nevertheless, AR5's introduction of a broader range of goals and decision processes than those of *homo economicus* had important implications for the evaluation of IPCC scenarios. It has introduced additional uncertainty about the effects of climate change (e.g., temperature increases or extreme weather) on human behaviour and hence future GHG emissions (Beckage et al. 2018). At the same time, an agency-based framework that includes the many influences on individual decisions that go beyond rational choice and rational expectations (e.g., responses to extreme events, perceived behavioural control, and perceived social norms) explains many anomalies observed by ecologists in the field (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, as discussed below.

However, even a broad set of agency-based decision factors accounts at best for 30-40% of the variance in climate action, suggesting that behavioral 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 and Möser 2007; Whitmarsh et al. 2017) . The current chapter reflects a more inclusive view of different disciplinary and philosophical perspectives on individual and collective energy decisions (Grubb 2014; Riahi et al. 2015; Grubler et al. 2018; Mundaca et al. 2019; Creutzig et al. 2018, 2016b). It broadens the individual-focused framework of micro- and behavioural economics and psychology on agency by also including considerations of structure and meaning, i.e., the hardware and software of the social, cultural, and physical context studied by disciplines like geography, ecology, sociology, urban planning, and anthropology. Below is an assessment of the motivations and capacity for demand-side emissions reductions by three classes of actors, before moving on to the role of structure and meaning.

5.4.1.1 Individuals and households

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 (*medium confidence*). 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. A 2018 Pew Research Center survey in 26 countries (Fagan and Huang 2019) shows a median of 67% of individuals say that global climate change is a major threat to their country, and increase from the 53% who said so in 2013, though a median of 29% also consider it a minor or no threat. Younger people and women as well as individuals with higher levels of education perceive climate risks to be larger (Weber 2016; Fagan and Huang 2019). Moral values and political ideology influence climate risk perception, as captured by a segmentation of the American public into "six Americas" that differ also in their demographics and beliefs about the outcomes and effectiveness of climate action (Maibach et al. 2011).

Generational and educational differences also exist in individuals' motivation to take action, with younger consumers in Europe saving energy (Avoid) to mitigate climate change, but older consumers also more motivated by financial savings (Mills and Schleich 2012). In India, young professional also do so for financial savings and higher awareness levels due to access to information on efficiency and climate change (Chakravarty and Roy 2016). Environmental goals, including climate goals, do sometimes but not always have the same importance in the Global South as in the Global North (Beer 2014). But in any region of the world, motivation for demand side mitigation behaviour can be increased by focusing on personal health or financial benefits rather than impersonal and more distant social or environmental benefits (Petrovic et al. 2014). Consistent with climate change being seen until recently as a distant, non-threatening, statistical issue by most members of the general public (Fox-Glassman and Weber 2016; Gifford 2011), personal experience with climate-linked flooding or other extreme weather events increases perceptions of risk and willingness to act (Weber 2013; Atreya and Ferreira 2015; Sisco et al. 2017).

Theoretical frameworks that go beyond traditional sociodemographic and economic predictors and also consider psychological variables such as awareness, subjective norms, and perceived behavioral control to predict willingness to change energy-related behavior (Schwartz 1977; Ajzen 1985; Stern 2000) do well (*high confidence*). Several large surveys investigating the determinants of A-S-I behaviors in households in the Netherlands and Spain (Abrahamse and Steg 2009; Niamir 2019; Niamir et al. 2020), the OECD (Ameli and Brandt 2015), and 11 European countries (Mills and Schleich 2012) find that awareness and personal and social norms are as important as monetary factors. Education and income increase Shift and Improve behavior, whereas personal norms help to increase the more difficult Avoid behaviors. Sociodemographic variables (e.g., household size and income) predict energy use (Ahmad et al. 2015), but psychological variables (e.g., perceived behavioral control, perceived responsibility) predict changes in energy use. Younger households are more likely to Improve, education increases Avoid decisions.

Also in developing countries, like India, improve and shift behaviors are predicted by different variables than avoid behaviors (Roy et al. 2018a). A survey-based study in mobility service demand among urban population in India shows that avoid decisions are made by the individuals championing a cause, while improve and shift increases with participation in awareness programmes, promotional materials highlighting environmental benefits, and financial benefits (Chakravarty and Roy 2016). Adoption of cleaner cookstoves has been widely studied in developing countries as an Improve solution to GHG emissions and air pollution, though typically by supplying households with such stoves, rather than by motivating demand (Nepal et al. 2010; Pant et al. 2014). A systematic review of 32 research studies of clean stove adoption or fuel choice from Asia, Africa, and Latin America finds that income, education, and urban location were positively associated with adoption in most studies, that the influence of fuel availability and prices, household size and composition, and gender was unclear, and that potentially important drivers such as credit, supply-chain strengthening, and social marketing remain ignored (Lewis and Pattanayak 2012).

The motivation and effort required for behavior change increase from Improve to Shift to Avoid decisions. Individuals in the USA set easy goals for themselves and more difficult ones for others (Attari et al. 2016). They are bad at predicting energy savings when they reduce their use of different energy devices, over predicting the small savings and under predicting the large ones (Attari et al. 2010), which suggests the need for guidance. Most households prefer personal actions in climate change mitigation of options that have small reduction potential, such as recycling and ecodriving, but restrain from options that have high impact (less flying, living car free) (Dubois et al. 2019).

Individual differences in climate risk perception and motivation to act suggest the need for segmentation in the way different consumer or voter groups are being targeted in information or climate action campaigns, with age, education, political values, and personal experience being important segmentation variables. Given that such segmentation is not always easily accomplished, it is useful to know that information relevant for different segments can be provided at the same time in the same display (e.g., metrics that allow individuals reduce their energy consumption for different reasons, for example when buying a more or less energy-efficient car or appliance). The new fuel-economy sticker for cars issued by the US Environmental Protection Agency in 2013 did so by displaying the energy requirements of each car either 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, but process-tracing research shows that different consumers selectively attend to the information that conforms to their motivation (Ungemach et al. 2017).

Individuals act in more roles than that of consumer when they make energy decisions and demand side policies need to consider tools beyond economic incentives (e.g., subsidies and taxes) (e.g., Chakravarty Roy, 2016; Niamir 2019; Niamir et al. 2018; Stern 2011; Mattauch, Ridgway, Creutzig 2016) (*very high confidence*). Instead, the social environment, cultural practices, public knowledge, producer technologies and services, and facilities used by consumers should all be considered when designing implementable and politically feasible policy options. Furthermore, the financial, social, and other instruments in the policy mix are most effective when applied as a coherent set where they can reinforce each other. In particular, the provision of targeted information, social advertisements, and power of celebrities, in combination with education, can be used to create better climate change knowledge and awareness in the longer run and can accompany and reinforce the effectiveness of other instruments, such as subsidies. Such soft policies can prove to be more effective in promoting green-energy solutions implemented by households than fiscal policy measures alone (Niamir et al. 2019, 2020; Niamir 2019).

Some choices such as a vegan diet or an SUV are more linked to identities and social status. These are powerful influences upon climate mitigation because they are processes that can operate across behavioural domains with the potential to ‘spill-over’ from one to another (e.g. from work to home or vice versa) (Whitmarsh and O’Neill 2010). Voluntary adoption of low materialistic behaviour is more prevalent in Brazil than the UK and easily associated behaviours such as recycling are more commonly undertaken than other forms of dematerialisation such as avoiding buying new things or avoiding packaging (Whitmarsh, Capstock, and Nash 2017).

Another alternative or complement to mandates and financial incentives are policies and policy implementations that are based on psychology and behavioral economics, sometimes described as “nudges” or choice architecture (Thaler and Sunstein 2009). These affect the behavior of individuals or households by shaping the soft infrastructure of their decisions. Yoeli et al. (2017) integrate a large behavioral literature on changing energy behavior via choice architecture into 4 objectives (get attention; engage desire to contribute to social good; facilitate accurate assessment of risks, costs, and benefits; make complex information more accessible) and 13 tools (e.g., set the proper default, provide timely feedback). Setting effective "green" defaults may be the most effective policy to mainstream low-carbon energy choices (Sunstein and Reisch 2014), and it has been adopted in many contexts (Jachimowicz et al. 2019). Multi country study shows that such defaults are also highly acceptable in the society (Sunstein et al. 2019). The California Public Utility Commission, for example, is mandating making Time-of-Use electricity plans to be the default choice option to be presented to utility customers by 2020.

While choice architecture and other soft interventions can help to shape the personal/agency drivers of energy behavior, this may not be sufficient for more difficult decisions on the Improve, Shift, and Avoid continuum. A large European household study found that changes with greater potential to reduce emissions (e.g., a high carbon tax on fuel, or regulation to reduce packaging) were not popular among households, suggesting that top-down solutions may be needed in addition to voluntary measures (Dubois et al. 2019).

5.4.1.2 Civil society, NGOs, and social movements

People, governed by values and social norms, make individual decisions on how to live, eat, travel, etc.: what they need in life, why and how they need it, and (within their means) what forms of consumption they choose. Collectively, the same values and social norms affect voting, politics, private sector and informal sector decision-making and policy, with the potential to induce even faster change (Adger 2003).

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

The Friday-For-Future international social movement with large numbers of youths' campaigning for climate action has put pressure on policy makers in several jurisdictions to declare a Climate Emergency, a change in meaning and discourse that can alter the boundaries of what is considered politically acceptable (Szałek 2013). It has also created a new cohort of active citizens participating in democratic processes of social change (Fisher 2019). However, the movement's emphasis upon using science to guide policy change may only be the starting point for answering the ethical and political dimensions of climate action (Evensen 2016). Research is required to evaluate the consequences of the movement for public engagement on climate mitigation and policy change.

SR15 used the Transition Town movement as an example of grassroots collective action that combine adaptation, mitigation and just transitions (Roy et al. 2018a). Transition Towns are found in over 40, mainly high income, countries. Aspirations to increase local resilience to climate impacts and peak oil are coupled with a focus on equity and lifestyle change, aiming to shift behavior and lifestyles away from reliance upon fossil-fuels (Grossmann and Creamer 2017)

Community energy initiatives involve collective action by civil society – typically local residents and community groups - on climate mitigation to improve energy efficiency, shift to renewable energy and reduce fuel poverty, through collective ownership, benefit and control over decision-making (Hicks and Ison 2018)(Creamer et al., in 2018). Community initiatives are integral to the 'sharing economy' (Acquier et al. 2017) mentioned in Section 5.3.3.1, involving non-contractual, non-hierarchical and non-monetised forms of interaction. For example, across Europe, the RESCOOP initiative brings together 1500 cooperatives and over 1 million citizen shareholders in energy renewable energy projects (REScoop 2019).

The benefits of community energy initiatives are context-dependent (Rydin and Turcu 2019). Community energy initiatives create opportunities for existing skills to be put into the service of the community (Seyfang et al. 2013; Walker et al. 2010) and develop new skills among participants (Roy et al. 2012), (Berka and Creamer 2018) including leadership, finance, management and engagement as well as technical knowledge about renewable energy (Hicks and Ison 2011; Callaghan and Williams 2014). Community initiatives have also been shown to be more enduring over time than initiatives led by private companies reliant upon fixed-term funding (Rydin and Turcu, 2019). As a result, community-led initiatives hold an advantage in enabling societal transformation towards net zero emissions (Devine-Wright 2019). Actively seeking community involvement can turn negative feedback cycles of project rejection towards positive feedback cycles, where communities are stakeholders and thus also accept energy initiative Figure 5.13.

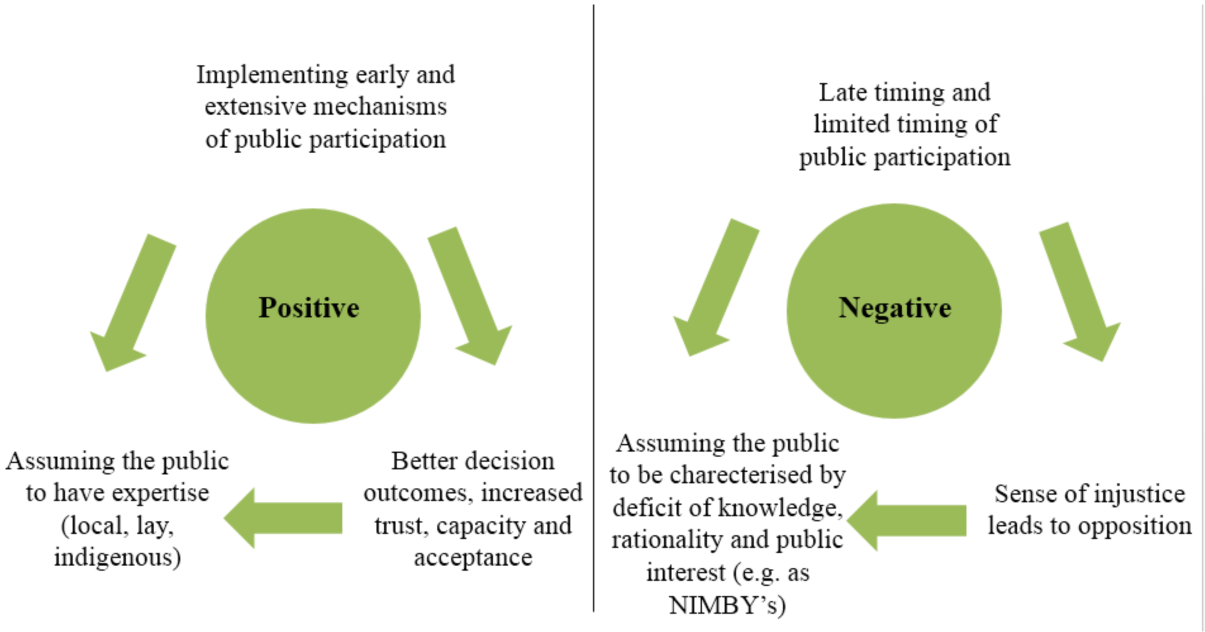


Figure 5.13 Positive and negative feedback loop in public participation in climate mitigation

High levels of trust and strong networks within a locality can both facilitate and constrain community energy action (Hoffman and High-Pippert 2010; Walker et al. 2010; Hargreaves et al. 2013a) and community energy has the ability to develop and reinforce social capital (Walker et al. 2010; Gubbins 2007; Hicks and Ison 2011). Community initiatives can encourage people to take pro-environmental action and to change lifestyles (Middlemiss and Parrish 2010), particularly those with low previous environmental engagement and who take part in a cohesive group (Middlemiss 2011). Through collective approaches, community energy can thus make climate change local and real, empowering people to take practical action (Middlemiss and Parrish 2010; Seyfang et al. 2013; Walker et al. 2010). Combined with the sharing of knowledge, skills and ideas, these effects contribute to shifting norms around energy and climate change (Hoffman and High-Pippert 2010), and can support overall climate governance (see also 5.2.3).

Co-operatives are a distinct form of community energy initiative with large and geographically dispersed memberships (i.e. communities of interest) that are prevalent in high income countries such as Germany and Belgium (Kalkbrenner and Roosen 2016; Bauwens 2016), US, South Korea, Chile and

Brazil (Simcock et al. 2016), and also have played an important role in providing access to electricity in rural Bangladesh, Nepal (Yadoo and Cruickshank 2010), and India. They enable access to clean energy and increase sustainable development in low income countries (IRENA 2018).

Voluntary climate actions at the community level and emissions-reducing consumption choices by individuals may encourage shifts in norms that lead to larger-scale transformations (Carattini et al. 2019). There are many types of context-specific influences on consumption and political choices with emissions implications, including the way these are assumed, understood and modelled (Shwom and Lorenzen 2012; Michalis 2003). People increasingly are aware of and compare their own consumption to international standards, which can create constituencies for voluntary climate action across countries (Heal 2008; Gupta 2012; Beer 2014; Bretschger 2017; Boran 2019; Wood and Roelich 2019; Hayward and Roy 2019). Much recent research indicates that broader-frame, longer-term, more collective, equity-oriented perspectives are emerging worldwide that is consistent with shifts in social norms and preferences toward synergistic, effective climate policy.

5.4.1.3 Business Organizations, Financial Sector, and Professional Organizations

Current effects of climate change are already threatening the viability of existing business practices as well as standard operating procedures in agriculture, infrastructure design, and will increasingly do so in the future. A reduction in energy demand or shift towards renewable energy sources, or regulations that limit the use of fossil fuels, introduces the risk of stranded assets. Companies, businesses and people who have investments in companies such as stocks, bonds, gold, real estates etc. are likely to incur losses due to climate change due to their assets becoming stranded. According to a European Systemic Risk Board (ESRB 2016) report of the Advisory Scientific Committee, insurance industries are very likely to incur losses due to liability risks. Companies, businesses and organizations might face liability claims for their contribution to changes especially in the carbon intensive energy sector. The insurance industry might be affected in their role as insurer of third-party liability both from natural disasters and from liability.

Inversely, uncertainty about future climate policy (and specifically levels of carbon prices) prevents investments into low-carbon technologies, reflecting status quo bias and risk aversion (Fan et al. 2010). In addition, companies fail to collectively respond to climate change due to the multiplicity of interests of actors, and associated 1) economic reasoning; 2) weak actor bonds; and 3) differing perceptions of the rules of the game (Finke et al. 2016).

Climate change also opens up opportunities for businesses. For example, a reduction in energy use saves billions of dollars for businesses (Henderson et al. 2016), and electrification of transport opens up new markets for more than a hundred million new vehicles by 2039 (Bunsen et al. 2018). In manufacturing, firms can save costs and reap competitive advantages by considering relocating to locations where they can access cheap utility-scale solar energy (Henderson et al. 2016).

Professional actors play important roles in climate mitigation. Working as building managers, landlords, energy efficiency advisers, technology installers and car dealers, they influence patterns of mobility and energy consumption (Shove 2003) by acting as 'middle actors' (Janda and Parag 2013; Parag and Janda 2014) or 'intermediaries' in the provision of building or mobility services (Grandclément et al. 2015), (De Rubens et al. 2018). As influencers on the process of diffusion of innovations (Rogers 2003), professionals can enable or obstruct improvements in efficient service provision or shifts towards low-carbon technologies (LCTs) (e.g. air and ground source heat pumps, solar hot water, underfloor heating, programmable thermostats, and mechanical ventilation with heat recovery) and mobility (e.g. electric vehicles) technologies. However, their influence is often overlooked, leading to a false dichotomy between 'buildings' and 'occupants' that underestimates important points of potential policy influence when buildings are understood as socio-technical systems involving chains of actors in networks (Grandclément et al. 2015). Metrics and associated rating systems are ways of drawing the attention of relevant professionals (e.g., infrastructure engineers and architects) to climate and sustainability issues (Sheily et al., 2016). Some professional actors obstruct improvements in energy efficiency or shifts to low carbon technologies for self-serving reasons or to satisfy other non-climate change related goals. A study in five European countries found that car dealers acted deceptively and were dismissive of electric vehicles, orienting potential customers away from shifting to EVs and towards conventional petrol and diesel vehicles (De Rubens et al. 2018). It has also been found that, in certain contexts such as residential care homes, building managers give low priority to energy savings in comparison to the provision of a warm and low-risk environment for older adults, thereby hindering advancements in shifts to low carbon technologies (Neven et al. 2015).

Business firms, financial markets, and professionals and their organizations play roles in demand-side climate change mitigation. In 2015, working with the World Economic Forum, the CEOs of 43 companies operating in over 150 countries and territories representing 20 economic sectors signed an open letter to world leaders urging for concrete climate action (Allen and Craig 2016). Hundreds of initiatives, standards, and codes of conduct are inducing business to invest into reduced emission products (Vandenbergh and Gilligan 2017).

Some corporates also play an obstructionist role by financing institutes and lobby firms that i) cover up corporate deception, ii) cloak activities in green sheen, even if activities are inconsistent with climate mitigation efforts; and iii) block or water down effective climate legislation (Oreskes and Conway 2010).

5.4.2 Structure

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, organizations and infrastructures) to trigger social consistent with mitigation targets. If these leverage points are activated separately there is a high probability that path dependencies and behavioral 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, organizations and rules, together with collective change of behaviors and adapted governance, will enable a real change in demand-side mitigation. Past lessons are helpful to fine-tune the required combination.

5.4.2.1 Infrastructures and technologies

Infrastructures, defined in relation to organized 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 a study (Oldenziel et al. 2016). Similar results can be derived from an analysis of district heating systems (Hawkey 2012) or at urban level (Bulkeley et al. 2014). In the power sector, huge investments in electricity generation are foreseen, due to both the strong growth in emerging countries and a shift in usage towards “decarbonable” sources. Therefore, there is a need for the transformation of networks because of urban concentration and more dispersed electricity generation resulting from the rise of renewables. It implies that a compromise has to be found between two transition options: the design of a new electricity system to maintain its qualities of supply and sustain its current levels of reliability; a change in consumption habits and the adaption of lifestyles compliant with more power supply interruption (Maïzi and Mazauric 2019; Maïzi et al. 2017). This illustrates the multiple-level relationships between infrastructures, technology choices, economic development and individual choices.

Infrastructure provision deserves more emphasis than previously thought because it has the potential to influence the values, preferences and identities of future people. Weinberger and Goetzke (2010) provide evidence that for the case of urban transport infrastructure, preferences for car ownership are determined by the built environment individuals are used to. When people move from a city with good public transport to a car-dependent city, they are more likely to own fewer vehicles due to learned preferences for lower levels of car ownership (Weinberger and Goetzke 2010). This effect may be socially mediated (Grinblatt et al. 2008). Infrastructure is thus not only required to make low-carbon travel possible, but can also be a pre-condition for the formation of low-carbon mobility preferences. (Bamberg et al. 2003) provide another case of social learning facilitated by infrastructure: when individuals moving to a new city with extensive public transport were given targeted material about public transport options, the modal share of public transport increased significantly. Similarly, (Larcom et al. 2017) show how an exogenous change to route choice in public transport makes commuters change their habitual routes. More investment in low-carbon transport infrastructure is warranted than assumed in environmental economics if it has to induce low-carbon preferences (Mattauch and Hepburn 2016; Mattauch et al. 2018; Creutzig et al. 2016b).

Transport infrastructure also serves as a frame in which decisions happen. While not changing preferences, in the economic sense of the term, it can act as a “nudge”, making people take different decisions by altering the decision-making procedure. In urban transport, some studies indicate that changes in infrastructure provision for active travel may contribute to uptake of more walking and cycling (Frank et al. 2019). These effects contribute to higher uptake of low-carbon travel options, albeit the magnitude of effects depends on design choices and context (Goodman et al. 2013, 2014; Song et al. 2017; Javaid et al.).

Low-carbon technology and infrastucture is crucial for demand-side transitions, not only for ‘improve’ options (like fuel-efficient appliances, electric vehicles, building insulation) but also for many ‘shift’ options (from cars to public transport and bicycles, from gas boilers to heat pumps or district heat, from meat products to plant based protein sources) and ‘avoid/reduce’ options (like compact cities, tele-working, passive house). Since technologies provide functionalities and end-user services, they are often deeply entwined with social practices (Judson et al. 2015; Ryghaug and Toftaker 2014).

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) (see 5.4.4.1 for PV adoption). 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): a) cognitive activities involve the learning of new skills and competencies, b) interpretive and sense-making activities imbue new technologies with meanings, c) practical activities involve adjustments in everyday routines and material contexts. On the other hand, users do not just adopt new technologies, but can also actively contribute to development and innovation processes by: a) providing feedback to engineers about how technologies function in real-world user contexts (Heiskanen and Lovio 2010; Schot et al. 2016; Sopjani et al. 2019), b) tinkering themselves with the technology (Hyysalo et al. 2013; Nielsen et al. 2016), c) developing new organizational templates and business models (Truffer 2003; Ornetzeder and Rohracher 2013; De Vries et al. 2016).

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

5.4.2.2 Organizations and rules

Business models (BMs) can shift towards sustainable products by a) targeting different consumer segments to consume sustainably (Tunn et al. 2019; Bocken and Short 2016); b) redesigning processes to meet consumer expectations of sustainable consumption (Porter and Kramer 2011); c) changing coupled production-consumption processes towards new service provisioning models that waste less, focusing on satisfying needs rather than producing wants (e.g., long-lasting products, thus relating to the circular economy (Mont and Plepys 2008; Boons and Lüdeke-Freund 2013; Bocken 2017; Pieroni et al. 2019)).

BMs are sustainable only if (1) consumption levels, consumption patterns and market size are challenged (Lorek and Spangenberg 2014); (2) sustainable consumption is allowed to contradict traditional growth objectives; (3) rebound effects are mitigated, e.g. by resource pricing (Zink and Geyer 2017); (4) cultural changes are integrated into the BMs. Potential drawbacks can be illustrated by exploring the exponential growth and adoption of sharing (also see 5.3.3.2) (Perboli et al. 2018). This type of BM is not necessarily positive in environmental, social and economic terms (e.g. (Dreyer et al. 2017; Frenken and Schor 2017; Martin and Shaheen 2011)). In this specific case, the business infrastructure has to be modified as value creation will increasingly shift from producing cars to managing car fleets (Fulton et al. 2017; Fulton 2018) with possibly wide ranging implications for existing car manufacturers and associated jobs, but also with a vast space of new opportunities. Autonomous vehicle also require regulation to avoid further run-away effects in passenger transport, and instead capture energy reduction and wellbeing benefits (Brown et al. 2018; Creutzig et al. 2019).

Demand-side strategies are dominated by supply-side approaches (Sorrell 2015; Cox et al. 2016; Royston et al. 2018). However, rebound effects, the ‘inelastic’ character of energy demand (Belke et al. 2011), or issues of acceptability (Carattini et al. 2017a) and behavior (Cayla and Maïzi 2015) all compromise the potential of supply-side approaches.

To overcome these drawbacks, (Shove and Walker 2014) advocate specifically questioning the amount of energy ‘needed’ in society and the role of policy in constituting these ‘needs’. Beside specific ‘energy’ policies, ‘non-energy’ policies (or ‘invisible energy’ policies, because of the invisibility of energy demand within policy and the invisible effects of policies on energy demand) shape and influence long-term patterns of energy demand that are very difficult to reverse (Butler et al. 2018); these include path dependencies created because of infrastructures (Weinberger and Goetzke 2010) and conventions of social practice (Jack 2017) or policy impacts (Gormally et al. 2019) (see also 5.4.2.1). Hence, structural approaches that shape energy demand may warrant more focus in climate change mitigation (Royston et al. 2018).

Modifying awareness towards common good for creating climate change perception help the dynamics of this radical shift (e.g. Halady and Rao 2010; Dombrowski et al. 2016; Odjugo and Ovuyovwiroye 2013)(e.g. Halady and Rao 2010; Dombrowski et al. 2016; Odjugo and Ovuyovwiroye 2013). This requires a remodeling of educational and pedagogy, where the barriers to be tackled include not only a lack of funding, but the conservative environment of the educational system itself (Ferrer-Balas et al. 2009) (Fisher and McAdams 2015) (Velazquez et al. 2006) (Leal Filho et al. 2018) where individual focus gets priority over common good. In many cases, environmental issues are invisible most of the time in educational institution (Mendoza and Roa 2014). A commitment to education for solidarity and care, as highlighted in the case of food (Anderson et al. 2019a), could also help environmental goals (see also 5.2.3). There is few investment to embed climate change education in a higher education context, such as universities. Serious gaming, such as climate modelling games, demonstrate the possibility of learning on climate change by active interaction, even among audiences that are sceptical on climate change issues (Rooney-Varga et al. 2018)

A culture of climate awareness through new educational forms based on a convergence between education and communication (educommunication) (Rodrigo-Cano et al. 2019) could be used as a base for action and social and environmental intervention unlike communication and disinformation campaigns that use the environment to convey a commercial message (Delmas and Burbano 2011; Megias-Delagado et al. 2018). Environmental educommunication and eco-citizenship (Sauve and Asselin 2017) are based on participatory processes such as pedagogical campaigns that direct environmental policy towards education. The so-called “Confint” program (Benayas del Álamo et al. 2017) has been replicated on many different educational levels and has led students to organize climate-awareness gatherings thanks to the following features: (a) Pedagogical: it explores concepts and values on eco-citizenship, the environment, democracy and participation; (b) Environmental: it seeks commitment and responsibility from young people in the face of the environmental crisis facing our planet; (c) Interactive: young people of different ages and from different regions, countries and continents learn and act together with a common purpose, i.e. to take care of the planet. The Thunberg's school strike outside the Swedish parliament fits into this environmental educational process and has raised young people’s awareness of climate change. It was taken up by students worldwide and spurred the global Fridays for Future youth movement (Hope 2019).

5.4.2.3 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).

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

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

5.4.3 Meaning, norms, values, lifestyles

5.4.3.1 Meaning

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

SR15 recognised that narratives and storytelling can enable the imagining of novel visions of place-based 1.5°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. Amitav Ghosh 2016), often presenting apocalyptic stories and imagery in an effort to capture attention and evoke emotional and behavioural response (O'Neill and Smith 2014). The idea of the Anthropocene has gained traction as a way of imagining a new era of human-environment relations characterised by unprecedent human influence over natural ecosystems, and to mobilise a sense of grief at the potential for mass extinction of species, including humanity (James Lovelock 2007; Head 2016; Heise 2017). In turn, epistemic evolution, the increasing dependency of global society in further developments in knowledge and technology to continue surviving in the anthropocene, mirrors a narrative of opportunity (Renn 2018).

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

5.4.3.2 Discourse and narratives

Meanings play a number of roles, both enabling and constraining action on mitigation (Buschmann and Oels 2019). At the societal level, imaginaries about the cities or homes of the future play important roles in enabling innovation by attracting attention, legitimating certain technology choices, rejecting or undermining others and attracting investment (e.g.,Tozer and Klenk 2019). 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 (*medium confidence*). 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).

5.4.3.3 Meanings of technology

At the design stage, expectations of potential users of energy technologies and services (e.g. cookstoves, meters, thermostats) are scripted into the appearance and functionalities of those devices. Experts and designers hold common assumptions that public users are characterised by deficits of knowledge, competence and interest in energy systems (Burningham et al. 2015; Skjølsvold and Lindkvist 2015; Owens and Driffill 2008). These assumptions shape pathways of technology development and deployment (Marvin et al. 1999) leading to smart technologies with passive roles for users rather than smart users playing more active roles in systems of provision, distribution, storage and consumption (Goulden et al. 2014).

Contrasting meanings signal more active roles, including 'prosumers' who act as producers as well as consumers in decentralised energy systems (Espe et al. 2018), 'energy citizens' who are motivated by altruistic and environmental concerns, not only self-interest (Devine-Wright 2007; Ryghaug et al. 2018) and collectives such as 'clean energy communities'(Gui and MacGill 2018) engaged in peer-to-peer trading of energy services (Fell et al. 2019). Policy has an important role to play in communicating which of these expectations are preferred pathways of low carbon transition.

Meanings shape the willingness of individuals to use existing technologies or adopt new ones. Individuals develop attachments to material possessions (Belk 1988) (*high confidence*), which symbolise consumer-related identities (Dittmar 2008) (*high confidence*). 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. 2013b). Smart meters raise concerns about reduced autonomy and independence (Wilson et al. 2017a). Failure of policy to recognise these emotional and symbolic processes can lead to overestimates of technology potentials, including emissions reduction.

When energy technologies are resisted by the public, meanings about objectors influence the responses of policy makers and energy companies (*high confidence)*. '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; Burningham et al. 2015; Wolsink 2007). When developers hold these views, it leads to strategies of community engagement that prioritise the provision of factual information and financial incentives as well as the avoidance of 'angry' crowds (Barnett et al. 2012; Walker et al. 2010). Engagement that overlooks technology meanings can produce unintended consequences, prolonging social conflict and reducing trust (Devine-Wright 2011; Wolsink 2007). Adopting alternative meanings of communities, e.g. viewing them as repositories of expertise and local knowledge, and enabling genuine participation and benefit sharing can reduce conflict and increase acceptance (Bell et al. 2013; Walker and Baxter 2017).

5.4.3.4 Meanings of place and landscape

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

5.4.3.5 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 refers to behaviour commonly shown by others, and affect behaviour because it provides information about which behaviour is most sensible in a given situation. Descriptive norms (or peer effects) are related to different mitigation behaviours, including household energy savings (Nolan et al. 2008), car use (Gardner and Abraham 2008), energy use (Farrow et al., 2019), the adoption of electric vehicles and participation in smart energy systems (Noppers et al. 2019), and recycling (Geiger et al. 2019). Similarly, descriptive norm information or socially comparative feedback (in which case one's own performance is compared to the performance of others) can encourage mitigation actions, although the overall effect size is not strong (Abrahamse and Steg 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 inconsistent with their preferences, when norm-based interventions are supported by other interventions and when the context support norm-congruent actions (Miller and Prentice 2016). Weak descriptive norms, in which case people think others do not act on climate change, may inhibit mitigation actions (Schultz et al. 2007). Yet, trending norms that communicate that the number of people engaging in a behaviour is increasing, even if this concerns only a minority of people, can encourage the targeted behaviour, although the effect size is. relatively small (Mortensen et al. 2019).

Human behaviour and choices are a function of –personal and social– norms and the content of norms depends on the context (Sunstein 1996; Thaler and Sunstein 2009; Niamir 2019). Climate change challenges pose major collective action problems. A group benefits from a certain action, but no individual has sufficient incentive to act alone (Niamir 2019; Nyborg et al. 2016). Here, formal institutions, e.g. laws and regulations, are not always able to impose collectively desirable outcomes. Instead, informal institutions, such as social norms, can play a crucial role. If conditions are right, policy can support social norm changes, helping address global problems (Nyborg et al. 2016; Niamir 2019). Sunstein (Sunstein 1996) appraise people's choices and preferences in terms of *intrinsic value*, *reputational effects*, and *effects on self-conception*. Law and regulations potentially play an important role, by which the function of law in expressing social values with the goal of shifting social norms. There can be a serious obstacle to freedom in the fact that individual choices are a function of social norms, social meanings, and social roles, which individuals may deplore, and over which individuals have little or no control (Sunstein 1996). Here collective action and movements may be necessary to enable people to change norms that they do not like (Bamberg et al. 2015; Niamir et al. 2020; Sunstein and Reisch 2014). Some norms are obstacles to human well-being and autonomy. It is appropriate for law to alter norms if they diminish well-being and autonomy (Thaler and Sunstein 2009; Sunstein 1996).

Being part of a group or organization 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, they may become 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 already adopted the promoted behavior or programmes themselves as this increases their credibility (Kraft-Todd et al. 2018).

5.4.3.6 Values, energy system change and resource efficiency

Pacala and Socolow (2004) formulated the decarbonisation wedge idea that commercially available technologies could be adopted on a sector by sector basis to meet different proportions or 'wedges' of a climate target. Dietz and colleagues (2014) have proposed extending this analysis to incorporate the human components of energy demand reduction. They analyse the scope for changed practices and behaviours in particular areas of demand reduction (e.g. transport choices, installing home weatherization, purchasing energy saving devices etc.) and use this to estimate the theoretical emissions savings across the USA given reasonable measures to promote their uptake. They also point out that behavioural plasticity varies by measure, in that some things (carpooling) will be harder to get people to do compared to other easier actions (installing efficient appliances). Societies rarely arrive at the theoretically achievable maximum of energy demand reduction projected in modelled scenarios and technical analyses, as the behavioural plasticity of measures depending upon a range of factors including people's individual circumstances and values, through to more social, cultural and structural factors (Wilson and Dowlatabadi 2007).

Values are important for behaviour change and energy demand to the extent that any particular intervention will need to be not only effective in reducing emissions, but also congruent with (or at least not directly contradict) the values that people want a future low carbon energy system to embody. While energy technology proposals always have technical and economic assessments before they go ahead, they would benefit also from undergoing a 'social acceptance assessment' to identify points of objection or contestation regarding people's values. Research by the UK Energy Research Centre (Pidgeon et al. 2014; Demski et al. 2015) on public acceptability of energy system change has identified a number of such values, including such things as autonomy, energy security and safety, equity and environmental protection alongside a desire for significant reductions in the use of finite resources and the minimisation of waste. On can think of these as conditions on acceptance, which help to illuminate when any particular intervention or behaviour change will be acceptable to people.

Cherry et al. (2018) apply this analysis to everyday consumption, to understand the carbon savings that could be achieved in the UK through a range of strategies to reduce the use of energy embedded in common products (clothes, domestic appliances, furniture etc.) and to cross-reference this against stated acceptability data from in-depth citizen workshops. Strategies analysed were (1) manufacturing more resource efficient products, (2) strategies to extend product lifetimes, including the adoption of product service systems and (3) community schemes for sharing products. Although there is a degree of overlap in categories, of these three the first can be classified as an example of 'reduce' while the second and third ones are instances of 'avoid'. Resource efficient products yield the greatest carbon savings while also being significantly aligned with people's values. A number of conditions on acceptance were identified for each strategy including affordability, trust in suppliers and manufacturers, quality and hygiene of shared products, and fair allocation of responsibilities for product service systems.

5.4.3.7 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-deWitt 2012]. This cognitive view is consistent with the idea of individuals pursuing a 'low-carbon lifestyle' to reduce their impact on climate change (discussed further below).

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).

5.4.3.7.1 How lifestyle is conceptualised and used varies between fields

In public health, for example, lifestyle is used to identify risk factors like overeating, physical inactivity, and smoking, which are associated with poor physical or mental health outcomes (Foster et al. 2018; Aliberti et al. 2019). Health researchers also identify situational factors that lead to unhealthy lifestyles such as deprivation in areas with limited access to services (ONS 2017).

In marketing, lifestyle is used to profile and segment consumers according to their likely purchasing decisions. The widely-used 'AIO' framework distinguishes activities (e.g., leisure or shopping habits), interests (e.g., related to family or work), and opinions (e.g., about the future or the self) (Hur et al. 2010; Jain 2019). Marketing researchers typically identify these constituents of lifestyle in a particular consumption domain such as food or tourism in order to help target relevant goods and services.

In the context of climate change, lifestyle is used both *descriptively* to identify clusters of low-carbon behaviours and quantify their emissions impact, and *normatively* to explore individuals' efforts to reduce their carbon footprint. As lifestyles are situational as well as behavioural and cognitive, these efforts can be strongly shaped by public policy and infrastructure.

In all these applications, lifestyle can sometimes be used interchangeably with behaviour. This is not appropriate as behaviours are discrete actions, whereas lifestyles comprise coherent sets of actions linked in a consistent way to cognitions and identity (Lawson and Todd 2002).

Lifestyles can be identified and measured using both qualitative and quantitative methods. Qualitative methods explore self-identity, situational influences, and the dynamics of how lifestyles are expressed. Common qualitative methods used to research lifestyles include interviews (Barr et al. 2011) and narratives (Hagbert and Bradley 2017).

Quantitative methods link lifestyles to outcomes and impacts, and identify segments and variation in a population. Common quantitative methods include cluster analysis, factor analysis (Kuan et al. 2019), hierarchical tree analysis (Baiocchi et al. 2015), and decision tree analysis (Le Gallic et al. 2018). These methods identify groups of individuals, who share similar sets of cognitions and behaviours in certain contexts.

Quantitative methods are commonly applied to survey datasets, which combine information on behaviours with self-reported cognitions. Examples of datasets include national social surveys, household expenditure surveys, and time use surveys. These allow lifestyle groups or types to be identified in a population, and linked to sociodemographic, geographic or other widely-available indicators. For example, a recent study in France used census, housing, travel and household budget surveys to identify lifestyles grouped along eight dimensions: cohabitation, relationship with technology, mobility practices, attitude to work, dwelling location, living standard, leisure practices and demographics (Millot et al. 2018).

Measuring lifestyles is useful for different reasons. First, lifestyles can be tested as predictors or explanations of an outcome of interest such as risk of dementia (Lourida et al. 2019), food preferences (Nie and Zepeda 2011), or propensity to buy an electric vehicle (Axsen et al. 2012). The outcome of interest varies widely across research fields.

Second, lifestyles can descriptively characterise common patterns of behaviour in specific domains or 'sites of practice' like shopping, food, domestic living, or energy and water consumption (Barr and Gilg 2006). This allows the relationship between lifestyles and situational factors to be explored in more depth.

Third, lifestyles can explain variation between households in a population. This captures an important dimension of heterogeneity which can then be applied in modelling and scenario studies of how lifestyles may change into the future (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, broadly distinguished by intention and 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.

Emphasising impacts, low-carbon lifestyles can also be identified by reductions in energy and material use or other consumption-based reductions in greenhouse gas emissions (Le Gallic et al. 2018).

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. 2019).

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 (Thøgersen 2017a; Hur et al. 2010). Some studies find that much of the variation in energy or resource consumption can be explained by domain-specific lifestyle factors (Sanquist et al. 2012). However it is hard to generalise insights across domains as relationships between low-carbon lifestyles and emissions tend to be heterogeneous as well as situational or context-dependent.

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

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

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

Differences underlying lifestyle choices influence efforts to meet targets for emissions reduction. A combined assessment of costs, lifestyles and technologies in France up to the year 2072 showed that an individualistic lifestyle with high take-up of digital technologies led to increased GDP but not carbon neutrality, in contrast to a society characterised by more collective lifestyles that resulted in less growth but greater emissions reductions (Millot et al. 2018). Voluntary lifestyle change typically focuses on relatively low impact behaviours (e.g. switching off lights at home, recycling) in a piecemeal manner instead of high impact behaviours (e.g. adopting a low meat diet or long-haul flights (Nash et al. 2019; Dubois et al. 2019).

As well as environmental values and worldviews, 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. 2019), and a demographic shift from rural to urban, from physical to virtual work, and from analogue to digital (Millot et al. 2018; Le Gallic et al. 2018).

Such studies in the controlled environment of a simulation model show significant emission reduction potentials from low-carbon lifestyle change. This is not just limited to the direct impact of lifestyle change on emissions, but also to the indirect impact of reducing the speed of required transformation upstream in energy and land-use systems (Grubler et al. 2018) (5.3.3.2).

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).

Estimating the effectiveness of low-carbon lifestyle as a purposeful strategy for rapid emission reductions is an important frontier for climate change research.

5.4.3.8 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). 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 (Bomberg and Hague 2018; Roy et al. 2012). Pope Francis' encyclical (2015) reframes climate action from being an economic and technological issue to one of moral stewardship of public goods. Understanding religion helps in understanding attitude towards climate change across communities and traditions (Jenkins et al. 2018). However, further research is required to capture the heterogeneous practices of diverse faith groups globally in relation to climate mitigation (Haluza-DeLay 2014).

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

5.4.4 Case studies to illustrate complex forces of change

5.4.4.1 CS1: 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 activist energy consumers who embraced PV's unique modularity and enabled a supportive policy environment. PV's evolution can be summarized as the result of distinct contributions by the US, Japan, Germany, Australia, and China—in that sequence over seven decades (Nemet 2019) (Figure 5.14).

Since its first commercial application in 1958, PV has satisfied 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 satisfy some demand—often not a policy-driven market but one driven by 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-power radios (NRC 1972; Perlin 1999). In India, activist entrepreneurs marketed solar-powered lanterns in rural areas with unreliable electricity. Off-grid housing, water pumps in Mali, and electronics provided important consumer niche markets (Perlin 2013).

The most important policy for PV was Germany's Erneuerbare-Energie Gesetz (EEG) passed in 2000, guaranteeing prices paid to prosumers of renewable electricity for 20 years (RESA 2001). The EEG quadrupled the size of the German solar market in one year and stimulated investment in designing PV-specific production equipment that was crucial for subsequent cost reductions accomplished by Chinese producers (Palz 2010; Wu and Mathews 2012).

The EEG adopted the policy innovation of guaranteed long term contracts that California regulators had designed to provide grid access to small energy producers in the 1980s (CPUC 1983; Hirsch 1999). It also adopted the Japanese innovations of a declining subsidy and the first national rooftop top solar program in 1995 (Kimura and Suzuki 2006). The 200,000 Japanese households who installed PV in the next ten years revealed latent consumer demand for solar (Shimamoto 2014). The subsidy was far less generous than the subsequent German program and surveys of adopters indicate that environmental consciousness was a stronger driver than economics (Kimura and Suzuki 2006). Japanese electronic conglomerates became the world's largest PV producers using experience incorporating PV 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 could address environmental protection, oil dependence, hegemony of electric utilities, concerns about nuclear power, and later climate change. PV thus attained meaning beyond its technical elegance; its main advocate in the German Parliament, Hermann Scheer emphasized the importance of its "emancipatory motivation" (Palz 2010). In 1998, when a policy window opened, broad societal support existed, cities had de-risked the technology, and policy implementation details had been worked out evidencing a timely co-occurrence of agency, structure and meaning elements for systemic change (Lauber and Jacobsson 2016).

Today's massive utility-scale PV projects are now a factor of 10,000 cheaper than the satellite cells. 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).

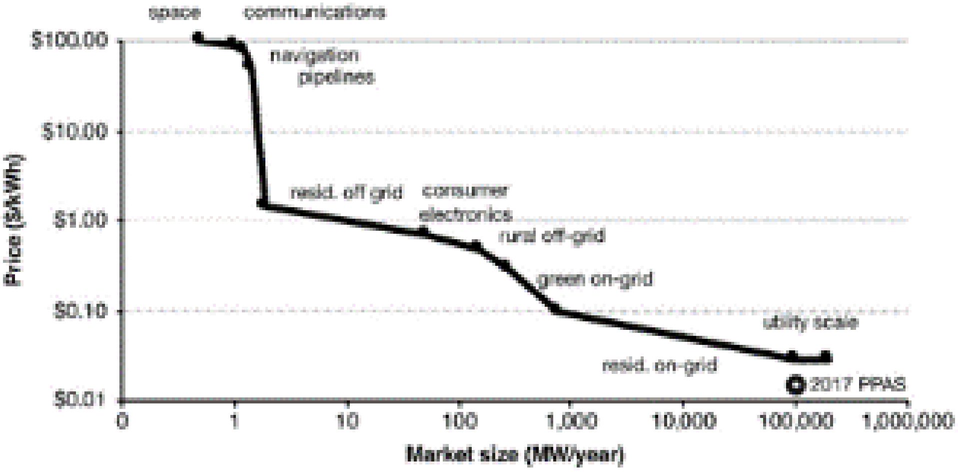


Figure 5.14 Technological learning curve of photovoltaic solar energy. Prices decline with production and associated innovation and economics of scale. As granular technology that can be matched to diverse settings, technological learning is faster than in most other technologies. Source: (Nemet 2019)

5.4.4.2 CS2: Energy services for cooking - Improve cookstoves and shift to new forms of energy

The majority of households in developing countries use solid biomass fuel for cooking and heating (Bonjour et al. 2013; IEA 2017c; Bhattacharya and Cropper 2010; Wester et al. 2019; Nepal et al. 2010). Biomass is mainly used in combination with inefficient stoves or traditional three-stone fires and kerosene, leading to inefficient and incomplete combustion of traditional biomass. This has been a major concern for deforestation (Kissinger et al. 2012) and for health, gender relations, and economic livelihood (Batchelor et al. 2019). For example, about 85% of the fine particulate matter (PM2.5) emission in Africa in 2018 came from the burning of biomass indoors (IEA 2019b).

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); reduce the burden on women (Hazra et al. 2014); deliver better health (Pant 2008; Bikram and Thakuri 2009); higher labour productivity (Kalyanaratne 2014) for the users and reduce emissions of greenhouse gases (Zhang et al. 2013; Somanathan and Bluffstone 2015). 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 2017c).

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). 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 5. 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. (Batchelor et al. 2018) 0.2 kWh could be enough to cook rice for a household of four in a rice cooker.

The increasing efficiency *improvements* in electric cooking technologies, together with the ongoing decrease in prices of renewable energy technologies, could enable households to shift to electrical cooking at mass scale. The use of pressure cookers and rice cookers is now widespread in South Asia and beginning to penetrate the African market as consumer attitudes are changing towards household appliances with higher energy efficiencies (Batchelor et al. 2019). *Shifts* towards electric and LPG stoves in Bhutan (Dendup and Arimura 2019), India (Pattanayak et al. 2019) and Ecuador (Gould et al. 2018; Martínez et al. 2017); and *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 helping to adopt ICS (Pattanayak et al. 2019).

Universal access to clean and modern cooking energy could cut premature death from HAP by two-third relative to baseline in 2030 while reducing forest degradation and deforestation and contribute to the reduction of up to 50% of CO_2 emissions from cooking relative to baseline by 2030 (IEA 2017c; Hof et al. 2019).

5.4.4.3 CS3: Shift in mobility service provision through public transport in Kolkata

In densely populated cities in the Global South, the majority of all trips are made through motorised public transport, walking and cycling (Tiwari et al. 2016,). Kolkata is a megacity in the state of West Bengal in India, where there are diverse modes of public transport systems that support day-to-day mobility in the city. Kolkata has as many as twelve different modes of public transportation, each with its own systemic agents, structure and stability. A key policy consideration in these circumstances is to strengthen coordination between regimes and transform these existing shared mobility infrastructures through fuel efficiency, comfort, digitalisation and other means as a way to discourage the demand shift from public to private mobility.

In India, mobility style is still predominantly public transport dependent. 46% of urban households have no private transport equipment, 42% owns bicycle and only 10% have privately owned four-wheelers. There is increasing shift towards comfortable, affordable public transport systems like railways, buses, metro, BRT, in public policy, equipment procurement policy, investment, legislation, regulatory norms, negotiation and better articulation among stakeholders in historically public transport rich cities like Kolkata and Mumbai through ‘fit and conform’ strategies but also by ‘stretch and transform strategy’ in new cities like Ahmedabad, Bangalore, Pune (Ghosh et al. 2016; Roy et al. 2018c; Ghosh and Schot 2019).

Over the past decade, each of these public transport regimes are changing along different pathways owing to new regulative rules, values, norms and expectations. Many of these changes are driven by new policy at national and local levels. Three are emphasised here: improvements to public buses and auto-rickshaws and the development of 'app-cabs'.

Supported by the policy under National Urban Renewal Mission in 2010, the West Bengal government rolled out 1200 new fuel-efficient, low floor buses with an aim to provide 'modern and efficient bus service to the urban middle-class citizens of Kolkata, who will be willing to pay a premium fare for comfortable and reliable bus service' (Ghosh and Schot 2019). Several changes in the state owned and run bus regime followed this effort to improve public bus infrastructure. These are improved efficiency in managing fleets, smart, real-time and integrated display and fare collection system. The primary focus on these strategies have been to change the image of old style buses crowded, hot, uncomfortable and encourage middle class, urban population of Kolkata to keep using public buses, catering to their demand for safety, reliability and comfort.

Alongside socio-cultural pressures built through mass-media like TV talks, news columns in daily news paper, awareness programmes by NGOs to reduce airpollution from buses withinin city limits, enviornmental campaign by civil societies involving school children, growing congenstion from car use and consequent slowing down of mobility triggered many changes in favour of Kolkata's public transport regimes.

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 mandated the use of single-mode Liquified petroleum gas (LPG) in this regime. 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 cultural meaning of auto-rickshaws from noisy, polluting, unregulated and informal paratransit mode into green, fast and efficient mode of shared mobility. This measure contributed positively along with measures in other sectors in bringing down the business as usual trend of green house gas emission per unit of GDP to half in one decade within Kolkata metropolitan area with potential for further reduction (Colenbrander et al. 2017).

However, in order to maintain these existing sustainable practises, as mentioned above in case of buses, the agency of political actors in implementing policy is not enough. Case study of auto-rickshaw transformation contributed positively in relative decoupling by bringing down emission intensity to GDP by half and emergence of app-cabs in Kolkata show that there are shifts in cultural meanings and the agency of commuters from "car is the only comfortable way of travelling" to "sharing a cab or auto is much faster and efficient". Such large-scale shifts of the more affluent urban population are crucial for transitioning towards sustainable mobility practice in megacities like Kolkata. At the same time, more thoughtful action at a policy level is required to sustain and coordinate the diversity of public transport modes. Some top down policy measures driven by road safety considerations towards banning cycling in major roads in Kolkata or dismantling of active electricity driven tram tracks to gave space to fast movement of fosil fuel run buses need further investigation in the light of environmental sustainability of these actions (Raven et al. 2017) and peoples' demand for cleaner city air. Therefore, a key challenge for urban mobility transition in the global south is to ensure that transitions are also pro-poor (Colenbrander S et al. 2016).

5.4.4.4 CS4: Dietary change and reduced meat consumption

UK meat consumption per capita declined by 12% between 2003 and 2015 to 929 gm week^{-1} (DEFRA 2017). Although more evidence is required, there is general agreement that this development resulted from interactions between agency, structure and meaning.

A substantial body of literature indicates that consumer motivations for shifting away from meat are dominated by concerns about animal welfare, personal health, food safety and provenance rather than climate change (Dibb and Fitzpatrick 2014). In recent years, environmental NGOs have launched public information campaigns to enhance consumer awareness of the link between meat production and climate change, leading to slow changes in meanings and understandings (Wellesley and Froggatt 2015). The UK also experienced a proliferation of civic-led behaviour change initiatives including ‘meat-free-Mondays’ and ‘Veganuary’ which encourage meat avoidance by providing practical guidance, creating social pressures, and changing beliefs. Although the longer-term effectiveness of interventions to reduce meat demand remain unknown (Godfray et al 2018; Garnett et al 2015) early research indicates that these civic-led initiatives have had relatively limited effects (Morris et al. 2014).

Companies have started to respond to the growing demand for ‘meat alternatives’ (e.g. veggie burgers): 16% of new UK food products launched in 2018 presented ‘non animal’ claims – a doubling since 2015 (MINTEL 2019). However, radical alternatives such as cultured meat, or algae and insect-based protein products, face substantial structural barriers (technological, organisational, institutional), which presently hinder their widespread diffusion (van der Weele et al. 2019). 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).

Deeper reductions in meat consumption are also hampered by lock-in mechanisms that stabilise the existing meat production-consumption system. The production of meat is supported with large agricultural subsidies that lower production cost and increase the meat intensity of diets at a population level (Simon 2013; Godfray et al. 2018). Meat consumption is also stabilised by a variety of positive meanings including vitality and sociality, which constrain dietary changes even among consumers that are motivated to eat less meat (Mylan 2018). Other constraints for enacting dietary change include lack of skills in preparing vegetarian meals and established habits of food purchase and provision (Pohjolainen et al. 2015).

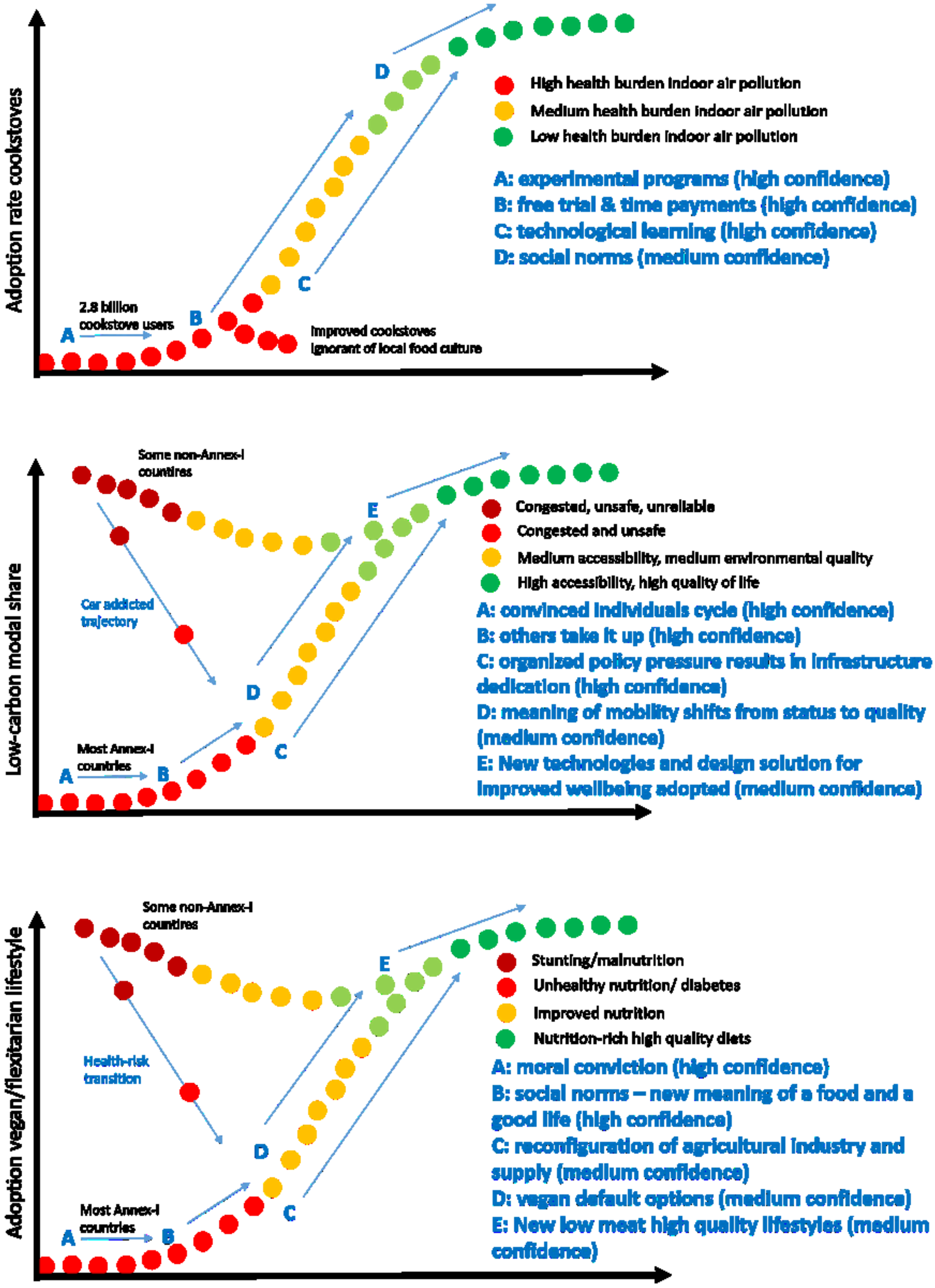


Figure 5.15 Examplary transition dynamics for the cases of improved cookstoves, modal shifts, and diet shift, based on the case studies in 5.4.4

5.4.5 An integrative view on transitioning

5.4.5.1 Interactions between agency, structure and meaning in the emergence of demand-side service-oriented solutions

The literature offers several integrative frameworks such as social practice theory (Shove and Walker 2014; Røpke 2009), the energy cultures framework (Stephenson et al. 2015; Jürisoo et al. 2019), and socio-technical transitions theory (McMeekin and Southerton 2012; Geels et al. 2017b), which all show that agency, structure and meaning interact throughout low-carbon demand-side transitions (*very high confidence*).

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 organizations, and policymakers reproduce or transform cultural and structural contexts through storytelling, political lobbying, innovation activities and infrastructure building (Lounsbury and Glynn 2001; Dolata 2009; Battilana et al. 2009).

The literature and the case studies described above demonstrate that the relative impulses of agency, structure and meaning vary between demand-side options (*high confidence*). For 'improve' transition pathways like LEDs and clean cookstoves, major impulses tend to come from changes in structural elements (like new technologies, regulations, and policies) and agency, especially from firms and policymakers but also from consumers who adopt and integrate the new technologies in their daily life practices (Sanderson and Simons 2014; Franceschini et al. 2016; Smith et al. 1993). Changes in meanings are less pertinent for some 'improve'-options, like LED lightbulb adoption, which tend to focus on technological substitution, while more relevant for improve-options, like clean cookstoves, that also connotate cultural meaning and traditions.

Changes in meanings and agency tend to be more important for 'shift' and 'avoid' transition pathways because these involve substantial behavioural change that requires strong motivations and new beliefs (*high confidence*). Shifts towards low-meat diets, for instance, are motivated by beliefs about the undesirability of meat, which often relate more to issues like health and nutrition than climate change or animal welfare (De Boer et al. 2014; Mylan 2018). Avoiding mobility through tele-working also requires changes in meanings and beliefs (about the importance of supervision, coaching, social contacts, or office politics). These may occur quickly where there a tangible benefits involved (e.g., for parents cherishing flexibility in working hours). In other cases, belief changes on telecommunicating have not yet widely occurred in many jobs (Hynes 2014, 2016). Many 'shift' and 'avoid' transition pathways also involve substantial changes in structural elements. Urban shifts towards public transport, for instance, involve new technologies (buses, trams), infrastructures (light rail, dedicated bus lanes), regulations (operational licenses, performance contracts), and institutions (new organizations, responsibilities, oversight) (Deng and Nelson 2011; Turnheim and Geels 2019).

Figure 5.15 displays transition curves for cookstoves, modal shift, and diet shift. Improved cookstoves (see 5.4.4.2) have the potential to improve the livelihood (less biomass collection, more gender equality, better health) for 2.8 billion cookstove users, reducing black carbon and biomass based GHG emissions. In early stages, experimental set-ups and trials explore the possibility of improved cookstoves in diverse communities. A key barrier is the costs of financing; free trial and time payments can improve adoption rates from about 5% to about 50% (Levine et al. 2018). Technological learning and social norms help to further increase adoption rates of ICS.

Modal shifts come in two flavors. In developing countries, flexible shared mobility, cycling and public transit are already low-carbon, but require an improvement in convenience, reliability, and quality. Kolkatta (5.4.4.3) demonstrated the possibility of such a pathway. In car-dependent countries, bicycle cities and radically shared mobility towns offer opportunities. Here activists first establish a new normal of what is healthy and environmentally appropriate. However, social norms saturate in communities that can afford cycling time-wise and concerning personal safety (about 10-20% of the population). In a second step, coordinated collective action can push policy makers to re-assigning traffic infrastructure to environmental modes, if public opinion sides with this objective. The cases of Dutch cities and Copenhagen demonstrate that design improvements of public infrastructures and local incentives for environmental modes can increase modal shares of cycling and public transit over decades.

Dietary shifts, too, first rely on groups of convinced individuals that change what is socially and morally appropriate. These groups also saturate (at about 10%) as costs of transitioning are too high for others embedded in agricultural-social systems of cheap meat productions and abundant supply. More encompassiong changes also in the production sytems (major economies still continue to subsidize indudstrial meat production) are required. In other cases, the rate of vegan lifestyles is already high, but can be associated with high rates of malnutrition and stunting. In these cases, nutrition must become more diverse and include previously rare nutrients, to enable a transition towards healthy plant-based diets, without falling into the new trap of unhealthy modern (meat and sugar-based) diets.

5.4.5.2 Lock-in mechanisms of existing systems and practices

Although there are many demand-side mitigation options (discussed in 5.3), low-carbon transitions do not happen easily because multiple lock-in mechanisms stabilize existing systems of service provision and social practices and thus hinder major change (*high confidence*) (Klitkou et al. 2015; Clausen et al. 2017; Ivanova et al. 2018; Seto et al. 2016). Existing activities and demand patterns are often stabilized by behavioural lock-in mechanisms identified by psychological and economic literature (*high confidence*): a) routines and habits tend to be repeated over time as ‘normal’ dietary, heating or travel patterns (Barnes et al. 2004; Maréchal 2010; Kurz et al. 2015; Hoolohan et al. 2018); b) preferences and attitudes can orient people positively towards existing practices over alternatives, e.g. private car travel over public transport (Sheller 2004); and c) cost-benefit calculations make people purchase technologies that are more practical or cheaper than alternatives (e.g. cars over public transport in rural areas; petrol cars over electric cars).

Structural elements of existing systems and practices are also stabilized by lock-in mechanisms as sociological, political science and innovation literature have demonstrated (*high confidence*). Institutional lock-in mechanisms can stabilize existing policies that support existing technologies and demand patterns: a) policy networks facilitate interactions between policymakers, specialists, and established business interests and tend to shape policymaking towards status quo protection or incremental reform rather than more radical policy change (Walker 2000; Knox-Hayes 2012; Geels 2014; Normann 2017; Roberts and Geels 2019); b) existing policy paradigms shape how policymakers frame problems and think about solutions (Kern et al. 2014; Rosenbloom 2018; Schmidt et al. 2019; Buschmann and Oels 2019), often leading to a focus on upstream technologies, market-based instruments, and hands-off policy styles (Whittle et al. 2019), c) incumbent firms use corporate political strategies and resistance tactics to delay or water down strong climate policies (Kolk and Pinkse 2007; 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) means that infrastructure-related technologies and practices are difficult to change. Existing roads, petrol stations and land-use patterns stabilize car-based mobility patterns (Seto et al. 2016), while gas infrastructures stabilize home-based boiler heating practices (Gross and Hanna 2019).

Existing meanings may also lock-in existing systems and practices (*high confidence*). Discourse and cultural studies literature have found that established meanings, values and discourses help legitimize and normalize 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 stabilize particular diets and hinder transitions to plant-based milk (Mylan et al. 2019). Most people and communities hold a plurality of cultural values; environmental protection and climate mitigation is only one value cluster amongst others such as efficiency, security and stability, social justice and fairness, autonomy and freedom, and improved quality of life (Plumecocq et al. 2018; Demski et al. 2015).

The various lock-in mechanisms for agency, structure and meaning stabilize existing systems and practices, and can thus create obstacles for the upscaling and diffusion of radical demand-side mitigation solutions, such as those described in Section 5.3 (*high confidence*).

5.4.5.3 Phases in transitions

Although there is variability between innovations, sectors, and countries, the transitions literature distinguishes four phases, characterized by generic core processes (*high confidence*) (Rotmans et al. 2001; Markard et al. 2012; Geels et al. 2017b). These four phases do not imply that transitions are linear, teleological processes, because set-backs or reversals may occur as a result of learning processes, conflicts, or changing coalitions (*very high confidence*) (Geels and Raven 2006; Messner 2015; Davidescu et al. 2018).

The emergence of radical innovations in the first phase is characterized by open-ended learning processes and the building of social networks to nurture and support the innovations (*high confidence*) (Kemp et al. 1998; Schot and Geels 2008). Radical innovations are characterized by many uncertainties about technical performance, consumer interest, and social acceptance. Research, development and demonstration projects, local community initiatives or grassroots projects, therefore, act as carriers of early niches to enable learning about these dimensions (Rosenbloom et al. 2018b; van Mierlo and Beers 2018; Hossain 2016; Borghei and Magnusson 2016; Sengers et al. 2019). Learning processes and network building are also important for the transfer of established technologies, like improved cookstoves, to developing countries, because new-to-the-country innovations require contextualization, adaptation, capability building, and the creation of local supply chains and innovation systems (Ockwell and Byrne 2016; Tigabu et al. 2017; Watson et al. 2015). Typical challenges of radical innovations in the first phase are fragmentation and high rates of project failure (den Hartog et al. 2018; Dana et al. 2019), limited funding (Auerswald and Branscomb 2003), limited market demand, and social acceptance problems due to being perceived as strange or unfamiliar (Lounsbury and Glynn 2001).

In the second phase, innovations find a foothold in small market niches, where early adopters provide a small but steady flow of financial resources (*high confidence*) (Zimmerman and Zeitz 2002; Dewald and Truffer 2011). Learning processes, knowledge sharing and codification activities help stabilize the innovation, leading to best practice guidelines, design standards, and formalized technical knowledge (*high confidence*) (Raven et al. 2008; Borghei and Magnusson 2018). Supporting social networks also expand and roles become more formalized, resulting in the creation of engineering communities, industry associations or 'intermediary actors' like energy or innovation agencies (Mignon and Kanda 2018; Kivimaa et al. 2019). User innovation may lead to the articulation of new routines, functionalities, and practices, as people integrate new technologies into their daily lives (Nielsen et al. 2016; Schot et al. 2016). Radical innovations remain confined to small niches in the second phase because they tend to be more expensive than existing technologies, complementary infrastructure may be missing (Markard and Hoffmann 2016), market demand is limited to small, dedicated groups (Schot et al. 2016).

In the third phase, radical innovations diffuse into wider communities and mainstream markets. Typical drivers are performance improvements, cost reductions, strong cultural appeal, widespread consumer interest, investments in infrastructure and complementary technologies, and institutional support (*high confidence*) (Wilson 2012; Markard and Hoffmann 2016; Raven et al. 2016; Malone et al. 2017; Kanger et al. 2019). The third phase often involves multiple struggles between diffusing innovations and associated actors and the existing system and incumbent actors, for instance, economic competition in markets, business struggles between incumbents and new entrants (Hockerts and Wüstenhagen 2010), discursive and framing struggles in civil society arenas, which affect cultural meanings and public opinion about low-carbon transitions (Kammermann and Dermont 2018; Hess 2019a; Rosenbloom 2018), political struggles over adjustments in policies and institutions, which shape markets and innovations (Meadowcroft 2011; Roberts and Geels 2019). These struggles may erode and weaken the technological, institutional and cultural lock-in mechanisms that stabilize existing systems (Turnheim and Geels 2012; Roberts 2017; Kuokkanen et al. 2018; Leipprand and Flachsland 2018).

In the fourth phase, the diffusing innovations replace or substantially reconfigure the existing system, which may lead to the downfall or reorientation of incumbent firms (*high confidence*) (Bergek et al. 2013; McMeekin et al. 2019). The new system becomes institutionalized and anchored in professional standards, technical capabilities, infrastructures, educational programs, regulations and institutional logics, user habits, and views of normality, which create new lock-ins (Galaskiewicz 1985; Barnes et al. 2018; Shove and Southerton 2000).

The demand-side solutions assessed in 5.3 vary substantially between regions and with regard to the four transition phases (*high confidence*). Some regions lag behind and some move ahead due to heterogeneity in individuals' sociodemographic (e.g., education and age), structural characteristics (e.g., type and size of dwellings), behavioural and social traits, and spatial characteristics (e.g., urban vs. rural) (Niamir 2019). With regard to the ASI-framework, some radical 'improve' options like electric vehicles, light-emitting diodes, or improved energy efficiency building codes are beginning to diffuse, moving from phase two to three in multiple countries (Berkeley et al. 2017; Franceschini et al. 2016). Many 'shift' and 'avoid/reduce' options like heat pumps, district heating, passive house designs, compact cities, less meat initiatives, flight and car use reduction have low momentum in most countries, and are often still in the first phase of isolated initiatives and projects (Bergman 2013; Morris et al. 2014; Bows-Larkin 2015; Bush et al. 2016; Kivimaa and Martiskainen 2018; Hoolohan et al. 2018). Structural transitions in Dutch cities and Copenhagen, however, demonstrate that transitions towards low-carbon lifestyles, developed around cycling, are possible (Colville-Andersen 2018). Low-carbon demand-side transitions are often still in early phases (*high confidence*).

5.4.5.4 Rates of change, acceleration

Rates of change are usually slow in the first and second transition phase, because experimentation, social and technological learning, the creation of standards, and the reduction of uncertainty take a long time, often decades (*high confidence*) (Bento et al. 2018; Bento 2013; Wilson 2012). Rates of change increase in the third phase, as radical innovations diffuse from initial niches into mainstream markets, propelled by the self-reinforcing mechanisms, discussed above. The rate of adoption (diffusion) of new practices, processes, artefacts, and behaviours is determined by a wide range of factors at the macro- and micro-scales, which have been identified by several decades of diffusion research in multiple disciplines (for comprehensive reviews see, e.g., Tornatzky and Klein, 1982; Feder & Umali, 1993;). (Ausubel 1991; Bayus 1994; Van den Bulte and Stremersch 2004; Comin and Hobijn 2003, 2010; Davis 1979; Meade and Islam 2006; Mahajan et al. 1990; Mansfield 1968; Martino et al. 1978; Peres et al. 2010; Rogers 1962; Grubler 1991; Rogers 2003).

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

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

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

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

Despite differences, the literature offers three robust conclusions on acceleration (*high confidence*):

First, size matters. Acceleration of transitions is more difficult for social, economic, or technological systems of larger size (in terms of number of users, financial investments, infrastructure, powerful industries) (Wilson 2009). Size also matters at the level of the systems component involved in a transition. Components with smaller unit-scale ("granular" and thus relatively cheap), such as light bulbs or household appliances, turn over much faster (often within a decade) than large-scale, capital-intensive lumpy technologies and infrastructures (such as transport systems) where rates of change involve typically several decades, even up to a century (Grubler 1991).

Second, complexity matters, which is often related to unit-scale (Ma et al. 2008). Acceleration is more difficult for options with higher degrees of complexity (e.g. compact cities, circular economy) representing higher technological and investment risks that can slow down change. Options with lower complexity are easier to accelerate because they involve less experimentation and debugging and require less adoption efforts and risk.

Third, agency, structure and meaning can accelerate transitions. The creation and mobilization of actor coalitions is widely seen as important for acceleration, especially if these involve actors with technical skills, financial resources and political capital (Kern and Rogge 2016; Hess 2019b; Roberts and Geels 2019). Changes in policies and institutions can also accelerate transitions, especially if these create stable and attractive financial incentives or introduce technology-forcing standards or regulations (Brand et al. 2013; Kester et al. 2018; Roberts et al. 2018). Changes in meanings and cultural norms can also accelerate transitions, especially when they affect consumer practices, enhance social acceptance, and create legitimacy for stronger policy support (Lounsbury and Glynn 2001; Rogers 2003; Buschmann and Oels 2019). Adoption of most advanced practices can support leapfrogging polluting technologies (Box 5.4).

Box 5.4. Is leapfrogging possible?

The concept of leapfrogging emerged in development economics (Soete 1985), energy policy (Goldemberg 1991) and environmental regulation (Perkins 2003), and refers to a development strategy that skips traditional and polluting development in favour of the most advanced concepts. For instance, in rural areas without telephone landlines or electricity access (cables), a direct shift to mobile telephony or distributed, locally-sourced energy systems is promoted, or economic development policies for pre-industrial economies forego the traditional initial emphasis of heavy industry industrialization, instead of focusing on services like finance or tourism. Often leapfrogging is enabled by learning and innovation externalities where improved knowledge and technologies become available for late adopters at low costs. The literature highlights many cases of successful leapfrogging (for a review see Watson and Sauter 2011); necessary conditions for leapfrog involve domestic environmental policies, government support in R&D, and knowledge transfer from advanced economies (Chen and Li-Hua 2011) (Gallagher 2006) (Cho et al. 1998; Lee and Lim 2001).

There are also some contentious topics in the debate on accelerated low-carbon transitions. First, while acceleration is desirable to mitigate climate change, there is a risk that accelerating change too much may short-cut crucial experimentation and social and technological learning in “formative phases” (Bento 2013; Bento et al. 2018) and potentially lead to a pre-mature lock-in of solutions that later turn out to have negative impacts (Cowan 1990, 1991).

Second, there is an ongoing debate about the most powerful leverage points and policies for speeding up change in social and technological systems. Farmer et al. 2019 suggested “sensitive intervention points” for low-carbon transitions, but do not quantify the impacts on transformations. Grubler et al. 2018 proposed an end-user and efficiency-focused strategy to achieve rapid emission reductions and quantified their scenario with a leading IAM. However, discussion of the policy implications of such a strategy have only just started (Wilson et al. 2019).

The last contentious issue is if policies can/should substitute for lack of economic/social appeal of change or for technological risks. Many large-scale supply-side climate mitigation options such as CCS or nuclear power involve high technological risks, critically depend on a stable carbon price, and are controversial in terms of social and environmental impacts. There is continuing debate if and how policies could counterbalance these impacts in order to accelerate transitions (Nordhaus 2019; Lovins 2015). Some demand-side options like large-scale public transport infrastructures such as “Hyperloop” (Decker et al. 2017) or concepts such as “Asian Super Grid” (maglev fast train coupled with superconducting electricity transmission networks) (AIGC 2017) may face similar challenges, which adds weight and robustness to those demand-side options that are more decentralized, granular in scale and provide potential tangible consumer benefits besides being low-carbon (like more efficient buildings and appliances, “soft” urban mobility options (walking and cycling), digitalization, among others, cf. Grubler et al. 2018).

A robust conclusion from this review is that there are no generic acceleration policies that are independent from the nature of what changes, by whom and how. Greater contextualization and granularity in policy approaches is therefore important to address the challenges of rapid transitions towards zero-carbon systems.

5.4.5.5 Rebound effects

Rebound effects. Rebound or takeback effects describe an economic response when through energy efficiency measures costs of service provision decline, shifting expenses to other categories which also imply energy use, hence “taking back” some of the energy savings originally anticipated. The concept was first formulated by Stanley Jevons in his 1866 book The Coal Question (after whom the effect is also referred to as Jevons Paradox (Jevons 1866). The extensive rebound literature differentiates between direct and indirect effects, and those operating at the micro-level (consumers, households, firms) and macro (economy) level. Direct rebound effects at the micro-level describe cases when due to energy efficiency measures (a better-insulated home, a more fuel-efficient car), the demand for the same service category (thermal comfort, mobility) increases due to lower service costs. Indirect rebound effects are those when the cost savings are spent on a different service or consumption category (e.g. an additional vacation trip, or on purchasing a work of art). Direct rebound effects at the macro-economic level describe a situation when lowered energy (service) costs in one sector (or country) lowers overall prices and hence incentivizes increases in energy demand in other sectors/countries. Lastly, indirect macro-economic rebound effects describe cases when lower demand and prices for energy lead to structural changes in the economy (e.g. more output from vehicle manufacturing of fuel-efficient cars leading to additional demands for light-weight materials such as energy-intensive aluminium.

Comprehensive reviews of the concept and of empirical estimates of the rebound effect in different applications, sectors and countries include (Greening and Greene 1998; Schipper and Grubb 2000; Berkhout 2002; Greening et al. 2000; Sorrell et al. 2009; Azevedo 2014; Chakravarty et al. 2013; Brown and Vergragt 2015) Stern (2007), Sorrel (2007), Dimitropoulos et al (2018). Sorrell (2007) reviews more than 500 studies and provides synthesized conclusions: First, the rebound effect is real, highly variable, but generally low (10-30% of anticipated energy savings). Secondly, in cases of suppressed demand (due to income constraints/poverty), rebound effects can be much larger, but in these cases, the energy efficiency measure is better viewed as a policy intervention to increase human welfare (improved access to services) than an energy reduction measure (Roy 2000). Lastly, confidence and robustness in rebound effect estimates as well as their magnitude decrease when moving from direct to indirect, and from micro- to macro-level analyses. Thus, while the effect is real, it can be accounted for by policy (e.g. through price adjustments) and should not distract from the importance of considering measures to improve the efficiency of service provision and need further analysis to understand if the economic concept and effect is overplayed (Gillingham et al. 2013).

5.4.5.6 Feasibility and barriers of demand-side transitions

While demand-side solutions have high mitigation potential (see Section 5.3), the widespread diffusion and transitioning of many options is challenging (*high confidence*). To assess these challenges, we use the multi-dimensional feasibility framework (IPCC 2018b), which we adjusted by removing two dimensions with limited relevance for demand (environmental/ecological and geophysical). We also split 'behaviour, consumer interest' off from the socio-cultural category, and add cultural dimensions to institutions.

Table 5.6 shows our assessment of feasibility barriers across four dimensions for avoid, shift and improve options. This assessment shows that improve options, which are mostly about technical component substitutions, face low to large feasibility barriers (which mostly relate to costs, consumer interest, and some industry reluctance, but can be strong if cultural practices are affected). 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 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.

Avoid-shift-improve options cannot be easily evaluated in terms of feasibility and speed of transition. At some point, some improve options might diffuse rapidly (LED lightbulbs), but other improve options, such as improved cooking stoves remain at low levels due to mismatch with cultural practices or cost barriers. Avoid and shift options may require longer time scales, especially if new infrastructures, such as tram lines, or massive retrofits of buildings, are involved. However, avoid and shift options not necessarily always have characteristics that would imply slow rates of change. Digital service provision models ranging from communication to entertainment, retail, or banking via integrated digital platforms (typically via smartphone apps) have seen very rapid diffusion, replacing conventional analogue and/or physical service provisioning systems (home entertainment systems, bank offices, or shops (TWI2050 2019). In essense, all options can be hard to implement, impeded by status quo bias and path dependence in socio-technical systems, but all options can shift into a rapid transition path, if technologies match users' needs, and if organized interest around climate-change relevant policies meets a receptive political environment, and matching narratives.

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 in the cases of 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, as discussed in 5.4.5.3. 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 (*very high confidence*).

Table 5.6 Assessment of feasibility barriers for the diffusion of demand-side mitigation options

	Examples	**Behavior, consumer interest**	**Technology, infrastructure**	**Economic**	**Institutional (political and cultural)**
Improve	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 behavioral routines -Costs, hassle factors or lack of interest may hold back purchase	**Small-medium** -Entail component substitutions that are technically feasible. -Some options require some infrastructure change (e.g. recharging)	**Medium-large** - Somewhat more expensive than existing technologies (although learning curves reduce costs) -Infrastructure change would add costs - Incumbent firms may delay reorientation to new technical capabilities.	**Small-large** -No major institutional change needed (as existing systems mostly remain intact) -Diffusion slow without policy support and financing models - Strong cultural barriers for end-use (ICS)
Shift	Shift from cars to public transport or cycling, less material-intensive construction, district heating, passive house, smaller devices, circular economy, shift towards from	**Medium-large** -Substantial change in behavioral routines -Not widespread consumer interest	**Small-Medium** -Substantial technical change -New provisioning systems and sometimes new infrastructures	**Medium-large** -Substantial investments required (in technologies, supply chains, business models, infrastructure)	**Medium-large** -Substantial institutional change (new agencies, responsibilities) -Large policy change (new goals,

	meat to other protein sources			- Resistance from incumbent industries	programs, instruments) - Large cultural change in some options (e.g. less meat) - Substantial political resistance and struggle
Avoid	Integrate 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 behavioral 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 cultural change in many options (e.g. smaller apartments, consume less)

5.4.6 Policy and Governance

Supply-side policies have dominated mitigation policies. While these have gone some way in the reduction or stabilization of GHG emissions across sectors in some countries, mostly developed economies, globally demand for energy has been increasing to meet growing demand for goods and services (UNEP 2019; IPCC 2018b). With millions of people across the world having limited or no access to basic services against a backdrop of high levels of development aspirations, expectations for improved living conditions and wellbeing are high. Hence, while supply-side mitigation policies and measures will remain important, a growing body of evidence demonstrates the importance of demand-side factors in shaping mitigation pathways where there is a two-way alignment between climate action and broader goals of wellbeing and sustainable development (Rojas-Rueda et al. 2012; OECD 2019b; Batchelor et al. 2018). Mitigation policies are likely to be easier to implement politically, economically and socially when they are able to communicate solutions that address short and medium-term challenges.

Policymakers can lower feasibility barriers (5.4.6) and stimulate demand-side transitions through many policies, which address the agency (5.4.1), structure (5.4.2) and meaning dimensions (5.4.3) discussed above (*high confidence*). Instruments that target the motivations and decisions of actors include adoption subsidies (e.g. for electric vehicle purchase or home insulation), and information provision (e.g. energy efficiency of consumer appliances, nutritional guidelines). Policymakers can also shape physical and institutional structures, e.g. through direct infrastructure investment (in railways, trams, district heating, compact cities), financial instruments that support private investment (e.g. cheap loans, capital grants), regulations and standards (e.g. for buildings, cars, appliances), and financial support for research, development and demonstration projects. Policymakers also shape meanings through the narratives and public campaigns that accompany policy initiatives (e.g. stories about high-speed rail investments, electric vehicle subsidies, zero-carbon home policies). They also engage in public debates, emphasizing some arguments and motivations over others, and shape future expectations through visions, targets and scenarios.

Despite the high mitigation potential of avoid-shift-improve options, there is widespread agreement that current energy efficiency and demand-side policies are fragmented, piecemeal and too weak to drive demand-side transitions commensurate with 1.5°C or 2°C climate goals (*very high confidence*) (Wilson et al. 2012; Moberg et al. 2019; Fawcett et al. 2019; Mundaca et al. 2019). Within the demand-side opportunity space, policies focus more on efficiency and 'improve' options than on 'shift' and 'avoid' options (Moberg et al. 2019; Dubois et al. 2019). Policy instruments focus more on information provision and adoption incentives than on regulation and investment (Rosenow et al. 2017; Moberg et al. 2019). Acceleration of demand-side transitions would thus require both broadening demand-side options and substantial strengthening of all of the above instruments to create targeted and comprehensive policy mixes (Kern et al. 2017; Rosenow et al. 2017) that lower the various feasibility barriers (*high confidence*). Demand-side transitions in developing and emerging economies would also require stronger administrative capacity as well as technical and financial support (UN-Habitat 2013; Creutzig et al. 2016b).

Demand-side policies tend to vary for different transition phases (*high confidence*) (Sandin et al. 2019; Roberts and Geels 2019). In the first phase, which is characterized by the emergence or introduction of radical innovations in small niches, policies focus on: a) supporting R&D and demonstration projects to enable learning and capability developments, b) nurturing the building of networks and multi-stakeholder interactions, and c) providing future orientation through visions or targets (Brown et al. 2003; López-García et al. 2019; Roesler and Hassler 2019). In the second phase, the policy emphasis shifts towards upscaling of experiments, standardization, cost reduction, and the creation of early market niches (Borghei and Magnusson 2018; Ruggiero et al. 2018). In the third and later phases, comprehensive policy mixes are used to stimulate mass adoption, infrastructure creation, social acceptance and business investment (Fichter and Clausen 2016; Geels et al. 2018; Strauch 2020). In the third phases, transitions can also be stimulated through policies that weaken or phase-out existing regimes such as removing subsidies (for cheap petrol or fuel oil), increasing taxes on carbon-intensive products and practices, or substantially tightening regulations and standards (Kivimaa and Kern 2016; David 2017; Rogge and Johnstone 2017).

The avoid-shift-improve (ASI) approach enables a systematic categorization of demand-side policy options in different sectors and services (Table 5.7). To this end, there is value in using this framework to assess specific policy instruments, how they have been implemented and draw specific lessons from these experiences.

Table 5.7 Mapping policies across the ASI framework

Policy measures	ASI outcome	Co-benefits	Possible trade-offs
Human settlement	- **Avoid** driving; shift to public transport	- lower air pollution	- possible higher energy bills; - household emissions

- Compact urban planning, urban containment, density control, modernise infrastructure - Invest in ICT infrastructure	- **Avoid** driving (telecommute)	- less fuel spending - less congestion	- potential inequalities resulting from policy implementation
Mobility - Investment in public transport - Investment in cycling facilities - Number plate, parking restrictions, parking - Fuel efficiency standards, fuel efficiency incentives; taxes on fuels; subsidies for EV and hybrid vehicles	- **Shift** to public transport - **Shift** to cycling **Shift** to online shopping - **Avoid** driving; **Shift** to public transport or cycling - move to electric vehicles; 2-3 wheelers; smaller cars (**Improve**); - **Improved** ICT enables car sharing and carpooling	- lower air pollution - less fuel spending - less congestion - savings - new jobs - R&D innovation	- May lead to higher uptake of taxi (Uber) services - Implications for local businesses
Food and nutrition - Charging according to how much food households throw away; improve education/awareness on food waste - Policies or incentives (mostly information & labelling) promoting vegetarian or low carbon diet - Promote locally grown food	- **Avoid** food waste - **Avoid** animal protein or **Shift** to non-animal protein - **Improve** local food production	- Savings - Avoid unsustainable practices - Improve health - Reduce health costs	- Benefits for the poorest may be limited unless the policy includes distributional impact analysis
Buildings - Tax deductions and subsidies for bioclimatic design and zero carbon buildings - Incentivise building standards and energy certification schemes - Incentives for modern cooking services	- **Avoid** heating and/or cooling - **Shift** to materials with high thermal standards;**Improve** insulation options; - **Shift** to improved biomass cookstoves; **Shift** to LPG or electric; Shift to new cooking appliances and Improve appliance efficiency	- Use local materials - New skills - New jobs - Localise benefits - better indoor air quality - Savings - GHG benefits	- Benefits for the poorest may be limited unless the policy includes distributional impact analysis

'*Avoid*' policies reduce energy use and emissions through lifestyle changes, either through personal choice as a result of values as the driver or through policies designed to change behaviour, lifestyle patterns and infrastructures Table 5.7. These would have the outcome of, for example, slowing travel growth through integrated city planning (Bakker et al. 2014) or building retrofits to avoid demand for transport, heating or cooling (de Feijter et al. 2019; Lucon et al. 2014). Spatial planning provides an important strategic framework in this regard for the growth of a city, influencing how people live and move for decades to come (Bakker et al. 2014). Dense, pedestrianized cities and towns and medium-density transit corridors are best placed to implement policies for car reductions than in 'sprawled' cities that are characterized by low-density, auto-dependent and separated land uses (Seto et al. 2014; Newman and Kenworthy 2015; Newman et al. 2017). The AR5 had suggested that over the medium to long-term, making cities more public transport-oriented and improving infrastructure for non-motorised transport could reduce GHG intensities by 20-50% below the 2010 baseline by 2050 (Sims et al. 2014). In getting the However, such a transition depends on the ability and political will of Cities and their leadership to provide incentives for changes in urban design that encourage walkable cities, non-motorized transport and shorter commuter distances (Mittal et al. 2016; Zhang et al. 2016).

Spatial planning strategies rely on a host of policy instruments and levers that have been developed, tested and implemented (Seto et al. 2014). They are divided roughly into the market based (economic instruments, information policies) and command and control (regulatory approaches and incentives), consisting of policies such as urban containment instruments, density regulations, building codes and parking regulation that are aimed at shaping behaviours and incentivizing innovations. One key aspect of successful spatial strategy towards reducing GHG emissions is the deployment of a combination of instruments and policies (Moberg et al. 2019), which countries in the Global North are well placed to take advantage of given their ability to mobilise significant governance and financial resources. Cities often employ a combination of policies such as Parking Restrictions, Building Quality, and Dense Development for meeting their operational needs and services while reducing urban GHG emissions (Panagopoulos et al. 2016; Deetjen et al. 2018). However, plans for advancing low-carbon development often face challenges, especially in fast-growing developing country cities. With many other pressing priorities for local governments with limited resources and capacities, their ability to manage and respond to escalating demands is often limited, where it is obvious that substantial economic opportunities exist in deploying low carbon measures at the city scale (UN-Habitat 2013; Creutzig et al. 2016b).

Policies that support the avoidance of higher emission lifestyles are also influenced by the introduction of new technologies, infrastructures and practices. Policies to avoid driving may be broadly linked to structural changes around spatial planning, but regulations and incentives such as investment in high-quality ICT infrastructure, regulations to restrict number plates as well as company policy around flexible working conditions influence individual preferences and decisions (Lachapelle et al. 2018; Shabanpour et al. 2018). However, given the limited size of the working population whose activities can be done at the home as well as the concern related to fragmentation of social network of the workplace, their contribution to the reduction of GHG emissions is likely to remain small (Seto et al. 2014).

Other policies and strategies to support efforts to 'avoid' unsustainable resource use are those that encourage bioclimatic or/and zero emissions building designs. These are aimed at integrating regional and localised analysis of the climate and the design of new buildings that use local materials and minimize heating and/or cooling. Much of this effort has been led by architects and builders, mostly in developing countries, and currently engaged in building evidence and information to influence policymakers and other decision-makers in housing developments and urban (& regional) planning (Toe and Kubota 2015; Desogus et al. 2016; Piderit et al. 2019). The majority of the new urban citizens of the approximately 70 million additional urban residents every year through to the middle part of this century will reside in small and medium-sized cities in low- and middle-income countries (UN DESA 2018; Roy et al. 2018a). The discussion surrounding future build could be integrated into the policy and political discussions of current and future land use as well as energy investments, given that the demand for cooling, for example, will exert greater pressure on electricity supply systems (Flores-Larsen et al. 2019).

'*Shift*' policies aim to enable and encourage low carbon lifestyles and behaviours Table 5.7. This would have various forms such as the use of low carbon materials for buildings and infrastructure in manufacturing and services and shift from meat-based protein to plant-based diets of other protein sources (Ritchie et al. 2018; Springmann et al. 2016). Nationally recommended diets (NRDs) by governmental or similar advisory bodies, compared to an average diet in 37 middle and high-income countries demonstrated a reduction in GHG emissions of 13.0-24.8% in high-income countries, a marginal decrease of 0.8-12.2% in middle-income countries and an increase of 12.4-17.0% in low-income countries; and overall net result showing a reduction in GHG emissions (Behrens et al. 2017). NRDs, as a policy tool to provide nutritional advice, places emphasis on reduction of meat and increase in vegetable intake in high-income countries, while the focus in low-income countries is about sufficient calorific and protein intake, hence policies that explicitly seek to integrate agricultural, environmental and nutritional objectives at national level are critical (Garnett 2011; Sunguya et al. 2014; Godfray et al. 2018). Policies for shifting away from meat diet and engage in food consumption that falls in line with low carbon futures are largely market-oriented across most countries where the nature of the actions involve less packaging, eat less processed food, more local, more organic and more vegetarian food (Moberg et al. 2019; Dubois et al. 2019). The implications of the dominance of market-based instruments mean that governments have a limited role to play beyond nudging citizens with information about health and wellbeing, and point-of-purchase labelling. The effectiveness of such policies on behaviour change overall and in particular that of marginalised communities may be limited (Shangguan et al. 2019; Pearson-Stuttard et al. 2017). Still, there is some room for policy to influence the actors upstream, i.e. industry and supermarkets which may give rise to longer-term, structural change. These can include excise or sales taxes on unhealthy items such as sugar-sweetened beverages and highly processed food (Mozaffarian et al. 2018).

The transport sector is one of the key areas where deliberate combination of market-based and command-and-control measures have been implemented successfully as part of the effort for a behavioural shift of large numbers of people out of their automobiles to take up public transport and cycling alternatives (Gehl et al. 2011). Financial incentives or payment schemes have been used to encourage individual actions that have led to climate-related outcomes in transport (Maki et al. 2016; Gota et al. 2019). In Singapore, Stockholm, London, and Gothenburg car ownership and car use reduced significantly over time as a result of introductions of congestion charges, indicating the direct link in GHG emissions reduction to the pricing and regulatory policies that facilitated behaviour change (Santos 2008; Eliasson 2014; Hallström et al. 2015; de Coninck et al. 2018; Chu 2015). What is not entirely clear is how stable these behavioural changes are. Under certain circumstances, financial incentives can promote sustainable consumption through the use of market-based tools, but may not necessarily lead to intrinsic pro-environmental motivation that are critical for climate action (Agrawal et al. 2015; Schwartz et al. 2015, 2019).

Public sector investment for the development of transport and energy services and/or improving ageing rail infrastructure plays a critical role for system-wide transitions (UNEP 2019). Attracting people to public transport would require sufficient spatial coverage of transport with adequate level of provision, good quality service at affordable fares (Sims et al. 2014; Moberg et al. 2019). Cities in developed countries enjoy an advantage in that network of high-quality public transport predates the advent of automobiles, whereas cities in the Global South are latecomers in large-scale network infrastructure (UN-Habitat 2013; Gota et al. 2019). New transport infrastructure such as mass transit systems and bus rapid transit (BRT) are to complement combined dense urban forms. Such efforts have led to less car use in Shanghai and Beijing (Gao and Newman 2018).

Investment in facilities and infrastructure has also been crucial in the greater uptake and *shift* to cycling (and walking) in many cities in both the Global North and Global South. Some of these were made possible by deliberate urban design principles including cycling lanes, introduction of public bicycle share schemes and the development of extensive cycling infrastructure (Sims et al. 2014; Schiller and Kenworthy 2018). While retrofitting cycling infrastructure into mature cities has seen challenges, there are ample opportunities to integrate cycling facilities in cities across developing countries as a way to provide cycling as a genuine alternative to motorised transport. Cities such as Bogota, Buenos Aires and Santiago have seen rapid growth, amounting to an increase by more than six-fold (Pucher and Buehler 2017). Impressive increases have also been recorded in Amsterdam and Copenhagen, which already had high cycling levels.

Electrification of the transport sector is also another area where 'shift' policies and strategies by public and private actors are showing the result in some countries. The effectiveness of policy instruments in 20 countries by measuring the influence of monetary incentives, traffic regulations favouring EVs as well as the charging infrastructure on the market share of EVs in these countries (Rietmann and Lieven 2019). The results showed that all policy measures positively influence the percentage of EVs, specifically monetary measures in interaction with the charging infrastructure. The issue of availability and access to public charging infrastructure was seen as a major decision factor for private car users if the EV market is to be stimulated significantly and rapidly (Gnann et al. 2018; Lieven and Rietmann 2018; Globisch et al. 2018). Norway leads in terms of the market share of EVs for new cars, approaching 60%, which is stimulated by the Norwegian car tax system where the purchase tax for all new cars is calculated by a combination of weight, CO_2 and NOx emissions (Haugneland and Kvisle 2015).

Here there are differences in developed and developing country uptake whereby in the former growth is concentrated in the private EVs and the latter in vehicles used for public transport. For example, for India's large and growing two-wheeler market, there exists a significant potential for increasing the share of electric two-wheelers in the short-term. This would also stimulate investment in charging infrastructure that can facilitate diffusion of larger EVs (Dhar et al. 2017), partly stimulated by the Indian Government's commitment to reach the target of 100% electric vehicle fleet by 2030. Similar opportunities exist for China where e-bikes have replaced car trips and are reported to act as intermediate links in the transition process from bicycle to bus and bus to car (Cherry et al. 2016).

'Shift' and 'improve' policies in cooking for households in developing countries are not new, but many initiatives have not been successful, largely because the diffusion of improved cookstoves (ICS) was not keeping up with population growth and urbanization and the promised health benefits did not live up to the high expectations (Batchelor et al. 2019). Initiatives implemented across many countries have included significant subsidies (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 helping to adopt ICS (Pattanayak et al. 2019), and grants for innovations that would support system-wide transitions (improved appliances, fuel efficiency, cleaner energy such as electricity). The increasing efficiency *improvements* in electric cooking technologies, together with the ongoing decrease in prices of renewable energy technologies, is opening policy opportunities to support households to *shift* to electrical cooking at mass scale (Puzzolo et al. 2019; IEA 2017c). Pressure cookers and rice cookers are now widely used in South Asia and increasingly in urban Africa against a rising cost of biomass fuel and expanding access to electricity services (Malakar 2018; Batchelor et al. 2019). *Shifts* towards electric and LPG-based cooking in various countries driven by a combination of government support for appliance purchases, shifting subsidy from kerosene or LPG to electricity, community-level consultation and awareness campaigns about the hazards associated with indoor air pollution from the use of fuelwood and kerosene, as well as education on the multiple benefits of electric cooking (Yangka

and Diesendorf 2016; Martínez-Gómez et al. 2016; Gould and Urpelainen 2018; Martínez et al. 2017; Dendup and Arimura 2019; Pattanayak et al. 2019). These actions towards cleaner energy for cooking often come with cooking-related reduction of GHG emissions, even though the extent of the reductions is highly dependent on context (Mondal et al. 2018; Rosenthal et al. 2018; Serrano-Medrano et al. 2018; Martínez et al. 2017; Hof et al. 2019).

While both *'avoid'* and *'shift'* policies can help to achieve significant efficiency improvements and emissions abatement, *'improve'* policies focus on the efficiency and enhancing technological performance of services. In transport systems, these include policies for improving vehicles, fuels, transport operations and management technologies; and in food, they include policies for improving diets in favour of healthy fresh foods over processed foods (Niles et al. 2018; Springmann et al. 2016). A number of studies have also shown that reducing consumption of processed foods could help minimize emissions associated with their processing, packaging and transportation (Green et al. 2015; Hanssen et al. 2017). Significant policy opportunities exist for incentivizing low carbon energy sources for heating through carbon taxes and grant schemes, as well as taxes on electricity to reduce consumption at the demand end (Tronchin et al. 2018; Moberg et al. 2019; Dubois et al. 2019). Policies for achieving large and long-term savings and emissions reductions from retrofitting existing buildings is a key policy for decarbonizing the building sector, and a variety of initiatives are deployed in different countries (Ortiz et al. 2019; Sebi et al. 2019). For example, the German programme combines the use of grants and loans through the KfW Development Bank, building and heating system labels, and technical renovation requirements as a way to continuously raise standards. In the US, focus is on a blend of rating and disclosure of energy use, financing, and technical assistance (Sebi et al. 2019).

Significant policy interest has arisen to address the energy access challenge in Africa using of low-carbon energy technologies, as a means to meet energy for poverty reduction and climate action simultaneously (Rolffs et al. 2015; Fuso Nerini et al. 2018; Mulugetta et al. 2019). This aspiration has been bolstered on the technical front by significant advances in light-emitting diode (LED) technology, complemented by the sharp reduction in the cost of renewable energy technologies, and largely driven by market stimulating policies and public R&D to mitigate risks (Alstone et al. 2015; Zubi et al. 2019) A number of decentralised energy service companies (DESCOs) have been established across Africa, having raised significant financing and currently provide energy services (minimum of multiple lighting and phone charging) to over 780,000 customers (Muchunku et al. 2018). The key innovation in this has been the pay-as-you-go (PAYG) end-user financing scheme that allows customers pay a small up-front fee for the equipment, followed by monthly payments, using mobile payment system (Yadav et al. 2019; Rolffs et al. 2015). PAYG systems have been made possible because they use existing money transfer platforms, supported by ICT infrastructure, enabling policy conditions and socio-cultural payment practices were in the countries where PAYG schemes have worked well, such as Kenya, Rwanda, Tanzania and Uganda (Ockwell et al. 2019; Yadav et al. 2019). Other successful SHS business models include Infrastructure Development Company Limited (IDCOL) in Bangladesh that reached 18 million people from 4.1 million systems installed as of 2017, supported by a combination of targeted grants and loans, simple payment schemes and robust maintenance services (Almeshqab and Ustun 2019; Nique and Smertnik 2015).

The transformation in energy, transport, and building sectors for stabilizing GHG concentrations to limit warming to 1.5oC calls for the deployment and interaction of supply-side and demand-side measures (Kivimaa and Virkamäki 2014; Rogge and Reichardt 2016; de Coninck et al. 2018; Edmondson et al. 2019). Policy coordination is critical to manage infrastructure interdependence across sectors, and to avoid trade-off effects (Hiteva and Watson 2019; Raven and Verbong 2007). For example, the amount of electricity required for cooking can overwhelm the grid which can lead to failure or end-users shifting back to traditional fuels (Ateba et al. 2018; Israel-Akinbo et al. 2018). Policy coordination mitigates against risks along the full chain of the electricity system. Equally, policies and strategies for the expansion of electric vehicles programme deal with issues raised at multiple sectors and levels, requiring greater dialogue between the power and transport sectors as well as inter-sectoral integration between local and regional administrations and their priorities with a view to avoid (Antonson and Carlson 2018). In these interactions lie opportunities and risks where electric vehicles can be affected by failure in the power sector in the form of frequent power cuts or electric vehicles (EVs) may make the grid more efficient and robust by allowing two-way energy and information flows (Coffman et al. 2017; Mahmud et al. 2018).

Box 5.5 Carbon pricing and fairness

Whether the public supports specific policy instruments for reducing greenhouse gas emissions is determined by cultural and political world views (Alberini et al. 2018; Cherry et al. 2017; Kotchen et al. 2017), with major implications for policy design**.** For example, policy proposals need to circumvent "solution aversion": that is, individuals can be more doubtful about the urgency of climate change mitigation if the proposed policy contradicts their political worldviews (Campbell and Kay 2014). While carbon pricing is the most efficient way to reduce emissions, a recent literature – focusing on populations in Western Europe and North America and carbon taxes – documents that this feature is not what makes citizens like or dislike carbon pricing schemes (Carattini et al. 2017b; Kallbekken et al. 2011; Klenert et al. 2018).

Citizens tend to ignore or doubt the idea that pricing carbon emissions reduces them (Kallbekken et al. 2011; Douenne and Fabre 2019; Maestre-Andrés et al. 2019). Further, citizens have fairness concerns about carbon pricing (Douenne and Fabre 2019; Maestre-Andrés et al. 2019), even if higher carbon prices can be made progressive by suitable use of revenues (Klenert and Mattauch 2016; Rausch et al. 2011; Williams et al. 2015). There are also non-economic properties of policy instruments that matter for public support: Calling a carbon price a "CO_2 levy" alleviates solution aversion (Carattini et al. 2017a; Kallbekken et al. 2011). It may be that the word “tax” evokes a feeling of distrust in government. Trust in politicians is correlated with higher carbon prices (Hammar and Jagers 2006; Rafaty 2018) and political campaigns for a carbon tax can lower public support for them (Anderson et al. 2019b).

To address these realities of public support for carbon pricing, some studies have examined whether specific uses of the revenue can increase public support for higher carbon prices (Beiser-McGrath and Bernauer 2019; Carattini et al. 2017a). First, doubt about the environmental effectiveness of carbon pricing may be alleviated if revenue from carbon pricing is earmarked for specific uses (Kallbekken et al. 2011; Carattini et al. 2017a) and higher carbon prices may then be supported (Beiser-McGrath and Bernauer 2019). This is especially the case for using the proceeds on “green investment” in infrastructure or energy efficiency programmes (Kotchen et al. 2017). Further, giving individuals the revenues back in a salient manner may increase public support and alleviate fairness proposals, given sufficient information (Carattini et al. 2017a; Klenert et al. 2018). Perceived fairness is one of the strongest predictors of policy support (Jagers et al. 2010; Whittle et al. 2019).

Demand-side policies and their implementation raise multiple questions of justice by delivering unanticipated (unintended) outcomes thereby reinforcing inequality of outcomes. For example, accelerated decarbonisation of the transport sector is not without its risks (Roy et al. 2018a). It may trigger increases of electricity prices and adversely affect poor populations, unless pro-poor redistributive policies are in place and in some cases policies that promote energy efficiency may increase the inequality of certain social groups such as the low income and the elderly (Klausbruckner et al. 2016). These are addressed better with innovative policy mixes and coordination (see Box 5.5), and in particular to the issues of affordability and implications to welfare trade-offs for different social groups.

5.5 Knowledge gaps

Knowledge gap 1: Climate action as if people matter

Knowledge on climate action that starts with the social practices and livelihood of people, and attempts to improve their wellbeing, is still in its infancy. Climate solutions remain supply-side oriented, and evaluated against GDP, without acknowledging the GPD loss due to climate impacts. GDP is a poor metric of human wellbeing, and climate policy evaluation requires better grounding in relation to decent living standards and other metrics of human wellbeing, as relevant in varying local contexts. Literature on how gender, informal economies, and solidarity and care frameworks translate into climate action, but also how climate action can improve the life of marginalized groups remains scarce.

Knowledge gap 2: Evaluation of the digital economy

The digital economy, as well as shared and circular economy, serves as templates for great narratives, hopes and fears. Yet, there is few systematic evaluation of what is already happening. Better and more timely data collection, and monitoring systems, for digital system energy use, to better gauge energy trends for rapidly evolving systems like data centres, AI, blockchain. Knowledge of these systems is poor due to lack of reliable data, and lack of timely data compared to how quickly ICT systems evolve. Better integration of mitigation models and materials cycle/LCA models for assessment of CE and SE implications on materials demand.

Knowledge gap 3: Scenario modelling of services

Scenarios start within parameter-rich models carrying a decade-long legacy of supply side technologies that are not always gauged in recent technological developments. Service provisioning systems are not explicitly modelled, and lifestyles rarely considered. A new class of flexible and modular models with focus on services and activities, based on big data collected and compiled is needed. There is scope for more sensitivity analysis on which behavioural/ organization changes has biggest impact on energy/emissions reductions, and on the scale for take-back effects, to better guide subsequent detailed studies on mechanisms and policy responses. Models mostly consider behavioural change free, and don’t account for how savings due to “avoid” measures may be re-spent.

Knowledge gap 4: Dynamic interaction between agency, structure and meaning

Better understanding is required in: (1) More detailed causal mechanisms in the mutual interactions between agency, structure and meaning and how these vary over time, i.e. what is their relative importance in different transition phases; (2) how narratives at different scales e.g. meanings associated with specific technologies, group identities, climate narratives influence each other and interact over time to enable and constrain mitigation outcomes; (3) how social media influences the development and impacts of narratives about low carbon transitions; (4) the effects of social movements (for climate justice, youth climate activism, fossil fuel divestment, and climate action more generally) on social norms and political change, especially in less developed countries; (5) how existing provisioning systems and social practices destabilise through the weakening of various lock-in mechanisms, and resulting deliberate strategies for accelerating demand-side transitions; (6) a dynamic understanding of feasibility, which addresses the dynamic mechanisms that lower barriers or drive mitigation options over the barriers.

Frequently Asked Questions (FAQs)

FAQ 5.1 What policy makers can do to change behaviour?

Demand-side behaviour reflects what various actors, e.g., consumers, perceive as costs and benefits, including considerations of moral commitments and social norms. Status quo bias and present bias often imply a continuation of existing behaviour even if it implies consequences against individuals' long-term interests. To influence human behaviour, policymakers have an assortment of instruments, including prohibitions, mandates, taxes, fees, subsidies, "nudges", defined to include such choice-preserving interventions as information, warnings, reminders, social norms, default rules, such as automatic enrolment in "green energy," such as wind or solar. The choice of instruments depends on the effects on wellbeing, and optimal policy mix depends on the context. For example, if carbon prices remain below optimal levels, automatic enrolment in green energy is likely to be a suitable complementary policy. Designing cities for walkability, cycling, and public transport constitutes a major policy choices, which enables flexibility in behavior.

Policy support for transitioning requires first supporting R&D, demonstration projects that enable learning, nurturing the building of networks, and providing future orientation through visions or targets. Second, policy may upscale experiments, and push for technological learning. Third, comprehensive policy mixes may stimulate mass adoption, infrastructure creation, and business investment. Removing subsidies for cheap petrol, increasing taxes on carbon-intensive products, or substantially tightening regulations and standards support shifts in social norms.

FAQ 5.2 How does society perceive transformative changes?

Human life is constantly changing, sometimes induced by generational rebellion, sometimes forced upon societies by outside calamities, and in other cases shaped by new technologies, such as digitalization and artificial intelligence. Change is normal and people are adaptive and creative in shaping their own destiny or carving out their own space for action. Historically human society has been successful in reorganizing themselves to make themselves better off, as for example measured in life expectancy, while in other circumstances, choices in livelihoods became more restricted for many, e.g. by new institutions and division of labor.

Inclusive and participatory processes have the potential to shape change to beneficial outcomes. But established meanings, values and discourses help legitimize and normalize the status quo, creating barriers for demand-side climate change mitigation. 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. Discourses that portray dairy milk as healthy and natural stabilize particular diets and hinder transitions to plant-based milk.

Climate change challenges pose major collective action problems that requires transformation of formal institutions, e.g. laws and regulations. Informal institutions, such as social norms, can play a crucial role in change; new narratives, along with organized political action, can support transformative and beneficial change.

FAQ 5.3 Is demand reduction compatible with economic growth?

Complex economic systems necessarily require large energy flows; correlation between energy consumption, GHG emissions and economic growth is strong and the linkages between the two are complex. Only a few countries with low economic growth rates have achieved absolute decoupling in both territorial and consumption-based GHG emissions from economic growth.

Many demand-side and service-oriented opportunities appear to be cost-effective and can deliver additional benefits such as improved energy security, reduced fuel poverty, in many cases fostering economic development. However, GDP is an incomplete indicator of human wellbeing. It excludes multiple constituents and drivers of human wellbeing and thus does not represent human need holistically which is linked through over lapping generations. There is need for alternative metric/indicator to measure progress in sustainable development. Human need satisfaction is closely linked to wellbeing. Constituents of wellbeing are multiple and multidimensional and not limited to material goods alone. Sustainable development seeks to meet the needs of people living today without compromising the needs of future generations, while balancing social, economic and environmental considerations. Achieving wellbeing for all, and reducing GHG emissions drastically is simultaneously achievable. The question of economic growth recedes into irrelevance if this twin goal is properly conceptualized.

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