WG III contribution to the Sixth Assessment Report

List of corrigenda to be implemented

The corrigenda listed below will be implemented in the Chapter during copy-editing.

CHAPTER 5

Document (Chapter, Annex, Supp. Material)	Page (Based on the final pdf FGD version)	Line	Detailed information on correction to make
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Chapter 5: Demand, services and social aspects of mitigation

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Executive summary

Assessment of the social science literature and regional case studies reveals how social norms, culture, and individual choices, interact with infrastructure and other structural changes over time. This provides new insight into climate change mitigation strategies, and how economic and social activity might be organised across sectors to support emission reductions. To enhance well-being, people demand services and not primary energy and physical resources per se. Focusing on demand for services and the different social and political roles people play broadens the participation in climate action.

Potential of demand-side actions and service provisioning systems

Demand-side mitigation and new ways of providing services can help *avoid*, *shift*, and *improve* final service demand. Rapid and deep changes in demand make it easier for every sector to reduce GHG emissions in the short and medium term (*high confidence*). {5.2, 5.3}

The indicative potential of demand-side strategies across all sectors to reduce emissions is 40-70% by 2050 (*high confidence*). Technical mitigation potentials compared to the IEA WEO, 2020 STEPS baseline amounts up to 5.7 $GtCO_2eq$ for building use and construction, 8 $GtCO_2eq$ for food demand, 6.5 $GtCO_2eq$ for land transport, and 5.2 $GtCO_2eq$ for industry. Mitigation strategies can be classified as *Avoid-Shift-Improve* (ASI) options, that reflect opportunities for socio-cultural, infrastructural, and technological change. The greatest *Avoid* potential comes from reducing long-haul aviation and providing short-distance low-carbon urban infrastructures. The greatest *Shift* potential would come from switching to plant-based diets. The greatest *Improve* potential comes from within the building sector, and in particular increased use of energy efficient end-use technologies and passive housing. {5.3.1, 5.3.2, Figure 5.7, Figure 5.8, Table 5.1, Table SM.2}

Socio-cultural and lifestyle changes can accelerate climate change mitigation (*medium confidence*). Among 60 identified actions that could change individual consumption, individual mobility choices have the largest potential to reduce carbon footprints. Prioritizing car-free mobility by walking and cycling and adoption of electric mobility could save 2 $tCO_2eq\ cap^{-1}\ yr^{-1}$. Other options with high mitigation potential include reducing air travel, cooling setpoint adjustments, reduced appliance use, shifts to public transit, and shifting consumption towards plant-based diets. {5.3.1, 5.3.1.2, Figure 5.8}

Leveraging improvements in end-use service delivery through behavioural and technological innovations, and innovations in market organisation, leads to large reductions in upstream resource use (*high confidence*). Analysis of indicative potentials range from a factor 10 to 20 fold improvement in the case of available energy (exergy) analysis, with the highest improvement potentials at the end-user and service-provisioning levels. Realisable service level efficiency improvements could reduce upstream energy demand by 45% in 2050. {5.3.2, Figure 5.10}

Alternative service provision systems, for example those enabled through digitalisation, sharing economy initiatives and circular economy initiatives, have to date made a limited contribution to climate change mitigation (*medium confidence*). While digitalisation through specific new products and applications holds potential for improvement in service-level efficiencies, without public policies and regulations, it also has the potential to increase consumption and energy use. Reducing the energy use of data centres, networks, and connected devices is possible in managing low-carbon digitalisation. Claims on the benefits of the circular economy for sustainability and climate change mitigation have limited evidence. {5.3.4, 5.3.4.1, 5.3.4.2, Figure 5.12, Figure 5.13}

Social aspects of demand-side mitigation actions

***Decent living standards (DLS) and well-being* for all are achievable through the implementation of high-efficiency low demand mitigation pathways (*medium confidence*).** Decent Living Standards (DLS) – a benchmark of material conditions for human well-being – overlaps with many Sustainable Development Goals (SDGs). Minimum requirements of energy use consistent with enabling well-being for all is between 20 and 50 GJ cap^{-1} yr^{-1} depending on the context. {5.2.2.1, 5.2.2.2, Box 5.3}

Providing better services with less energy and resource input has high technical potential and is consistent with providing well-being for all (*medium confidence*). Assessment of 19 demand-side mitigation options and 18 different constituents of well-being show that positive impacts on well-being outweigh negative ones by a factor of 11. {5.2, 5.2.3, Figure 5.6,}

Demand-side mitigation options bring multiple interacting benefits (*high confidence*). Energy services to meet human needs for nutrition, shelter, health, etc. are met in many different ways with different emissions implications that depend on local contexts, cultures, geography, available technologies, social preferences. In the near term, many less-developed countries and poor people everywhere require better access to safe and low-emissions energy sources to ensure decent living standards and increase energy savings from service improvements by about 20-25%. {5.2, 5.4.5, Figure 5.3, Figure 5.4, Figure 5.5, Figure 5.6, Box 5.2, Box 5.3}

Granular technologies and decentralized energy end-use, characterised by modularity, small unit sizes and small unit costs, diffuse faster into markets and are associated with faster technological learning benefits, greater efficiency, more opportunities to escape technological lock-in, and greater employment (*high confidence*). Examples include solar photovoltaic systems, batteries, and thermal heat pumps. {5.3, 5.5, 5.5.3}

Wealthy individuals contribute disproportionately to higher emissions and have a high potential for emissions reductions while maintaining decent living standards and well-being *(high confidence)*. Individuals with high socio-economic status are capable of reducing their GHG emissions by becoming role models of low-carbon lifestyles, investing in low-carbon businesses, and advocating for stringent climate policies. {5.4.1, 5.4.3, 5.4.4, Figure 5.14}

Demand-side solutions require both motivation and capacity for change (*high confidence*). Motivation by individuals or households worldwide to change energy consumption behaviour is generally low. Individual behavioural change is insufficient for climate change mitigation unless embedded in structural and cultural change. Different factors influence individual motivation and capacity for change in different demographics and geographies. These factors go beyond traditional socio-demographic and economic predictors and include psychological variables such as awareness, perceived risk, subjective and social norms, values, and perceived behavioural control. Behavioural nudges promote easy behaviour change, e.g., "*improve*" actions such as making investments in energy efficiency, but fail to motivate harder lifestyle changes. (*high confidence*) {5.4}

Meta-analyses demonstrate that behavioural interventions, including the way choices are presented to consumers[1], work synergistically with price signals, making the combination more effective (*medium confidence*). Behavioural interventions through nudges, and alternative ways of redesigning and motivating decisions, alone provide small to medium contributions to reduce energy

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FOOTNOTE [1] The way choices are presented to consumers is known as 'choice architecture' in the field of behavioural economics.

consumption and GHG emissions. Green defaults, such as automatic enrolment in "green energy" provision, are highly effective. Judicious labelling, framing, and communication of social norms can also increase the effect of mandates, subsidies, or taxes. {5.4, 5.4.1, Table 5.3a, Table 5.3b}

Coordinated change in several domains leads to the emergence of new low-carbon configurations with cascading mitigation effects *(high confidence).* Demand-side transitions involve interacting and sometimes antagonistic processes on the behavioural, socio-cultural, institutional, business, and technological dimensions. Individual or sectoral level change may be stymied by reinforcing social, infrastructural, and cultural lock-ins. Coordinating the way choices are presented to end users and planners, physical infrastructures, new technologies and related business models can rapidly realise system-level change. {5.4.2, 5.4.3, 5.4.4, 5.4.5, 5.5}

Cultural change, in combination with new or adapted infrastructure, is necessary to enable and realise many *Avoid* and *Shift* options (*medium confidence*). By drawing support from diverse actors, narratives of change can enable coalitions to form, providing the basis for social movements to campaign in favour of (or against) societal transformations. People act and contribute to climate change mitigation in their diverse capacities as consumers, citizens, professionals, role models, investors, and policymakers. {5.4, 5.5, 5.6}

Collective action as part of social or lifestyle movements underpins system change (*high confidence*). Collective action and social organising are crucial to shift the possibility space of public policy on climate change mitigation. For example, climate strikes have given voice to youth in more than 180 countries. In other instances, mitigation policies allow the active participation of all stakeholders, resulting in building social trust, new coalitions, legitimising change, and thus initiate a positive cycle in climate governance capacity and policies. {5.4.2, Figure 5.14}

Transition pathways and changes in social norms often start with pilot experiments led by dedicated individuals and niche groups (*high confidence*). Collectively, such initiatives can find entry points to prompt policy, infrastructure, and policy reconfigurations, supporting the further uptake of technological and lifestyle innovations. Individuals' agency is central as social change agents and narrators of meaning. These bottom-up socio-cultural forces catalyse a supportive policy environment, which enables changes. {5.5.2}

The current effects of climate change, as well as some mitigation strategies, are threatening the viability of existing business practices, while some corporate efforts also delay mitigation action (*medium confidence*). Policy packages the include job creation programs help to preserve social trust, livelihoods, respect, and dignity of all workers and employees involved. Business models that protect rent extracting behaviour may sometimes delay political action. Corporate advertisement and brand building strategies may also attempt to deflect corporate responsibility to individuals or aim to appropriate climate care sentiments in their own brand–building. {5.4.3, 5.6.4}

Middle actors -professionals, experts, and regulators- play a crucial albeit underestimated and underutilised role in establishing low-carbon standards and practices (*medium 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 and need greater capacity and motivation to play this role. {5.4.3}

Social influencers and thought leaders can increase the adoption of low-carbon technologies, behaviours, and lifestyles (*high confidence*). Preferences are malleable and can align with a cultural shift. The modelling of such shifts by salient and respected community members can help bring about changes in different service provisioning systems. Between 10% and 30% of committed individuals are required to set new social norms. {5.2.1, 5.4}

Preconditions and instruments to enable demand-side transformation

Social equity reinforces capacity and motivation for mitigating climate change (*medium confidence*). Impartial governance such as fair treatment by law and order institutions, fair treatment by gender, and income equity, increases social trust, thus enabling demand-side climate policies. High status (often high carbon) item consumption may be reduced by taxing absolute wealth without compromising well-being. {5.2, 5.4.2, 5.6}

Policies that increase the political access and participation of women, racialized, and marginalised groups, increase the democratic impetus for climate action. (*high confidence*). Including more differently situated knowledge and diverse perspectives makes climate mitigation policies more effective. {5.2, 5.6}

Carbon pricing is most effective if revenues are redistributed or used impartially (*high confidence*). A carbon levy earmarked for green infrastructures or saliently returned to taxpayers corresponding to widely accepted notions of fairness increases the political acceptability of carbon pricing. {5.6, Box 5.11}

Greater contextualisation and granularity in policy approaches better addresses 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**.** Creating and scaling up entirely new systems takes longer than replacing existing technologies and practices. Late adopters tend to adopt faster than early pioneers. Obstacles and feasibility barriers are high in the early transition phases. Barriers decrease as a result of technical and social learning processes, network building, scale economies, cultural debates, and institutional adjustments. {5.5, 5.6}

The lockdowns implemented in many countries in response to the COVID-19 pandemic demonstrated that behavioural change at a massive scale and in a short time is possible (*high confidence*). COVID-19 accelerated some specific trends, such as an uptake in urban cycling. However, the acceptability of collective social change over a longer term towards less resource-intensive lifestyles depends on social mandate building through public participation, discussion and debate over information provided by experts, to produce recommendations that inform policy-making. {Box 5.2}

Mitigation policies that integrate and communicate with the values people hold are more successful (*high confidence*). Values differ between cultures. Measures that support autonomy, energy security and safety, equity and environmental protection, and fairness resonate well in many communities and social groups. Changing from a commercialised, individualised, entrepreneurial training model to an education cognizant of planetary health and human well-being can accelerate climate change awareness and action {5.4.1, 5.4.2}

Changes in consumption choices that are supported by structural changes and political action enable the uptake of low-carbon choices (*high confidence*). Policy instruments applied in coordination can help to accelerate change in a consistent desired direction. Targeted technological change, regulation, and public policy can help in steering digitalization, the sharing economy, and circular economy towards climate change mitigation. {5.3, 5.6}

Complementarity in policies helps in the design of an optimal demand-side policy mix (*medium confidence*). In the case of energy efficiency, for example, this may involve CO_2 pricing, standards and norms, and information feedback.{5.3, 5.4, 5.6}

5.1 Introduction

The Sixth Assessment Report of the IPCC (AR6), for the first time, features a 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 2007; Roy and Pal 2009; IPCC 2014a), the Global Energy Assessment (Roy et al. 2012), and the AR5, which identified sectoral demand-side mitigation options across chapters (IPCC 2014b; Creutzig et al. 2016b; IPCC 2014a). 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 (Creutzig et al. 2021a) (Box 5.2). Demand-side solutions support near-term climate change mitigation (Méjean et al. 2019; Wachsmuth and Duscha 2019) and include consumers' technology choices, behaviours, lifestyle changes, coupled production-consumption infrastructures and systems, service provision strategies, and associated socio-technical transitions. This chapter's assessment of the social sciences (also see Supplementary Materials I Chapter 5) reveals that social dynamics at different levels offer diverse entry points for acting on and mitigating climate change (Jorgenson et al. 2018).

Three entry points are relevant for this chapter. First, well-designed demand for services scenarios are consistent with adequate levels of well-being for everyone (Rao and Baer 2012; Grubler et al. 2018; Mastrucci et al. 2020; Millward-Hopkins et al. 2020), with high and/or improved quality of life (Max-Neef 1995), improved levels of happiness (Easterlin et al. 2010) and sustainable human development (Arrow et al. 2013; Dasgupta and Dasgupta 2017).

Second, demand-side solutions support staying within planetary boundaries (Haberl et al. 2014; Matson et al. 2016; Hillebrand et al. 2018; Andersen and Quinn 2020; UNDESA 2020; Hickel et al. 2021; Keyßer and Lenzen 2021): they entail fewer environmental risks than many supply side technologies (Von Stechow et al. 2016) and make carbon dioxide removal technologies, such as Bio-Energy with Carbon Capture and Storage (BECCS) less relevant (Van Vuuren et al. 2018) or possibly irrelevant in modelling studies (Grubler et al. 2018; Hickel et al. 2021; Keyßer and Lenzen 2021) still requiring ecosystem based carbon dioxide removal. In the IPCC's SR1.5C (IPCC 2018), four stylised scenarios have explored possible pathways towards stabilising global warming at 1.5°C (SPM SR.15 Figure 3a (IPCC 2014a), (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 low-energy demand pathways eliminate the need for technologies with high uncertainty, such as BECCS.

Third, interrogating demand for services from the well-being perspective also opens new avenues for assessing mitigation potentials (Brand-Correa and Steinberger 2017; Mastrucci and Rao 2017; Rao and Min 2018a; Mastrucci and Rao 2019; Baltruszewicz et al. 2021). Arguably, demand-side interventions often operate institutionally or in terms of restoring natural functioning and have so far been politically side lined but COVID-19 revealed interesting perspectives (Box 5.2). Such demand-side solutions also support near-term goals towards climate change mitigation and reduce the need for politically challenging high global carbon prices (Méjean et al. 2019) (Box 5.11). The well-being focus emphasises equity and universal need satisfaction, compatible with Sustainable Development Goals (SDGs) progress (Lamb and Steinberger 2017).

The requisites for well-being include collective and social interactions as well as consumption-based material inputs. Moreover, rather than material inputs *per se*, people need and demand services for dignified survival, sustenance, mobility, communication, comfort and material well-being (Nakićenović et al. 1996b; Johansson et al. 2012; Creutzig et al. 2018). These services may be provided in many different context-specific ways using physical resources (biomass, energy, materials, etc.) and available technologies (e.g. cooking tools, appliances). Here we understand demand as demand for services (often requiring material input), with particular focus on services that are required for well-being (such as lighting, accessibility, shelter, etc.), and that are shaped by culturally and geographically differentiated social aspects, choice architectures and the built environment (infrastructures).

Focusing on demand for services broadens the climate solution space beyond technological switches confined to the supply side, to include solutions that maintain or improve well-being related to nutrition, shelter and mobility while (sometimes radically) reducing energy and material input levels (Creutzig et al. 2018; Cervantes Barron 2020; Baltruszewicz et al. 2021; Kikstra et al. 2021b). This also recognises that mitigation policies are politically, economically and socially more feasible, as well as more effective, when there is a two-way alignment between climate action and well-being (OECD 2019a). There is *medium evidence and high agreement* that well-designed demand for services scenarios are consistent with adequate levels of well-being for everyone (Rao and Baer 2012; Grubler et al. 2018; Rao et al. 2019b; Millward-Hopkins et al. 2020; Kikstra et al. 2021b), with high and/or improved quality of life (Max-Neef 1995; Vogel et al. 2021) and improved levels of happiness (Easterlin et al. 2010) and sustainable human development (Gadrey and Jany-Catrice 2006; Arrow et al. 2013; Dasgupta and Dasgupta 2017). While demand for services is high as development levels increase, and related emissions are growing in many countries (Yumashev et al. 2020; Bamisile et al. 2021), there is also evidence that provisioning systems delink services provided from emissions (Conte Grand 2016; Patra et al. 2017; Kavitha et al. 2020). Various mitigation strategies, often classified into Avoid-Shift-Improve (ASI) options, effectively reduce primary energy demand and/or material input (Haas et al. 2015; Haberl et al. 2017; Samadi et al. 2017; Hausknost et al. 2018; Haberl et al. 2019; Van den Berg et al. 2019; Ivanova et al. 2020). Users' participation in decisions about how services are provided, not just their technological feasibility, is an important determinant of their effectiveness and sustainability (Whittle et al. 2019; Vanegas Cantarero 2020).

Sector-specific mitigation approaches (Chapters 6-11) emphasise the potential of mitigation via improvements in energy- and materials- efficient manufacturing (Gutowski et al. 2013; Gramkow and Anger-Kraavi 2019; Olatunji et al. 2019; Wang et al. 2019), new product design (Fischedick et al. 2014), energy-efficient buildings (Lucon et al. 2014), shifts in diet (Bajželj et al. 2014; Smith et al. 2014), and transport infrastructure design shifts (Sims et al. 2014), compact urban forms (Seto et al. 2014). In this chapter, service-related mitigation strategies are categorized as **A**void, **S**hift, or **I**mprove (ASI) options to show how mitigation potentials, and social groups who can deliver them, are much broader than usually considered in traditional sector-specific presentations. ASI originally arose from the need to assess the staging and combinations of interrelated mitigation options in the provision of transportation services (Hidalgo and Huizenga 2013). In the context of transportation services, ASI seeks to mitigate emissions through *avoiding* 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 *improving* the carbon intensity of modes utilised (e.g., electric buses powered by renewables) (Creutzig et al. 2016a). This chapter summarises ASI options and potentials across sectors and generalises the definitions. 'Avoid' refers to all mitigation options that reduce unnecessary (in the sense of being not required to deliver the desired service output) energy consumption by redesigning service provisioning systems; 'shift' refers to the switch to already existing competitive efficient technologies and service provisioning systems; and 'improve' refers to improvements in efficiency in existing technologies. The Avoid-Shift-Improve framing operates in three domains: 'Socio-cultural', where social norms, culture, and individual choices play an important role – a category especially but not only relevant for avoid options; 'Infrastructure', which provides the cost and benefit landscape for realising options and is particularly relevant for shift options; and 'Technologies', especially important for the improve options. Avoid, Shift, and Improve choices will be made by individuals and households, instigated by salient and respected role models and novel social norms, but require support by adequate infrastructures designed by urban planners and building and transport professionals, corresponding investments, and a political culture supportive of mitigation action. This is particularly true for many Avoid and Shift decisions that are difficult because they encounter psychological barriers of breaking routines, habits and imagining new lifestyles and the social costs of not conforming to society (Kaiser 2006). Simpler Improve decisions like energy efficiency investments on the other hand can be triggered and sustained by traditional policy instruments complemented by behavioural nudges.

A key concern about climate change mitigation policies is that they may reduce quality of life. Based on growing literature, in this chapter we adopt the concept of Decent Living Standards (DLS, explained further in relation to other individual and collective well-being measures and concepts in the Social Sciences Primer) as a universal set of service requirements essential for achieving basic human well-being. DLS includes the dimensions of nutrition, shelter, living condition, clothing, health care, education, and mobility (Frye et al. 2018; Rao and Min 2018b). DLS provides a fair, direct way to understand the basic low-carbon energy needs of society and specifies the underlying material and energy requirements. This chapter also comprehensively assesses related well-being metrics that result from demand-side action observing overall positive effects (5.3). Similarly, ambitious low-emissions demand-side scenarios suggest that well-being could be maintained or improved while reducing global final energy demand, and some current literature estimates that it is possible to meet Decent Living Standards for all within the 2-degree warming window (Grubler et al. 2018; Burke 2020; Keyßer and Lenzen 2021) (5.4). A key concern here is how to blend new technologies with social change to integrate Improving ways of living, Shifting modalities and Avoiding certain kinds of emissions altogether (5.6). Social practice theory emphasizes that material stocks and social relations are key in forming and maintaining habits (Reckwitz 2002; Haberl et al. 2021) . This chapter reflects these insights by assessing the role of infrastructures and social norms in GHG emission intensive or low-carbon lifestyles (5.4).
A core operational principle for sustainable development is equitable access to services to provide well-being for all, while minimising resource inputs and environmental and social externalities/trade-offs, underpinning the Sustainable Development Goals (SDGs) (Princen 2003; Lamb and Steinberger 2017; Dasgupta and Dasgupta 2017). Sustainable development is not possible without changes in consumption patterns within the widely recognised constraints of planetary boundaries, resource availability, and the need to provide decent living standards for all (Langhelle 2000; Toth and Szigeti 2016; O'Neill et al. 2018). Inversely, reduced poverty and higher social equity offer opportunities for delinking demand for services from emissions, e.g., via more long-term decision making after having escaped poverty traps and by reduced demand for non-well-being enhancing status consumption (Nabi et al. 2020; Ortega-Ruiz et al. 2020; Parker and Bhatti 2020; Teame and Habte 2020) (5.3).

Throughout this chapter we discuss how people can realise various opportunities to reduce GHG emission-intensive consumption (5.2 and 5.3), and act in various roles (5.4), within an enabling environment created by policy instruments and infrastructure that builds on social dynamics (5.6).

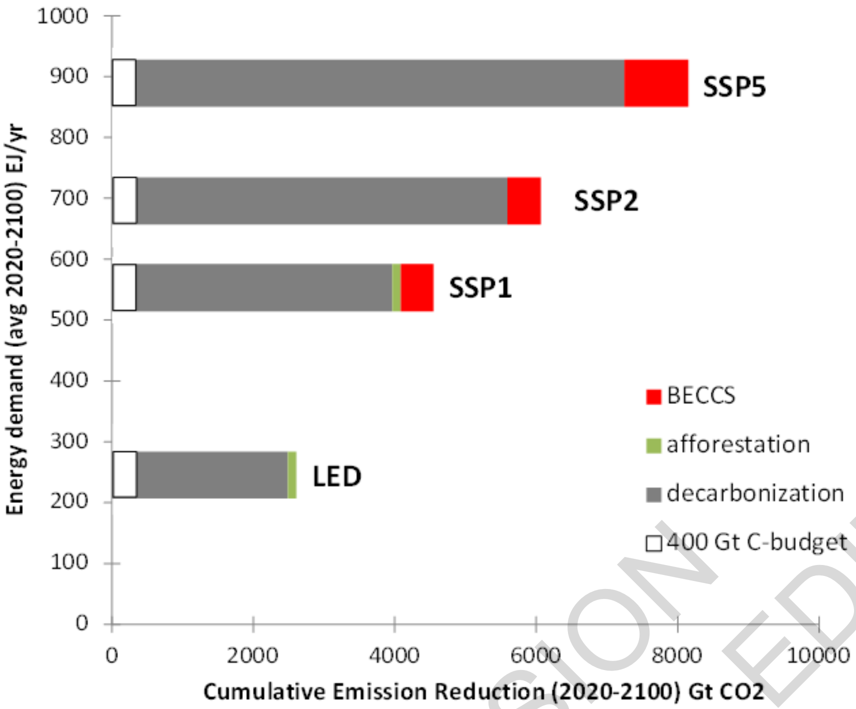


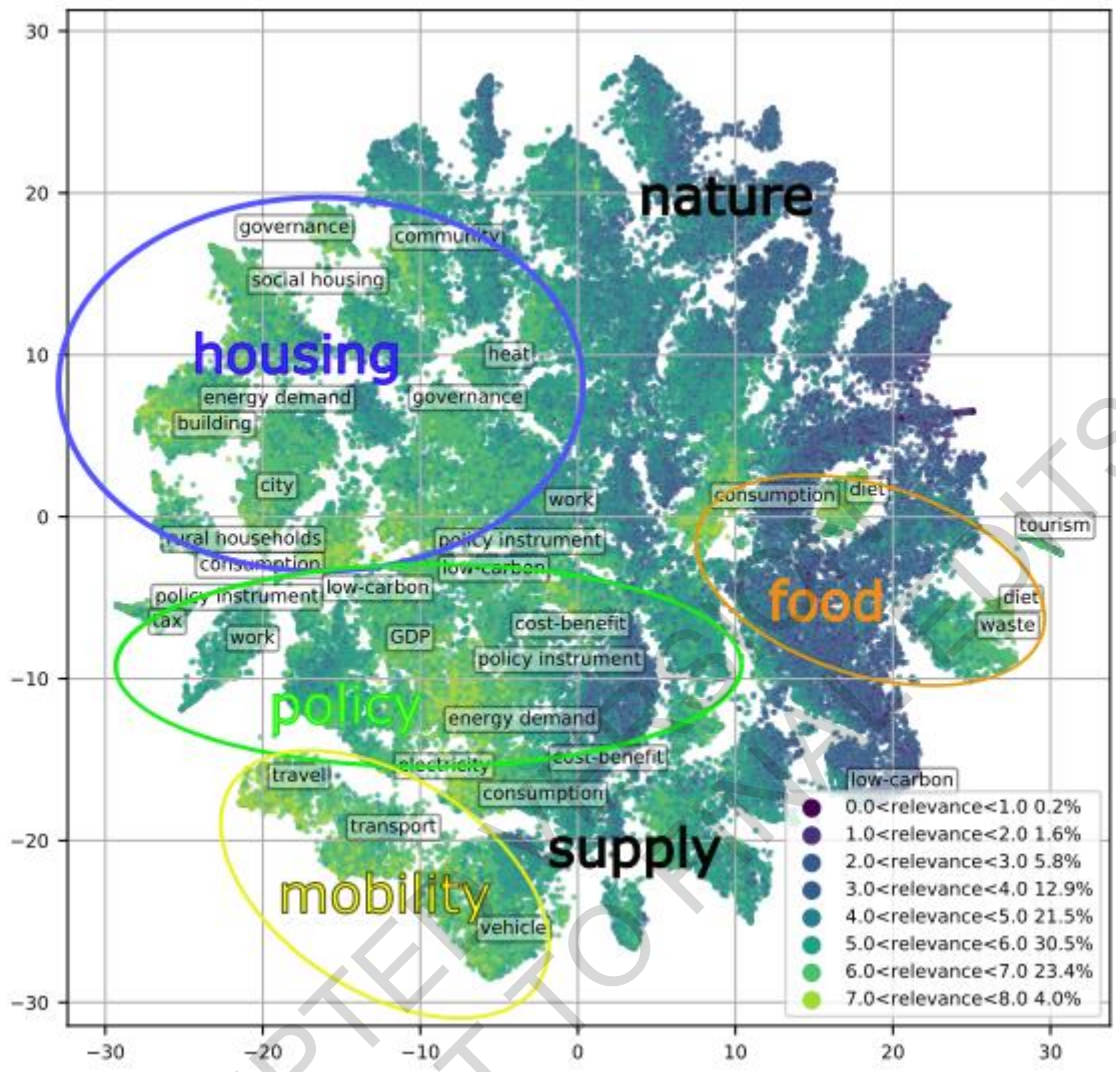
Figure 5.1 Low Energy Demand (LED) Scenario needs no BEECS and needs less decarbonisation efforts. Dependence of the size of the mitigation effort to reach a 1.5°C climate target (cumulative $GtCO_2$ emission reduction 2020-2100 by option) as a function of the level of energy demand (average global final 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). In this figure an example of remaining carbon budget of 400 Gt has been taken (from Rogelj, 2019) for illustrative purpose. 400 Gt is also the number given in Table SPM.2 (pg. 29, IPCC 2021) for a probability of 67% to limit global warming to 1.5°C .

START BOX 5.1 HERE

Box 5.1 Bibliometric foundation of demand-side climate change mitigation

A bibliometric overview of the literature found 99,065 academic peer-reviewed papers identified with 34 distinct search queries addressing relevant content of this chapter (Creutzig et al. 2021a). The literature is growing rapidly (15% yr^{-1}) and the literature body assessed in the AR6 period (2014-2020) is twice as large as all literature published before.

A large part of the literature is highly repetitive and/or includes no concepts or 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%, included relevant data (Wiedenhofer et al. 2020). In another systematic review, assessing quantitative estimates of consumption-based solutions (Ivanova et al. 2020), only 0.8% of papers were considered after consistency criteria were enforced. Altogether, we relied on systematic reviews wherever possible. Other important papers were not captured by systematic reviews, but included in this chapter through expert judgement. Based on topical modelling and relevance coding of resulting topics, the full literature body can be mapped into two dimensions, where spatial relationships indicate topical distance (Box 5.1, Figure 1). The interpretation of topic demonstrates that the literature organises in four clusters of high relevance for demand-side solutions (housing, mobility, food, and policy), whereas other clusters (nature, energy supply) are relatively less relevant.



Box 5.1, Figure 1 Map of the literature on demand, services and social aspects of climate change mitigation.
Dots show document positions obtained by reducing the 60-dimensional topic scores to two dimensions aiming to preserve similarity in overall topic score. The two axes therefore have no direct interpretation but represent a reduced version of similarities between documents across 60 topics. Documents are coloured by query category. Topic labels of the 24 most relevant topics are placed in the centre of each of the large clusters of documents associated with each topic. % value in caption indicates the proportion of studies in each "relevance" bracket.
Source: (Creutzig et al. 2021a)

END BOX 5.1 HERE

Section 5.2 provides evidence on the links among mitigation and well-being, services, equity, trust, and governance. Section 5.3 quantifies the demand-side opportunity space for mitigation, relying on the Avoid, Shift and Improve framework. Section 5.4 assesses the relevant contribution of different parts of society to climate change mitigation. Section 5.5 evaluates the overall dynamics of social transition processes while Section 5.6 summarises insights on governance and policy packages for demand-side mitigation and well-being. A Social Science Primer defines and discusses key terms and social science concepts used in the context of climate change mitigation.

START BOX 5.2 HERE

Box 5.2 COVID-19, service provisioning and climate change mitigation

There is now *high evidence and high agreement* that the COVID-19 pandemic has increased the political feasibility of large-scale government actions to support the services for provision of public goods, including climate change policies. Many behavioural changes due to COVID-19 reinforce sufficiency and emphasis on solidarity, economies built around care, livelihood protection, collective action, and basic service provision, linked to reduced emissions.

COVID-19 led to direct and indirect health, economic, and confinement-induced hardships and suffering, mostly for the poor, and reset habits and everyday behaviours of the well-off too, enabling a reflection on the basic needs for a good life. Although COVID-19 and climate change pose different kinds of threats and therefore elicit different policies, there are several lessons from COVID-19 for advancing climate change mitigation (Klenert et al. 2020; Manzanedo and Manning 2020; Stark 2020). Both crises are global in scale, requiring holistic societal response; governments can act rapidly, and delay in action is costly (Bouman et al. 2020a; Klenert et al. 2020). The pandemic highlighted the role of individuals in collective action and many people felt morally compelled and responsible to act for others (Budd and Ison, 2020). COVID-19 also taught the effectiveness of rapid collective action (physical distancing, wearing masks, etc.) as contributions to the public good. The messaging about social distancing, wearing masks and handwashing during the pandemic called attention to the importance of effective public information (e.g. also about reducing personal carbon footprints), recognising that rapid pro-social responses are driven by personal and socio-cultural norms (Sovacool et al. 2020a; Bouman et al. 2020a). In contrast, low trust in public authorities impairs the effectiveness of policies and polarizes society (Bavel et al. 2020; Hornsey 2020).

During the shutdown, emissions declined relatively most in aviation, and absolutely most in car transport (Le Quéré et al. 2020, Sarkis et al. 2020), and there were disproportionally strong reductions in GHG emissions from coal (Bertram et al. 2021)(Chapter 2). At their peak, CO_2 emissions in individual countries decreased by 17% in average (Le Quéré et al. 2020). Global energy demand was projected to drop by 5% in 2020, energy-related CO_2 emissions by 7%, and energy investment by 18% (IEA 2020a). Covid-19 shock and recovery scenarios project final energy demand reductions of 1–36 EJ yr−1 by 2025 and cumulative CO2 emission reductions of 14–45 GtCO2 by 2030 (Kikstra et al. 2021a). Plastics use and waste generation increased during the pandemic (Klemeš et al. 2020; Prata et al. 2020). Responses to COVID-19 had important connections with energy demand and GHG emissions due to quarantine and travel restrictions (Sovacool et al. 2020a). Reductions in mobility and economic activity reduced energy use in sectors such as industry and transport, but increased energy use in the residential sector (Diffenbaugh et al. 2020). COVID-19 induced behavioural changes that may translate into new habits, some beneficial and some harmful for climate change mitigation. New digitally enabled service accessibility patterns (videoconferencing, telecommuting) played an important role in sustaining various service needs while avoiding demand for individual mobility. However, public transit lost customers to cars, personalised two wheelers, walking and cycling, while suburban and rural living gained popularity, possibly with long-term consequences. Reduced air travel, pressures for more localised food and manufacturing supply chains (Hobbs 2020; Nandi et al. 2020; Quayson et al. 2020), and governments' revealed willingness to make large-scale interventions in the economy also reflect sudden shifts in service provisions and GHG emissions, some likely to be lasting (Aldaco et al. 2020; Bilal et al. 2020; Boyer 2020; Norouzi et al. 2020; Prideaux et al. 2020; Hepburn et al. 2020; Sovacool et al. 2020a). If changes in some preference behaviours, e.g. for larger homes and work environments to enable home working and online education, lead to sprawling suburbs or gentrification with linked environmental consequences, this could translate into long-term implications for climate change (Beaunoyer et al. 2020; Diffenbaugh et al. 2020). Recovering from the pandemic by adopting low energy demand practices – embedded in new travel, work, consumption and production behaviour and patterns– could reduce carbon prices for a 1.5°C consistent pathway by 19%, reduce energy supply investments until 2030 by 1.8 trillion USD, and lessen pressure on the upscaling of low-carbon energy technologies (Kikstra et al. 2021a).

COVID-19 drove hundreds of millions of people below poverty thresholds, reversing decades of poverty reduction accomplishments (Krieger 2020; Mahler et al. 2020; Patel et al. 2020; Sumner et al. 2020) and raising the spectre of intersecting health and climate crises that are devastating for the most vulnerable (Flyvbjerg 2020; Phillips et al. 2020). Like those of climate change, pandemic impacts fall heavily on disadvantaged groups, exacerbate the uneven distribution of future benefits, amplify existing inequities, and introduce new ones (Devine-Wright et al. 2020; Beaunoyer et al. 2020). Addressing such inequities is a positive step towards the social trust that leads to improved climate policies as well as individual actions. Increased support for care workers and social infrastructures within a solidarity economy is consistent with lower-emission economic transformation (Shelley 2017; Di Chiro 2019; Pichler et al. 2019; Smetschka et al. 2019).

Fiscally, the pandemic may have slowed the transition to a sustainable energy world: governments redistributed public funding to combat the disease, adopted austerity and reduced capacity, i.e. among nearly 300 policies implemented to counteract the pandemic, the vast majority are related to rescue, including worker and business compensation, and only 4% of these focus on green policies with potential to reduce GHG emissions in the long-term; some rescue policies also assist emissions-intensive business (Leach et al. 2021; Hepburn et al. 2020). However, climate investments can double as the basis of the COVID-19 recovery (Stark 2020), with policies focused on both economic multipliers and climate impacts such as clean physical infrastructure, natural capital investment, clean R&D and education and training (Hepburn et al. 2020). This requires attention to investment priorities, including often-underprioritized social investment, given how inequality intersects with and is a recognised core driver of environmental damage and climate change (Millward-Hopkins et al. 2020).

END BOX 5.2 HERE

5.2 Services, well-being and equity in demand-side mitigation

As outlined in section 5.1, mitigation, equity and well-being go hand in hand to motivate actions. Global, regional, and national actions/policies that advance inclusive well-being and build social trust strengthen governance. There is *high evidence and high agreement* that demand-side measures cut across all sectors, and can bring multiple benefits (Mundaca et al. 2019; Wachsmuth and Duscha 2019; Geels 2020; Niamir et al. 2020b; Garvey et al. 2021; Roy et al. 2021). Since effective demand requires affordability, one of the necessary conditions for acceleration of mitigation through demand side measures is wide and equitable participation from all sectors of society. Low-cost low-emissions technologies, supported by institutions and government policies, can help meet service demand and advance both climate and well-being goals (Steffen et al. 2018a; Khosla et al. 2019). This section introduces metrics of well-being and their relationship to GHG emissions, and clarifies the concept of service provisioning.

5.2.1 Metrics of well-being and their relationship to GHG emissions

There is *high evidence and agreement* in the literature that human well-being and related metrics provide a societal perspective which is inclusive, compatible with sustainable development, and generates multiple ways to mitigate emissions. Development targeted to basic needs and well-being for all entails less carbon-intensity than GDP-focused growth (Rao et al. 2014; Lamb and Rao 2015).

Current socioeconomic systems are based on high-carbon economic growth and resource use (Steffen et al. 2018b). Several systematic reviews confirm that economic growth is tightly coupled with increasing CO_2 emissions (Ayres and Warr 2005; Tiba and Omri 2017; Mardani et al. 2019; Wiedenhofer et al. 2020) although the level of emissions depends on inequality (Baležentis et al. 2020; Liu et al. 2020b), and on geographic and infrastructural constraints that force consumers to use fossil fuels (Pottier et al. 2021). 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. (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, measures designed to lower GHG emissions may reduce economic growth. However, energy substitution and efficiency gains may offer opportunities to break the bidirectional dependency (Komiyama 2014; Brockway et al. 2017; Shuai et al. 2019). Worldwide trends reveal that at best only relative decoupling (resource use grows at a slower pace than GDP) was the norm during the twentieth century (Jackson 2009; Krausmann et al. 2009; Ward et al. 2016; Jackson 2017), while absolute decoupling (when material use declines as GDP grows) is rare, observed only during recessions or periods of low or no economic growth (Heun and Brockway 2019; Hickel and Kallis 2019; Vadén et al. 2020; Wiedenhofer et al. 2020). Recent trends in OECD countries demonstrate the potential for absolute decoupling of economic growth not only from territorial but also from consumption-based emissions (Le Quéré et al. 2019), albeit at scales insufficient for mitigation pathways (Vadén et al. 2020) (Chapter 2).

Energy demand and demand for GHG intensive products increased from 2010 until 2020 across all sectors and categories. 2019 witnessed a reduction in energy demand growth rate to below 1% and 2020 an overall decline in energy demand, with repercussions into energy supply disproportionally affecting coal via merit order effects (Bertram et al. 2021) (Cross-Chapter Box 1 in Chapter 1). There was a slight but significant shift from high carbon beef consumption to medium carbon intensive poultry consumption. Final energy use in buildings grew from 118 EJ in 2010 to around 128 EJ in 2019 (increased about 8%). The highest increase was observed in non-residential buildings, with a 13% increase against 8% in residential energy demand (IEA 2019a). While electricity accounted for one-third of building energy use in 2019, fossil fuel use also increased at a marginal annual average growth rate of 0.7% since 2010 (IEA 2020a). Energy-related CO_2 emissions from buildings have risen in recent years after flattening between 2013 and 2016. Direct and indirect emissions from electricity and commercial heat used in buildings rose to 10 $GtCO_2$ in 2019, the highest level ever recorded. Several factors have contributed to this rise, including growing energy demand for heating and cooling with rising air-conditioner ownership and extreme weather events. A critical issue remains for how comfortable people feel with temperatures they will be exposed to in the future and this depends on factors such as physical, psychological and behavioral (Singh et al. 2018; Jacobs et al. 2019). Literature now shows *high evidence and high agreement* around the observation that policies and infrastructure interventions that lead to change in human preferences are more valuable for climate change mitigation. 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, individuals' preferences do shift and this can contribute to climate change mitigation (Gough 2015). 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 (Fleurbaey and Tadenuma 2014; Dietrich and List 2016; Mattauch and Hepburn 2016; Roy and Pal 2009; Komiyama

2014). 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; Brownell and Warner 2009). Further evidence on changing preferences in consumption choices pertinent to decarbonisation includes (Grinblatt et al. 2008; Weinberger and Goetzke 2010) for mobility; (Erb et al. 2016; Muller et al. 2017; Costa and Johnson 2019) for diets; (Baranzini et al. 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 2021). In particular, if policy instruments, such as awareness campaigns, infrastructure development or education, can change people's preferences, then policies or infrastructure provision – socially constrained by deliberative decision making -- which change both relative prices and preferences, are more valuable for mitigation than previously thought (Mattauch et al. 2016, 2018; Creutzig et al. 2016b). The provisioning context of human needs is participatory, so transformative mitigation potential arises from social as well as technological change (Lamb and Steinberger 2017). Many dimensions of well-being and 'basic needs' are social not individual in character (Schneider 2016), so extending well-being 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 beyond individual consumer choice. Climate policies that affect collective behaviour fairly are the most acceptable policies across political ideologies (Clayton 2018); thus collective preferences for mitigation are synergistic with evolving policies and norms in governance contexts that reduce risk, ensure social justice and build trust (Atkinson et al. 2017; Cramton et al. 2017; Milkoreit 2017; Tvinnereim et al. 2017; Smith and Reid 2018; Carattini et al. 2019).

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; Sager 2017; Burstein et al. 2019). A number of different well-being metrics are valuable in emphasising the constituents of what is needed for a decent life in different dimensions (Porter et al. 2017; Smith and Reid 2018; Lamb and Steinberger 2017). 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 well-being (Gough 2017). For the purposes of this chapter, indicators directly relating GHG emissions to well-being for all are particularly relevant.

Well-being can be categorised 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 minimising pain, assuming that the individual is motivated to enhance personal freedom, self-preservation and enhancement (Sirgy 2012; Ganglmair-Wooliscroft and Wooliscroft 2019; Brand-Correa and Steinberger 2017; 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; Max-Neef et al. 1991) and models of psychosocial well-being (Ryan and Deci 2001). Measures of well-being differ somewhat in developed and developing countries (Sulemana et al. 2016; Ng and Diener 2019); for example, food insecurity, associated everywhere with lower subjective well-being, is more strongly associated with poor subjective well-being in more-developed countries (Frongillo et al. 2019); in wealthier countries, the relationship between living in rural areas is less strongly associated with negative well-being than in less-developed countries (Requena 2016); and income inequality is negatively associated with subjective well-being in developed countries, but positively so in less-developed countries (Ngamaba et al. 2018). This chapter connects demand side climate mitigation options to multiple dimensions of well-being going beyond single dimensional metric of GDP which is at the core of IAMs. Many demand side mitigation solutions generate positive and negative impacts on wider dimensions of human well-being which are not always quantifiable (*medium evidence, medium agreement).*

5.2.1.1 Services for well-being

Well-being needs are met through services. Provision of services associated with low-energy demand is a key component of current and future efforts to reduce carbon emissions. Services can be provided in various culturally-appropriate ways, with diverse climate implications. There is *high evidence and high agreement* in the literature that many granular service provision systems can make 'demand' more flexible, provide new options for mitigation, support access to basic needs, and enhance human well-being. Energy services offer an important lens to analyse the relationship between energy systems and human well-being (Jackson and Papathanasopoulou 2008; Druckman and Jackson 2010; Mattioli 2016; Walker et al. 2016; Fell 2017; Brand-Correa et al. 2018; King et al. 2019; Pagliano and Erba 2019; Whiting et al. 2020). Direct and indirect services provided by energy, rather than energy itself, deliver well-being benefits (Kalt et al. 2019). For example, illumination and transport are intermediary services in relation to education, healthcare, meal preparation, sanitation, etc. which are basic human needs. Sustainable consumption and production revolve around 'doing more and better with the same ' and thereby increasing well-being 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 use and/or shift to low-carbon energy, if associated with the maintenance or improvement of services, can not only ensure better environmental quality but also directly enhance well-being (Roy et al. 2012) the correlation between human development and emissions are not necessarily coupled in the long term, which implies prioritize human well-being and the environment over economic growth (Steinberger et al. 2020). At the interpersonal and community level, cultural specificities, infrastructure, norms, and relational behaviours differ. (Box 5.3). 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, incomes, and outside temperatures (Campbell et al. 2018; Ivanova et al. 2018; IEA 2019b; Dreyfus et al. 2020; Brand-Correa et al. 2018). In personal mobility, different variable needs satisfiers (e.g., street space allocated to cars, bussesor bicycles) can help satisfy human needs, such as accessibility to jobs, health care, and education. Social interactions and normative values play a crucial role in determining energy demand. Hence, demand-side and service-oriented mitigation strategies are most effective if geographically and culturally differentiated (Niamir et al. 2020a).

Decent Living Standards (DLS) serves as a socio-economic benchmark as 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.), recognising 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. Therefore, one key way of thinking about providing well-being for all with low carbon emissions centres around prioritising ways of providing services for DLS in a low-carbon way (including choices of needs satisfiers, and how these are provided or made accessible). They may be supplied to individuals or groups / communities, both through formal markets and/or informally, e.g. by collaborative work, in coordinated ways that are locally-appropriate, designed and implemented in accordance with overlapping local needs.

The most pressing DLS service shortfalls, as shown in Figure 5.2, lie in the areas of nutrition, mobility, and communication. Gaps in regions such as Africa and the Middle East are accompanied by current levels of service provision in the highly industrialised 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 GHG emissions associated with high levels of consumption and material throughput by those far above DLS levels has potential to address both emissions and inequality in energy and emission footprints (Otto et al. 2019). This, in turn, has further potential benefits; under the conditions of 'fair' income reallocation public services, this can reduce national carbon footprint by up to 30% while allowing the consumption of those at the bottom to increase (Millward-Hopkins and Oswald 2021). The challenge then is to address the upper limits of consumption. When consumption supports the satisfaction of basic needs any decrease causes deficiencies in human-need satisfaction, contrary, in the case of consumption that exceeds the limits of basic needs. A deprivation causes a subjective discomfort (Brand-Correa et al. 2020) therefore, establishing minimum and maximum standards of consumption or sustainable consumption corridors (Wiedmann et al. 2020) has been suggested to collectively not surpassing the environmental limits depending on the context. In some countries, carbon intensive ways of satisfying human needs have been locked-in, e.g. via car-dependent infrastructures (Druckman and Jackson 2010; Jackson and Papathanasopoulou 2008; King et al. 2019; Mattioli 2016), and both infrastructure reconfiguration and adaptation are required to organise need satisfaction in low-carbon ways (see also Section 10.2 in Chapter 10).

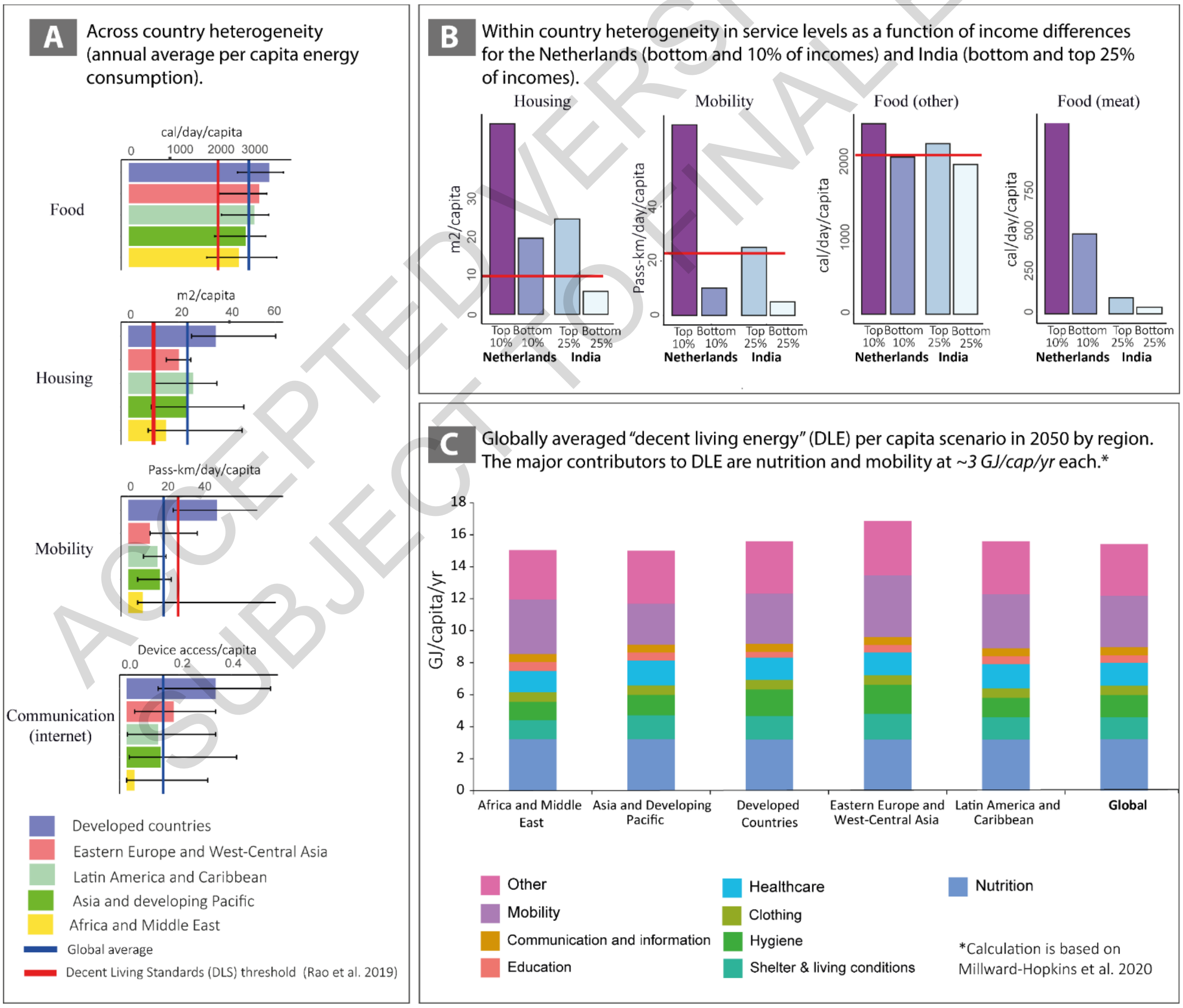


Figure 5.2 [2] Heterogeneity in access to and availability of services for human well-being within and across countries.
Panel A. Across –country differences in panel (a) food-meat, (b)food other, (c) housing, (d) mobility, (e) Communication –mobile phones, and (f) high speed internet access. Variation in service levels across countries within a region are shown as error bars (black). Values proposed as decent standards of living threshold (Rao et al. 2019b) are shown (red dashed lines). Global average values are shown (blue dashed lines). Panel B. Within-country differences in service levels 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. 2012b) (data update 2016). Panel C. Decent living energy (DLE) scenario using global, regional and DLS dimensions for final energy consumption at 149 EJ (15.3 GJ capita^{-1}yr^{-1}) in 2050 (Millward-Hopkins et al. 2020), requiring advanced technologies in all sectors and radical demand-side changes. Values are shown for 5 world regions based on WG III AR6 Regional breakdown. Here we use passenger km/day/capita as metric for mobility only as a reference, however, transport and social inclusion research suggest the aim is to maximize accessibility and not travel levels or travelled distance.

There is *high evidence and high agreement* in the literature that vital dimensions of human well-being correlate with consumption, but only up to a threshold. High potential for mitigation lies in using low-carbon energy for new basic needs satisfaction while cutting emissions of those whose basic needs are already met (Grubler et al. 2018; Rao and Min 2018b; Millward-Hopkins et al. 2020; Rao et al. 2019b; Keyßer and Lenzen 2021). Decent Living Standards indicators serve as tools to clarify this socio-economic benchmark and identify well-being for all compatible mitigation potential. Energy services provisioning opens up avenues of efficiency and possibilities for decoupling energy services demand from 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; Tanikawa et al. 2021). Vital dimensions of well-being correlate with consumption, but only up to a threshold, decent living energy thresholds range ~13–18.4 GJ^{-1}cap^{-1}yr of final energy consumption but the current consumption ranges from under 5 GJ^{-1}cap^{-1}yr to over 200 GJ^{-1}cap^{-1}yr (Millward-Hopkins et al. 2020), thus a mitigation strategy that protects minimum levels of essential-goods service delivery for DLS, but critically views consumption beyond the point of diminishing returns of needs satisfaction, is able to sustain well-being while generating emissions reductions (Goldemberg et al. 1988; Jackson and Marks 1999; Druckman and Jackson 2010; Girod and De Haan 2010; Vita et al. 2019a; Baltruszewicz et al. 2021). Such relational dynamics are relevant both within and between countries, due to variances in income levels, lifestyle choice (see also 5.4.4), geography, resource assets and local contexts. Provisioning for human needs is recognised as participatory and interrelational; transformative mitigation potential can be found in social as well as technological change (Mazur and Rosa 1974; Goldemberg et al. 1985; Hayward and Roy 2019; Lamb and Steinberger 2017; O'Neill et al. 2018; Vita et al. 2019a). More equitable societies which provide DLS for all can devote attention and resources to mitigation (Dubash 2013; Rafaty 2018; Richards 2003; Oswald et al. 2021). For further exploration of these concepts, see the Chapter 5 Supplementary Material I.

5.2.2 Inequity in access to basic energy use and services

5.2.2.1 Variations in access to needs-satisfiers for Decent Living Standards

There is very *high evidence and very high agreement* that globally, there are differences in the amount of energy that societies require to provide the basic needs for everyone. At present nearly one-third of the world's population are 'energy-poor' facing challenges in both access and affordability, i.e., more than 2.6 billion people have little or no access to energy for clean cooking. About 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 current per capita energy requirement to provide a decent standard

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[2] FOOTNOTE The countries and areas classification in this figure deviate from the standard classification scheme adopted by WGIII as set out in Annex II, section 1.

of living range from ~5 to 200 GJ cap^{-1}yr^{-1} (Steckel et al. 2013; Lamb and Steinberger 2017; Rao et al. 2019b; Millward-Hopkins et al. 2020), which shows the level of inequality that exists; this depends on the context such as geography, culture, infrastructure or how services are provided (Brand-Correa et al. 2018) (Box 5.3). However, through efficient technologies and radical demand-side transformations, the final energy requirements for providing DLS by 2050 is estimated at 15.3 GJ cap^{-1}yr^{-1} (Millward-Hopkins et al. 2020). Recent DLS estimates for Brazil, South Africa, and India are in the range between 15 and 25 GJ cap^{-1}yr^{-1} (Rao et al. 2019b).The most gravely energy-poor are often those living in informal settlements, particularly 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). For example, in Brazil, India and South Africa, where inequality is extreme (Alvaredo et al. 2018) mobility (51-60%), food production and preparation (21-27%) and housing (5-12%) dominate total energy needs (Rao et al. 2019b). Minimum requirements of energy use consistent with enabling well-being for all is between 20 and 50 GJ cap^{-1} yr^{-1} depending on context (Rao et al. 2019b). Inequality in access to and availability of services for human well-being varies in extreme degree across countries and income groups. In developing countries the bottom 50% receive about 10% of the energy used in land transport and less than 5% in air transport, while the top 10% use ~45% of the energy for land transport and around 75% for air transport (Oswald et al. 2020). Within-country analysis shows that particular groups in China— women born in the rural West with disadvantaged family backgrounds— face unequal opportunities for energy consumption (Shi 2019). Figure 5.3 shows the wide variation across world regions in people's access to some of the basic material prerequisites for meeting DLS, and variations in energy consumption, providing a starting point for comparative global analysis.

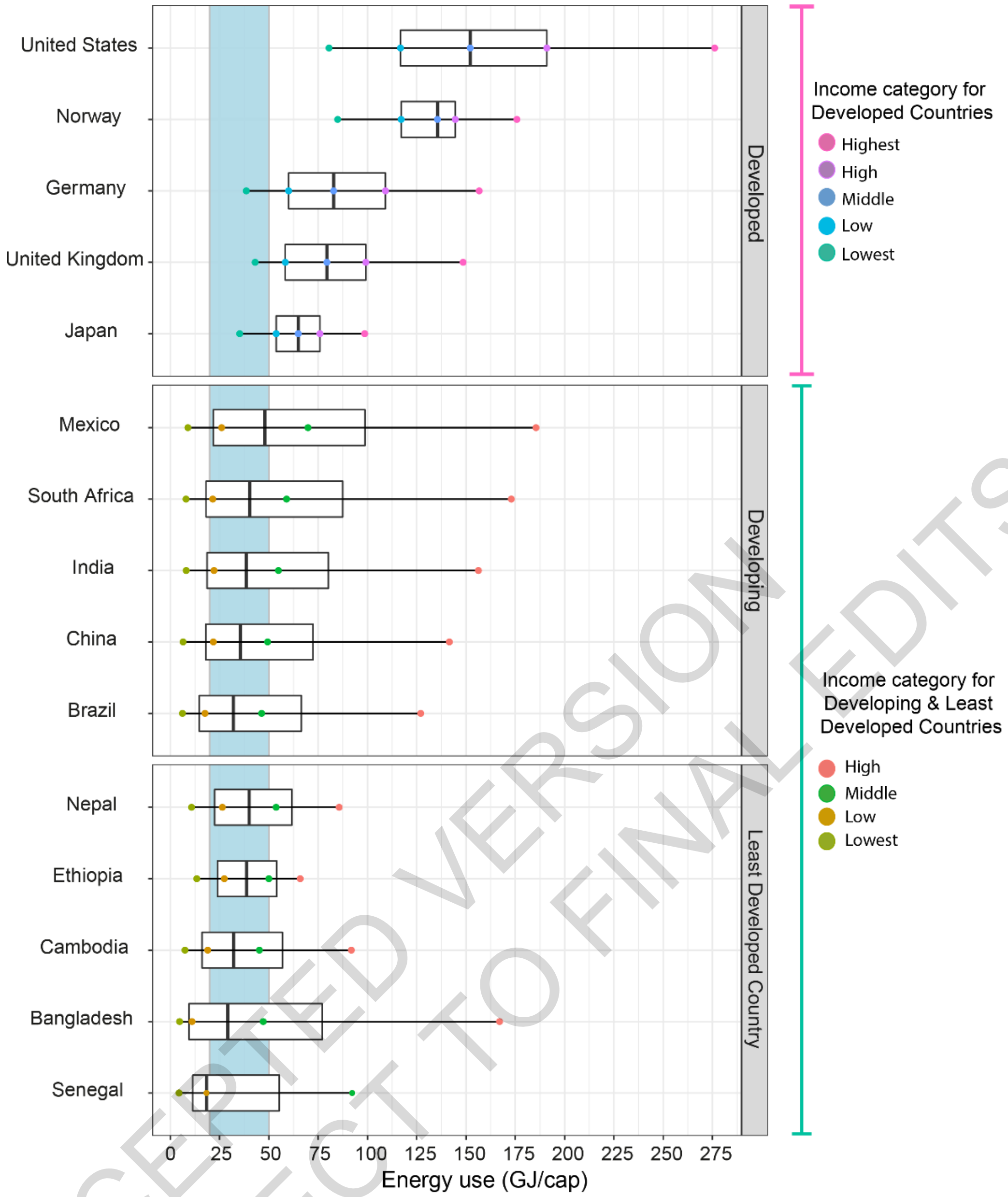


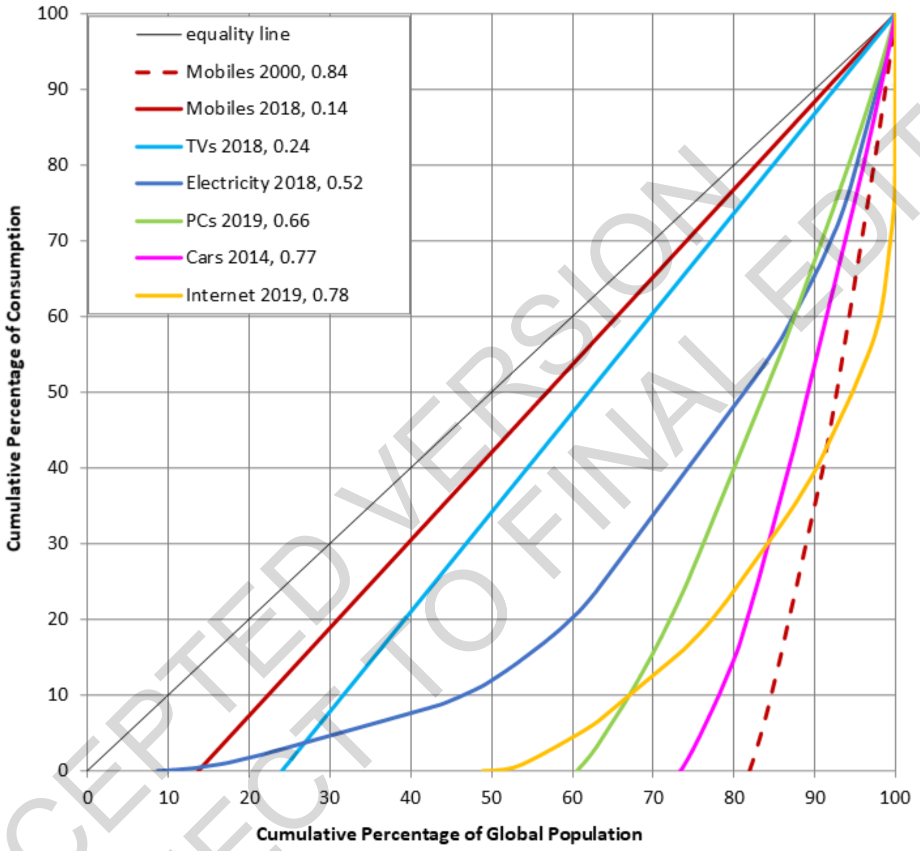
Figure 5.3 Energy use per capita of three groups of countries ranked by socioeconomic development and displayed for each country based on four or five different income groups (according the data availability) as well as geographical representation. The final energy use for decent living standards (20-50 GJ cap^{-1}) is indicated in the blue column (Rao et al. 2019b) as a reference for global range, rather than dependent on each country .

Data based on (Oswald et al. 2020).

START BOX 5.3 HERE

Box 5.3 Inequities in access to and levels of end-use technologies and infrastructure services

Acceleration in mitigation action needs to be understood from societal perspective. Technologies, access and service equity factors sometimes change rapidly. Access to technologies, infrastructures and products, and the services they provide, are essential for raising global living standards and improving human well-being (Alkire and Santos 2014; Rao and Min 2018b). Yet access to and levels of service delivery are distributed extremely inequitably as of now. How fast such inequities can be reduced by granular end-use technologies is illustrated by the cellphone (households with mobiles), comparing the situation between 2014 and 2018. In this eighteen-year period, cellphones changed from a very inequitably-distributed technology to one with almost universal access, bringing accessibility benefits especially to populations with very low disposable income and to those whose physical mobility is limited (Porter 2016). Every human has the right to dignified decent life, to live in good health and to participate in society. This is a daunting challenge, requiring that in the next decade governments build out infrastructure to provide billions of people with access to a number of services and basic amenities in comfortable homes, nutritious food, and transit options (Rao and Min 2018b). For long, this challenge was thought to also be an impediment to developing countries' participation in global climate mitigation efforts. However, recent research shows that this need not be the case (Millward-Hopkins et al. 2020; Rao et al. 2019b).



Technology/Infrastructure	Gini	Year	Population without access bn	Population without access %	Coverage world population %	Coverage included countries number	Source
Mobiles*	0.84	2000	4.0	81.9	80.4	43	ITU+/WBWDI/WPDS+
Mobiles*	0.14	2018	0.8	13.7	78.3	43	ITU+/WBWDI/WPDS+
TVs*	0.24	2018	1.6	24.1	89.8	86	ITU+/WBWDI/WPDS+
Electricity (kWh)	0.52	2018	0.6	8.7	95.9	142	WB WDI/IEA
PCs	0.66	2019	4.6	60.5	98.0	183	ITU/WBWDI/WPDS+
Cars*	0.77	2014	4.2	73.3	78.9	44	PEW/WBWDI
International bandwidth (bits/sec)	0.78	2019	3.7	48.8	99.3	197	ITU/WBWDI

Box 5.3, Figure 1 International inequality in access and use of goods and services. Upper panel: International Lorenz curves and Gini coefficients accounting for the share of population living in households without access (origin of the curves on the y-axis), multiple ownership not considered. Lower panel: Gini, number of people without access, access rates and coverage in terms of share of global population and number of countries included. *Reduced samples lead to underestimation of inequality. A sample, for example, of around 80% of world population (taking the same 43 countries as

for mobiles and cars) led to a lower Gini of around 0.48 (-0.04) for electricity. The reduced sample was kept for mobiles in 2018 to allow for comparability with 2000.

Source: (Zimm 2019)

Several of the United Nations Sustainable Development Goals (SDGs) (UN 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. Multidimensional poverty indices, such as the Social Progress Indicator (SPI) and the Individual Deprivation Measure, go beyond income and focus on tracking the delivery of access to basic services by the poorest population groups, both in developing countries (Fulton et al. 2009; Alkire and Robles 2017; Alkire and Santos 2014; Rao and Min 2018b), and in developed countries (Townsend 1979; Aaberge and Brandolini 2015; Eurostat 2018). At the same time, the SDGs, primarily 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 and among the indicators used to track their progress (UNESC 2017; UN 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 (public transit, 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 for participation in society and the economy (Smith et al. 2015). In 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).

END BOX 5.3 HERE

5.2.2.2 Variations in energy use

There is *high evidence and high agreement* in the literature that through equitable distribution, well-being for all can be assured at the lowest-possible energy consumption levels (Steinberger and Roberts 2010; Oswald et al. 2020) by reducing emissions related to consumption as much as possible, while assuring DLS for everyone (Annecke 2002; de Zoysa 2011; Ehrlich and Ehrlich 2013; Spangenberg 2014; Toroitich and Kerber 2014; Dario Kenner 2015; Smil 2017; Toth and Szigeti 2016; Otto et al. 2019; Baltruszewicz et al. 2021). 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); those patterns are explained by context in terms of various climate, cultural and historical factors influencing consumption Context matter even in within country analysis ,e.g. electricity consumption in US show that efficiency innovations do exert positive influence on savings of residential energy consumption, but the relationship is mixed; on the contrary, affluence (household income and home size) and context (geographical location) drives significantly resource utilization (Adua and Clark 2019), affluence is central to any future prospect in terms of environmental conditions (Wiedmann et al. 2020). In China, inequality of energy consumption and expenditure varies highly depending on the energy type, end-use demand and climatic region (Wu et al. 2017).

Consumption is energy and materials-intensive and expands along with income. 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 and the structure of consumption as a function of income level (Wolfram et al. 2016; Arto et al. 2016; Santillán Vera et al. 2021). International trade plays a central tole being responsible for shifting burdens in most cases from low-income developing countries producers to high income developed countries as consumers (Wiedmann et al. 2020). China is the largest importing market for EU and United States, which accounts for near half and 40% of their imports in energy use respectively (Wu et al. 2019). Wealthy countries have exported or outsourced their climate and energy crisis to low and middle-income countries (Baker 2018) exacerbated by intensive international trade (Steinberger et al. 2012; Scherer et al. 2018). Therefore, issues of total energy consumption are inseparably related to the energy inequity among the countries and regions of the world.

Within the energy use induced by global consumer products, household consumption is the biggest contributor, contributing to around three quarters of the global total (Wu et al. 2019). A more granular analysis of household energy consumption reveals that the lowest two quintiles in countries with average annual income below 15,000 USD cap^{-1} consume less energy than the international energy requirements for DLS (20-50 GJ cap^{-1}); 77% of people consume less than 30 GJ cap^{-1}yr^{-1} and 38% consume less than 10 GJ cap^{-1}yr^{-1} (Oswald et al. 2020). Many energy-intensive goods have high price elasticity (>1.0), implying that growing incomes lead to over-proportional growth of energy footprints in these consumption categories. 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 (Gössling 2019; Oswald et al. 2020).

Socio-economic dynamics and outcomes affect whether provisioning of goods and services is achieved at low energy demand levels (Figure 5.4). Specifically, multivariate regression shows that public service quality, income equality, democracy, and electricity access enable higher need satisfaction at lower energy demand, whereas extractivism and economic growth beyond moderate levels of affluence are reduce need satisfaction at higher energy demand (Vogel et al. 2021). Altogether this demonstrates that at a given level of energy provided, there is large scope to improve service levels for well-being by modifying social economic context without increasing energy supply (Figure 5.4).

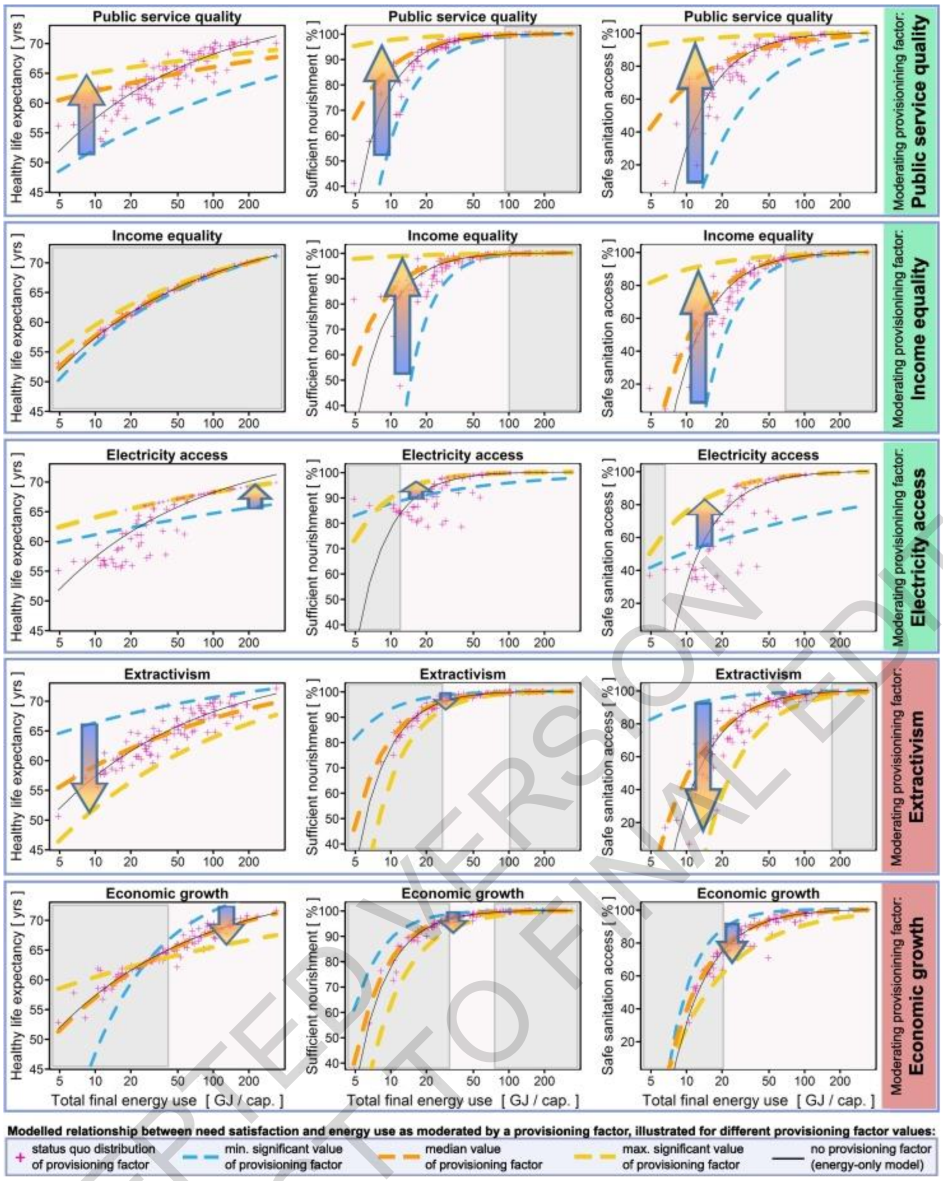


Figure 5.4 Improving services for well-being is possible, often at huge margin, at a given (relatively low) level of energy use

Source:(Vogel et al. 2021)

5.2.2.3 Variations in consumption-based emissions

The carbon footprint of a nation is equal to the direct emissions occurring due to households' transport, heating and cooking, as well as the impact embodied in the production of all consumed goods and services (Wiedmann and Minx 2008; Davis and Caldeira 2010; Hübler 2017; Vita et al. 2019a). There are large differences in carbon footprints between the poor and the rich. As a result of energy use inequality, the lowest global emitters (the poorest 10% in developing countries) in 2013 emitted about 0.1t CO_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), . The poorest 50% of the world's population are responsible for only about 10% of total lifetime consumption emissions, in contrast about ~50% of the world's GHG emissions can be attributed to consumption by the world's richest 10%, with the average carbon footprint of the richest being 175 times higher than that of the poorest 10% (Chancel and Piketty 2015) consuming the global carbon budget by nearly 30% during the period 1990-2015 (Kartha et al. 2020; Gore 2020). While the mitigation efforts often focus on the poorest, the lifestyle and consumption patterns of the affluent people often influence the growing middle class (Otto et al. 2019), e.g. Across

EU countries, only 5% of households are living within the 1.5% climate limits and the top 1% emit more than 22 times the target on average, being the transport in both land and air a characteristic of the highest emitters (Ivanova and Wood 2020).

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). Per capita carbon footprints average 1.6 tonnes per year for the lowest income category, then quickly increase to 4.9 and 9.8 tonne for the two middle-income categories and finally to an average of 17.9 tonnes 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 (Hubacek et al. 2017; Chancel and Piketty 2015). In wealthy nations, services such as private road transport, frequent air travel, private jet ownership, meat-intensive diets, entertainment and leisure add significant emissions, while a considerable fraction of the carbon footprint is imported from abroad, embedded in goods and services (Hubacek et al. 2017).

High income households consume and demand energy at an order of magnitude greater than what is necessary for DLS (Oswald et al. 2020). Energy-intensive goods, such as package holidays, have a higher income elasticity of demand than less energy-intensive goods like food, water supply and housing maintenance, which results in high-income individuals having much higher energy footprints (Oswald et al. 2020). Evidence highlights highly unequal GHG emission in aviation: only 2-4% of global population flew internationally in 2018, with 1% of world population emitting 50% of CO_2 from commercial aviation (Gössling and Humpe 2020). Some individuals may add more than 1,600 t CO_2 yr^{-1} individually by air travel (Gössling 2019).

The food sector dominates in all income groups, comprising 28% of households' carbon footprint, with cattle and rice the major contributors (Scherer et al. 2018), food also accounts for 48% and 70% of household impacts on land and water resources, being the meat, dairy, and processed food rising fast together with income (Ivanova et al. 2016). Roughly 20-40% of food produced worldwide is lost to waste before it reaches the market, or is wasted by households, the energy embodied in wasted food was estimated at ~36 $EJyr^{-1}$, and during the period 2010-2016 global food loss and waste equalled 8-10% of total GHG emissions (Godfray and Garnett 2014; Springmann et al. 2018; Mbow et al. 2019). Global agri-food supply chains are crucial in the variation of per capita food consumption-related-GHG footprints, mainly in the case of red meat and dairy (Kim et al. 2020) since highest per capita food-consumption-related GHG emissions do not correlate perfectly with the income status of countries. Thus, it is also crucial to focus on high-emitting individuals and groups within countries, rather than only those who live in high-emitting countries, since the top 10% of emitters live on all continents and one third of them are from the developing world (Chakravarty et al. 2009; Pan et al. 2019).

The environmental impact of increasing equity across income groups can be either positive or negative (Hubacek et al. 2017; Scherer et al. 2018; Rao and Min 2018a; Millward-Hopkins et al. 2020). Projections for achieving equitable levels of service provision globally predict large increases in global GHG emissions and demand for key resources (Blomsma and Brennan 2017), especially in passenger transport, which is predicted to increase nearly three-fold between 2015 and 2050, from 44 trillion to 122 trillion passenger-kilometres (OECD 2019a), and associated infrastructure needs, increasing freight (Murray et al. 2017), increasing demand for cooling (IEA 2018), and shifts to carbon-intensive high-meat diets (FAO 2018).

Increasing incomes for all to attain DLS raises emissions and energy footprints, but only slightly (Jorgenson et al. 2016; Chakravarty et al. 2009; Scherer et al. 2018; Millward-Hopkins et al. 2020;

Oswald et al. 2020, 2021). The amount of energy needed for a high global level of human development is dropping (Steinberger and Roberts 2010) and could by 2050 be reduced to 1950 levels (Millward-Hopkins et al. 2020) requiring a massive deployment of technologies across the different sectors as well as demand-side reduction consumption. The consumption share of the bottom half of the world's population represents less than 20% of all energy footprints, which is less than what the top 5% of people consume (Oswald et al. 2020).

Income inequality itself also raises carbon emissions (Hao et al. 2016; Sinha 2016; Uzar and Eyuboglu 2019; Baloch et al. 2020; Wiedmann et al. 2020; Oswald et al. 2020; Vogel et al. 2021). Wide inequality can increase status-based consumption patterns, where individuals spend more to emulate the standards of the high-income group (the Veblenian effect); inequality also diminishes environmental efforts by reducing social cohesion and cooperation (Jorgenson et al. 2017) and finally, inequality also operates by inducing an increase in working hours that leads to higher economic growth and, consequently, higher emissions and ecological footprint, so working time reduction is key for policy to both reduce emissions and protect employment (Fitzgerald et al. 2015, 2018).

5.2.3 Equity, trust, and participation in demand-side mitigation

There is *high evidence and high agreement* in literature that socio-economic equity builds not only well-being for all, but also trust and effective participatory governance, which in turn strengthen demand-side climate mitigation. Equity, participation, social trust, well-being, governance and mitigation are parts of a continuous interactive and self-reinforcing process (Figure 5.5). Section SM5.1 in the Supplemental Material for this chapter contains more detail on these links, drawing from social science literature.

Economic growth in equitable societies is associated with lower emissions than in inequitable societies (McGee and Greiner 2018), and income inequality is associated with higher global emissions (Ravallion et al. 1997; Rao and Min 2018c; Diffenbaugh and Burke 2019; Fremstad and Paul 2019; Liu and Hao 2020; McGee and Greiner 2018). Relatively slight increases in energy consumption and carbon emissions produce great increases in human development and well-being in less-developed countries, and the amount of energy needed for a high global level of human development is dropping (Steinberger and Roberts 2010). Equitable & democratic societies which provide high quality public services to their population have high well-being outcomes at lower energy use than those which do not, whereas those which prioritize economic growth beyond moderate incomes and extractive sectors display a reversed effect (Vogel et al. 2021).

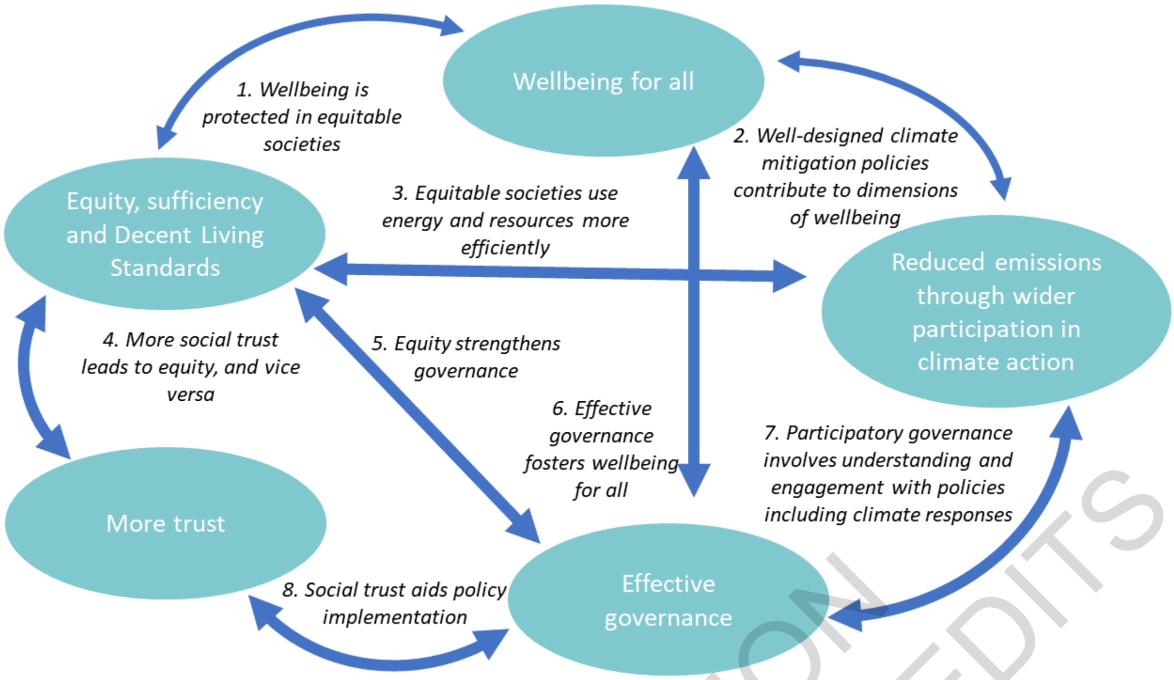


Figure 5.5 Well-being, equity, trust, governance and climate mitigation: positive feedbacks. Well-being for all, increasingly seen as the main goal of sustainable economies, reinforces emissions reductions through a network of positive feedbacks linking effective governance, social trust, equity, participation and sufficiency. This diagram depicts relationships noted in this chapter text and explained further in the Social Science Primer (supplementary material I in this Chapter). The width of the arrows corresponds to the level of confidence and degree of evidence from recent social sciences literature.

Well-designed climate mitigation policies ameliorate constituents of well-being (Creutzig et al. 2021b). The study shows that among all demand-side option effects on well-being 79% are positive, 18% are neutral (or not relevant/specify), and only 3% are negative (*high confidence*) (Creutzig et al. 2021b) (Figure 5.6). Figure 5.6 illustrates active mobility (cycling and walking), efficient buildings and prosumer choices of renewable technologies have the most encompassing beneficial effects on wellbeing with no negative outcome detected. Urban and industry strategies are highly positive overall for wellbeing, but they will also reshape supply-side businesses with transient intermediate negative effects. Shared mobility, like all others, has overall highly beneficial effects on wellbeing, but also displays a few negative consequences, depending on implementation, such as a minor decrease in personal security for patrons of ridesourcing.

Well-being improvements are most notable in health quality, air, and energy (*high confidence*). These categories are also most substantiated in the literature, often under the framing of co-benefits. In many cases, co-benefits outweigh the mitigation benefits of specific GHG emission reduction strategies. Food (*medium confidence*), mobility (*high confidence*), and water (*medium confidence*) are further categories where wellbeing is improved. Mobility has entries with highest well-being rankings for teleworking, compact cities, and urban system approaches. Effects on well-being in water and sanitation mostly comes from buildings and urban solutions. Social dimensions, such as personal security, social cohesion, and especially political stability are less predominantly represented. An exception is economic stability, suggesting that demand-side options generate stable opportunities to participate in economic activities (*high confidence*). Although the relation between demand-side mitigation strategies and the social aspects of human wellbeing is important, this has been less reflected in the literature so far, and hence the assessment finds more neutral/unknown interactions (Figure 5.6).

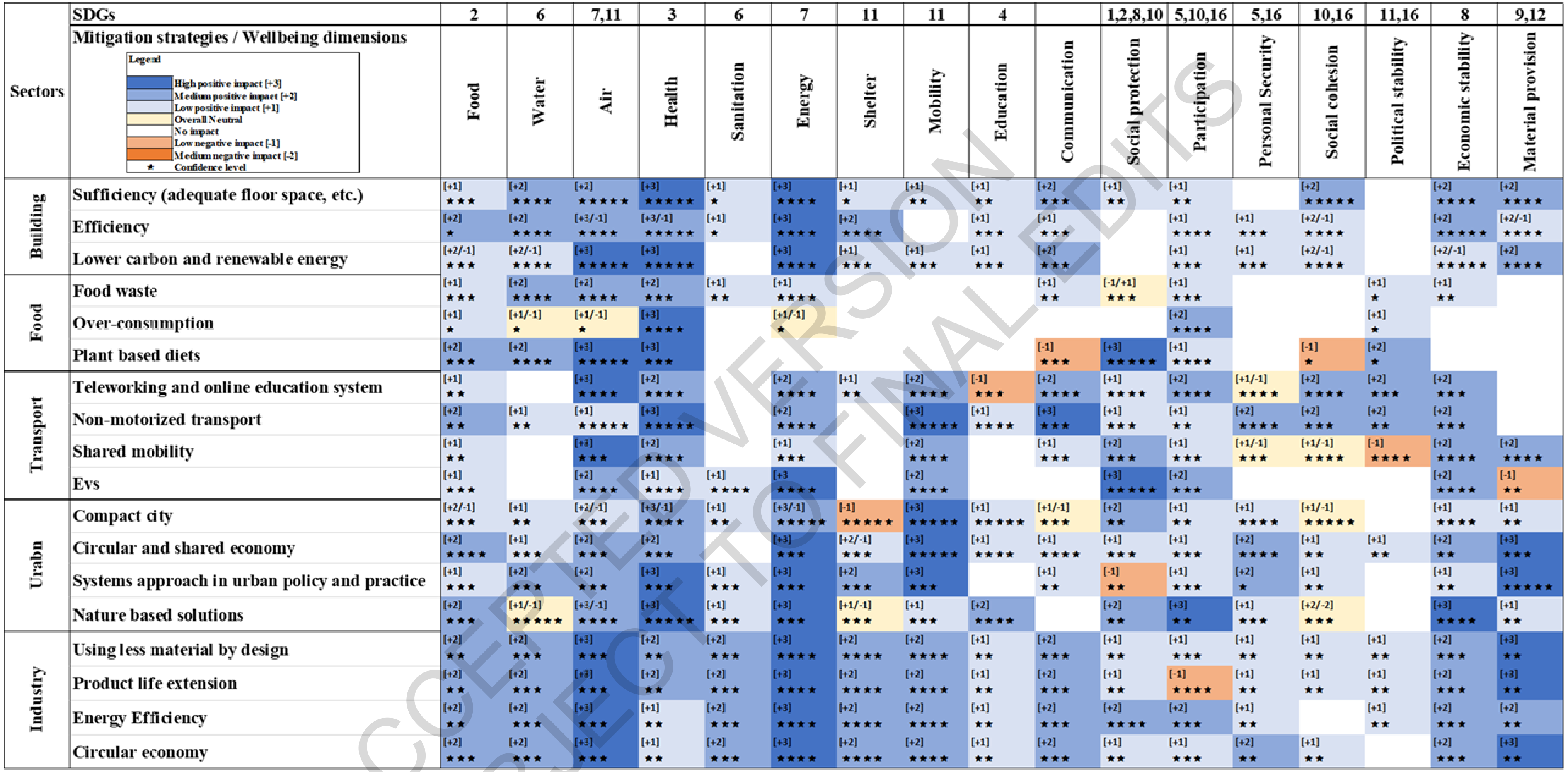
Policies designed to foster higher well-being for all via climate mitigation include reducing emissions through wider participation in climate action, building more effective governance for improved mitigation, and including social trust, greater equity, and informal-sector support as integral parts of climate policies. Public participation facilitates social learning and people's support of and engagement with climate change priorities; improved governance is closely tied to effective climate policies (Phuong et al. 2017). 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, centralised or decentralised (Tanner et al. 2009; Lorenz 2013; Chu 2015; Cloutier et al. 2015; Mitchell 2015; Martin and Shaheen 2016; Vandeweerdt et al. 2016; Turnheim et al. 2018). Morover, these factors are the ones identified as enablers of high need satisfaction at lower energy use (Vogel et al. 2021).

There is less policy lock-in in more equitable societies (Seto et al. 2016). 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 prioritised (Klinsky and Winkler 2014). Thus, there is high confidence in the literature that addressing inequities in income, wealth, and DLS not only raises overall well-being and furthers the SDGs but also improves the effectiveness of climate change mitigation policies. For example, 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). At all scales of governance, the popularity and sustainability of climate policies requires attention to the fairness of their health and economic implications for all, and participatory engagement across social groups – a responsible development framing (Cazorla and Toman 2001; Dulal et al. 2009; Chuku 2010; Shonkoff et al. 2011; Navroz 2019; Hofstad and Vedeld 2020; Muttitt and Kartha 2020; Waller et al. 2020; Roy and Schaffartzik 2020; Temper et al. 2020). Far from being secondary or even a distraction from climate mitigation priorities, an equity focus is intertwined with mitigation goals (Klinsky et al. 2016). Demand-side climate mitigation options have pervasive ancillary, equity-enhancing benefits, e.g. for health, local livelihoods, and community forest resources (Figure 5.6) (Chhatre and Agrawal 2009; Garg 2011; Shaw et al. 2014; Serrao-Neumann et al. 2015; Klausbruckner et al. 2016; Salas and Jha 2019). Limiting climate change risks is fundamental to collective well-being (Max-Neef et al. 1989; Yamin et al. 2005; Nelson et al. 2013; Pecl et al. 2017; Tschakert et al. 2017; Gough 2015, 2017). Section 5.6 discusses well-designed climate policies more fully, with examples. Rapid changes in social norms which are underway and which underlie socially-acceptable climate policy initiatives are discussed in section 5.4.

The distinction between necessities and luxuries helps to frame a growing stream of social sciences literature with climate policy relevance (Arrow et al. 2004; Ramakrishnan and Creutzig 2021). Given growing public support worldwide for strong sustainability, sufficiency, and sustainable consumption, changing demand patterns and reduced demand are accompanying environmental and social benefits (Jackson 2008; Fedrigo et al. 2010; Schroeder 2013; Figge et al. 2014; Spangenberg and Germany 2016; Spengler 2016; Mont et al. 2020; Burke 2020). Beyond a threshold, increased material consumption is not closely correlated with improvements in human progress (Kahneman and Deaton 2010; Vita et al. 2019b, 2020; Frank 1999; Steinberger and Roberts 2010; Oishi et al. 2018; Xie et al. 2018; Wang et al. 2019; Roy et al. 2012). Policies focusing on the "super-rich," also called the "polluter elite," are gaining attention for moral or norms-based as well as emissions-control reasons (Kenner 2019; Pascale et al. 2020; Stratford 2020; Otto et al. 2019) (see Section 5.2.2.3). 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 (Brand and Boardman 2008; Brand and

Preston 2010; Gore 2015; Sahakian 2018; Osuoka and Haruna 2019; Lynch et al. 2019; Roy and Pal 2009; Hubacek et al. 2017; Jorgenson et al. 2017; Gössling 2019; Kenner 2019; Roy et al. 2012).

Since no country now meets its citizens' basic needs at a level of resource use that is globally sustainable, while high levels of life satisfaction for those just escaping extreme poverty require even more resources, the need for transformative shifts in governance and policies is large (O'Neill et al. 2018; Vogel et al. 2021).



Legend

- 🟦 High positive impact [+3]
- 🟦 Medium positive impact [+2]
- 🟦 Low positive impact [+1]
- 🟨 Overall Neutral
- ⬜ No impact
- 🟧 Low negative impact [-1]
- 🟧 Medium negative impact [-2]
- ★ Confidence level

Sectors	SDGs	2	6	7,11	3	6	7	11	11	4		1,2,8,10	5,10,16	5,16	10,16	11,16	8	9,12
	Mitigation strategies / Wellbeing dimensions	Food	Water	Air	Health	Sanitation	Energy	Shelter	Mobility	Education	Communication	Social protection	Participation	Personal Security	Social cohesion	Political stability	Economic stability	Material provision
Building	Sufficiency (adequate floor space, etc.)	[+1] ★★★	[+2] ★★★★	[+2] ★★★★★	[+3] ★★★★★	[+1] ★	[+3] ★★★★	[+1] ★	[+1] ★★	[+1] ★★	[+2] ★★★	[+1] ★★	[+1] ★★		[+2] ★★★★★		[+2] ★★★★	[+2] ★★★★
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	Lower carbon and renewable energy	[+2/-1] ★★★	[+2/-1] ★★★★	[+3] ★★★★★	[+3] ★★★★★		[+3] ★★★★	[+1] ★★★	[+1] ★★★	[+1] ★★★	[+2] ★★★		[+1] ★★★	[+1] ★★★	[+2/-1] ★★★★		[+2/-1] ★★★★★	[+2] ★★★★
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Transport	Teleworking and online education system	[+1] ★★		[+3] ★★★★	[+2] ★★★★		[+2] ★★★★	[+1] ★★	[+2] ★★★★	[-1] ★★★	[+2] ★★★★	[+1] ★★★★	[+2] ★★★★	[+1/-1] ★★★★	[+2] ★★★★	[+2] ★★★	[+2] ★★★	
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	Evs	[+1] ★★★		[+2] ★★★★	[+1] ★★★★	[+1] ★★★★	[+3 ★★★★		[+2] ★★★★			[+3] ★★★★★	[+2] ★★★				[+2] ★★★★	[-1] ★★
Urabn	Compact city	[+2/-1] ★★★	[+1] ★★	[+2/-1] ★★★	[+3/-1] ★★★★	[+1] ★★	[+3/-1] ★★★★★	[-1] ★★★★★	[+3] ★★★★★	[+1] ★★★★★	[+1/-1] ★★★	[+2] ★★	[+1] ★★	[+1] ★★★★	[+1/-1] ★★★★★		[+1] ★★★★	[+1] ★★
	Circular and shared economy	[+2] ★★★★	[+1] ★★★	[+2] ★★★	[+2] ★★★		[+3] ★★★	[+2/-1] ★★★	[+3] ★★★★★	[+1] ★★★★	[+1] ★★★★	[+1] ★★★	[+1] ★★★	[+2] ★★★★	[+1] ★★	[+1] ★★	[+2] ★★	[+3] ★★★
	Systems approach in urban policy and practice	[+1] ★★★	[+2] ★★★	[+2] ★★★	[+3] ★★★	[+1] ★★★	[+3] ★★★	[+2] ★★★	[+3] ★★★		[+1] ★★	[-1] ★★	[+1] ★★★	[+2] ★	[+1] ★★		[+1] ★★	[+3] ★★★★★
	Nature based solutions	[+2] ★★★	[+1/-1] ★★★★★	[+3/-1] ★★★★	[+3] ★★★★★	[+1] ★★★	[+3] ★★★	[+1/-1] ★★★	[+1] ★★★	[+2] ★★★★		[+2] ★★	[+3] ★★	[+1] ★★★	[+2/-2] ★★★		[+3] ★★★★	[+1] ★★
Industry	Using less material by design	[+2] ★★	[+2] ★★★	[+3] ★★★	[+2] ★★	[+2] ★★★	[+3] ★★★★	[+2] ★★★★	[+2] ★★★★	[+1] ★★	[+2] ★★★	[+1] ★★	[+1] ★★★	[+1] ★★	[+1] ★★	[+1] ★★	[+2] ★★★	[+3] ★★
	Product life extension	[+2] ★★	[+2] ★★★	[+3] ★★★	[+2] ★★	[+2] ★★★	[+3] ★★★★	[+2] ★★★★	[+2] ★★★★	[+1] ★★	[+2] ★★★	[+1] ★★	[-1] ★★★★	[+1] ★★	[+1] ★★	[+1] ★★	[+2] ★★★	[+3] ★★
	Energy Efficiency	[+2] ★★	[+2] ★★★	[+3] ★★★	[+1] ★★	[+2] ★★★	[+3] ★★★★	[+2] ★★★★	[+2] ★★★★	[+1] ★★	[+2] ★★★	[+2] ★★★★	[+2] ★★★	[+1] ★★		[+1] ★★	[+2] ★★★	[+2] ★★
	Circular economy	[+2] ★★★	[+2] ★★★	[+3] ★★★	[+1] ★★	[+2] ★★★	[+3] ★★★★	[+2] ★★★★	[+2] ★★★★	[+1] ★★	[+2] ★★★	[+1] ★★	[+1] ★★★	[+2] ★★	[+1] ★★		[+2] ★★★	[+3] ★★

Figure 5.6 Two-way link between demand-side climate mitigation strategies and multiple dimensions of human well-being and SDGs. All demand-side mitigation strategies improve well-being in sum, though not necessarily in each individual dimension. Incumbent business (in contrast to overall economic performance) may be challenged.

Source: Creutzig et al. 2021b

Inequitable societies use energy and resources less efficiently. Higher income inequality is associated with higher carbon emissions, at least in developed countries (Grunewald et al. 2011; Golley and Meng 2012; Chancel et al. 2015; Grunewald et al. 2017; Jorgenson et al. 2017; Sager 2017; Klasen 2018; Liu et al. 2019); reducing inequality in high-income countries helps to reduce emissions (Klasen 2018). There is high agreement in the literature that alienation or distrust weakens collective governance and fragments political approaches towards climate action (Smit and Pilifosova 2001; Adger et al. 2003; Hammar and Jagers 2007; Van Vossole 2012; Bulkeley and Newell 2015; Smith and Howe 2015; ISSC et al. 2016; Smith and Mayer 2018; Fairbrother et al. 2019; Kulin and Johansson Sevä 2019; Liao et al. 2019; Alvaredo et al. 2018; Hayward and Roy 2019).

Populism and politics of fear are less prevalent under conditions of more income equality (Chevigny 2003; Bryson and Rauwolf 2016; O'Connor 2017; Fraune and Knodt 2018; Myrick and Evans Comfort 2019). Ideology and other social factors also play a role in populist climate scepticism, but many of these also relate to resentment of elites and desire for engagement (Swyngedouw 2011; Lockwood 2018; Huber et al. 2020). "Climate populism" movements are driven by an impetus for justice (Beeson 2019; Hilson 2019). When people feel powerless and/or that climate change is too big a problem to solve because others are not acting, they may take less action themselves (Williams and Jaftha 2020). However, systems for benefit-sharing can build trust and address large-scale "commons dilemmas", in the context of strong civil society (Barnett 2003; Mearns and Norton 2009; Inderberg et al. 2015; Sovacool et al. 2015; Hunsberger et al. 2017; Soliev and Theesfeld 2020). Leadership is also important in fostering environmentally-responsible group behaviours (Liu and Hao 2020).
In some less-developed countries, higher income inequality may in fact be associated with lower per capita emissions, but this is because people who are excluded by poverty from access to fossil fuels must rely on biomass (Klasen 2018). Such energy poverty – the fact that millions of people do not have access to energy sources to help meet human needs – implies the opposite of development (Guruswamy 2010, 2020). In developing countries, livelihood improvements do not necessarily cause increases in emissions (Peters et al. 2012; Reusser et al. 2013; Creutzig et al. 2015a; Chhatre and Agrawal 2009; Baltruszewicz et al. 2021) and poverty alleviation causes negligible emissions (Chakravarty et al. 2009). Greater equity is an important step towards sustainable service provisioning (Godfray et al. 2018; Dorling 2019; Timko 2019).

As discussed in Section 5.6, policies to assist the low-carbon energy transition can be designed to include additional benefits for income equality, besides contributing to greater energy access for the poor (Burke and Stephens 2017; Frank 2017; Healy and Barry 2017; Sen 2017; Chapman et al. 2018; La Viña et al. 2018; Chapman and Fraser 2019; Piggot et al. 2019; Sunderland et al. 2020). 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) (see Box 5.4).

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 (Mulder et al. 2006; Harriss and Shui 2010; Grinde et al. 2018; Spangenberg and Lorek 2019; Figge et al. 2014; Vita et al. 2020). Less waste, better emissions control and more effective carbon policies lead to better governance and stronger democracies. Systems-dynamics models linking strong emissions-reducing policies and strong social equity policies show that a low-carbon transition in conjunction with social sustainability is possible, even without economic growth (Kallis et al. 2012; Jackson and Victor 2016; Stuart et al. 2017; S. D'alessandro et al. 2019; Huang et al. 2019; Victor 2019; Chapman and Fraser 2019; Gabriel and Bond 2019). Such degrowth pathways may be crucial in combining technical feasibility of mitigation with social development goals (Hickel et al. 2021; Keyßer and Lenzen 2021).

Multi-level or polycentric governance can enhance well-being and improve climate governance and social resilience, due to varying adaptive, flexible policy interventions at different times and scales (Kern and Bulkeley 2009; Lidskog and Elander 2009; Amundsen et al. 2010; Keskitalo 2010; Lee and Koski 2015; Jokinen et al. 2016; Lepeley 2017; Marquardt 2017; Di Gregorio et al. 2019). Institutional transformation may also result from socio-ecological stresses that accompany climate change, leading to more effective governance structures (David Tàbara et al. 2018; Patterson and Huitema 2019; Barnes et al. 2020). An appropriate, context-specific mix of options facilitated by policies can deliver both higher well-being and reduced disparity in access to basic needs for services concurrently with climate mitigation (Thomas and Twyman 2005; Klinsky and Winkler 2014; Lamb et al. 2014; Mearns and Norton 2009; Lamb and Steinberger 2017). Hence, nurturing equitable human well-being through provision of decent living standards for all goes hand in hand with climate change mitigation (ISSC et al. 2016; OECD 2019a). There is *high confidence* in the literature that addressing inequities in income, wealth, and DLS not only raises overall well-being and furthers the SDGs but also improves the effectiveness of climate change mitigation policies.

Participatory governance involves understanding and engagement with policies, including climate policies. Greater public participation in climate policy processes and governance, by increasing the diversity of ideas and stakeholders, builds resilience and allows broader societal transformation towards systemic change even in complex, dynamic and contested contexts (Dombrowski 2010; Wise et al. 2014; Haque et al. 2015; Jodoin et al. 2015; Mitchell 2015; Kaiser 2020; Alegria 2021). This sometimes involves complex policy discussions that can lead to governance innovations, also influencing social norms (Martinez 2020). A specific example are citizen assemblies, deliberating public policy challenges, such as climate change (Devaney et al. 2020). Activist climate movements are changing policies as well as normative values (see Section 5.4 and the Social Science Primer). Environmental justice and climate justice activists worldwide have called attention to the links between economic and environmental inequities, collected and publicised data about them, and demanded stronger mitigation (Goodman 2009; Schlosberg and Collins 2014; Jafry et al. 2019; Cheon 2020). Youth climate activists, and Indigenous leaders, are also exerting growing political influence towards mitigation (Helferty and Clarke 2009; White 2011; Powless 2012; Petheram et al. 2015; Curnow and Gross 2016; Grady-Benson and Sarathy 2016; Claeys and Delgado Pugley 2017; UN 2015; O'Brien et al. 2018; Rowlands and Gomez Peña 2019; Bergmann and Ossewaarde 2020; Han and Ahn 2020; Nkrumah 2021). Indigenous resurgence (activism fuelled by ongoing colonial social / environmental injustices, land claims, and deep spiritual/cultural commitment to environmental protection) not only strengthens climate leadership in many countries, but also changes broad social norms by raising knowledge of Indigenous governance systems which supported sustainable lifeways over thousands of years (Wildcat 2014; Chanza and De Wit 2016; Whyte 2018, 2017; Temper et al. 2020). Related trends include recognition of the value of traditional ecological knowledge, Indigenous governance principles, decentralisation, and appropriate technologies (Lange et al. 2007; Goldthau 2014; Whyte 2017).

Social trust aids policy implementation. More equal societies display higher trust, which is a key requirement for successful implementation of climate policies (Rothstein and Teorell 2008; Carattini et al. 2015; Klenert et al. 2018; Patterson et al. 2018). Inter-personal trust among citizens often promotes pro-environment behaviour by influencing perceptions (Harring and Jagers 2013), enhancing cooperation, and reducing free-riding and opportunistic behaviour (Gür 2020). Individual support for carbon taxes and energy innovations falls when collective community support is lacking (Bolsen et al. 2014; Simon 2020; Smith and Mayer 2018). Social trust has a positive influence on civic engagement among local communities, NGOs, and self-help groups for local clean cooking fuel installation (Nayak et al. 2015).

Section 5.6 includes examples of climate mitigation policies and policy packages which address the interrelationships shown in Figure 5.5. Improving well-being for all through climate mitigation includes emissions-reduction goals in policy packages that ensure equitable outcomes, prioritize social trust-building, support wide public participation in climate action including within the informal sector, and facilitate institutional change for effective multi-level governance, as integral components of climate strategies. This strategic approach, and its feasibility of success, rely on complex contextual factors that may differ widely, especially between Global North and Global South (Atteridge et al. 2012; Patterson et al. 2018; Jewell and Cherp 2020; Singh et al. 2020, 2021).

START BOX 5.4 HERE

Box 5.4 Gender, race, intersectionality and climate mitigation

There is *high evidence* and *high agreement* that empowering women benefits both mitigation and adaptation, because women prioritise climate change in their voting, purchasing, community leadership, and work both professionally and at home (*high evidence*, *high agreement*). Increasing voice and agency for those marginalised in intersectional ways by Indigeneity, race, ethnicity, dis/ability, and other factors has positive effects for climate policy (*high evidence, high agreement*).

Climate change affects people differently along all measures of difference and identity, which have intersectional impacts linked to economic vulnerability and marginalisation (Morello Frosch et al. 2009; Dankelman 2010; Habtezion 2013; Godfrey and Torres 2016; Walsh 2016; Flatø et al. 2017; Goodrich et al. 2019; Perkins 2019; Gür 2020). Worldwide, racialized and Indigenous people bear the brunt of environmental and climate injustices through geographic location in extraction and energy "sacrifice zones", areas most impacted by extreme weather events, and/or through inequitable energy access (Aubrey 2019; Gonzalez 2020; Lacey-Barnacle et al. 2020; Porter et al. 2020; Temper et al. 2020; Jafry et al. 2019) Disparities in climate change vulnerability not only reflect pre-existing inequalities, they also reinforce them. For example, inequities in income and in the ownership and control of household assets, familial responsibilities due to male out-migration, declining food and water access, and increased disaster exposure can undermine women's ability to achieve economic independence, enhance human capital, and maintain physical and mental health and well-being (Chandra et al. 2017; Eastin 2018; Das et al. 2019). Studies during the COVID crisis have found that, in general, women's economic and productive lives have been affected disproportionately to men's (Alon et al. 2020; ILO 2020). Women have less access to social protections and their capacity to absorb economic shocks is very low, so they face a "triple burden" during crises -- including those resulting from climate change -- and this is heightened for women in the less-developed countries and for those who are intersectionally vulnerable (Coates et al. 2020; McLaren et al. 2020; Wenham et al. 2020; Azong and Kelso 2021; Erwin et al. 2021; Maobe and Atela 2021; Nicoson 2021; Sultana 2021; Versey 2021). Because men currently hold the majority of energy-sector jobs, energy transition will impact them economically and psychologically; benefits, burdens and opportunities on both the demand and supply sides of the mitigation transition have a range of equity implications (Pearl-Martinez and Stephens 2017; Standal et al. 2020; Mang-Benza 2021). Mitigating gendered climate impacts requires addressing inequitable power relations throughout society(Wester and Lama 2019).

Women's well-being and gender-responsive climate policy have been emphasized in international agreements including the Paris accord (UNFCCC 2015), CEDAW General Recommendation 37 (Vijeyarasa 2021), and the 2016 Decision 21/CP.22 on Gender and Climate Change (UNFCCC 2016; Larson et al. 2018). Increasing the participation of women and marginalised social groups, and addressing their special needs, helps to meet a range of SDGs, improve disaster and crisis response, increase social trust, and improve climate mitigation policy development and implementation (Alber

2009; Whyte 2014; Elnakat and Gomez 2015; Salehi et al. 2015; Buckingham and Kulcur 2017; Cohen 2017; Kronsell 2017; Lee and Zusman 2019).

Women have a key role in the changing energy economy due to their demand and end use of energy resources in socially-gendered productive roles in food production and processing, health, care, education, clothing purchases and maintenance, commerce, and other work both within and beyond the home (Räty and Carlsson-Kanyama 2009; Oparaocha and Dutta 2011; Bob and Babugura 2014; Macgregor 2014; Perez et al. 2015; Bradshaw 2018; Clancy and Feenstra 2019; Clancy et al. 2019; Fortnam et al. 2019; Rao et al. 2019a; Quandt 2019; Horen Greenford et al. 2020; Johnson 2020). Women's work and decision-making are central in the food chain and agricultural output in most developing countries, and in household management everywhere. Emissions from cooking fuels can cause serious health damages, and unsustainable extraction of biofuels can also hurt mitigation (Bailis et al. 2015), so considering health, biodiversity and climate tr adeoffs and co-benefits is important (Rosenthal et al. 2018; Aberilla et al. 2020; Mazorra et al. 2020) . Policies on energy use and consumption are often focused on technical issues related to energy supply, thereby overlooking 'demand-side' factors such as household decision-making, unpaid work, livelihoods and care (Himmelweit 2002; Perch 2011; Fumo 2014; Hans et al. 2019; Huyer and Partey 2020). Such gender-blindness represents the manifestation of wider issues related to political ideology, culture and tradition (Carr and Thompson 2014; Thoyre 2020; Perez et al. 2015; Fortnam et al. 2019).

Women, and all those who are economically and/or politically marginalised, often have less access to energy and use less, not just because they may be poorer but case studies show because their consumption choices are more ecologically-inclined and their energy use is more efficient (Lee et al. 2013; Permana et al. 2015; Li et al. 2019). 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 (Isenhour and Ardenfors 2009; Räty and Carlsson-Kanyama 2010; Barnett et al. 2012; Medina and Toledo-Bruno 2016; Ahmad et al. 2017; Fernström Nåtby and Rönnerfalk 2018; Räty and Carlsson-Kanyama 2009; Li et al. 2019). 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). Also, advances in female education and reproductive health, especially voluntary family planning, can contribute greatly to reducing world population growth (Abel et al. 2016; Dodson et al. 2020).

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). While most people recognize that climate change is happening (Lewis et al. 2018; Ballew et al. 2019), climate denialism is more prevalent among men (McCright and Dunlap 2011; Anshelm and Hultman 2014; Jylhä et al. 2016; Nagel 2015), while women are more likely to be environmental activists, and to support stronger environmental and climate policies (Stein 2004; McCright and Xiao 2014, Whyte 2014). Racialised groups are more likely to be concerned about climate change and to take political action to support climate mitigation policies (Leiserowitz and Akerlof 2010; Schuldt and Pearson 2016; Pearson et al. 2017; Ballew et al. 2020; Godfrey and Torres 2016; Johnson 2020). This underscores the important synergies between equity and mitigation. The contributions of women, racialised 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 (Dankelman and Jansen 2010; Wickramasinghe 2015; Black 2016; Vinyeta et al. 2016; Pearse 2017). Equitable power, participation, and agency in climate policy-making is hence an effective contribution for improving governance and decision making on climate change mitigation (Reckien et al. 2017; Collins 2019). Indigenous knowledge is an important source of guidance for biodiversity conservation, impact assessment, governance, disaster preparedness and resilience (Salick and Ross 2009; Green and Raygorodetsky

2010; Speranza et al. 2010; Mekuriaw Bizuneh 2013; Mekuriaw 2017), and women are often the local educators, passing on and utilising traditional and Indigenous knowledge (Ketlhoilwe 2013; Onyige 2017; Azong et al. 2018).

Higher female political participation, controlled for other factors, leads to higher stringency in climate policies, and results in lower GHG emissions (Cook et al. 2019). Gender equity also is correlated with lower per capita CO_2-eq emissions (Ergas and York 2012). 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 militarisation, and more emphasis on equity and social policies e.g. via wealth and capital gains taxes (Resurrección 2013; UNEP 2013; Glemarec et al. 2016; Bryan et al. 2018; Crawford 2019; Ergas and York 2012). Changing social norms on race and climate are linked and policy-relevant (Benegal 2018; Elias et al. 2018; Slocum 2018; Gach 2019; Wallace-Wells 2019; Temple 2020; Drolet 2021). For all these reasons, climate policies are strengthened by including more differently-situated knowledge and diverse perspectives, such as feminist expertise in the study of power (Bell et al. 2020a; Lieu et al. 2020); clarifying equity goals (e.g. distinguishing among 'reach, 'benefit', and 'empowerment'; obtaining disaggregated data and using clear empirical equity measures; and confronting deeply-engrained inequities in society (Lau et al. 2021). Inclusivity in climate governance spans mitigation-adaptation, supply-demand and formal-informal sector boundaries in its positive effects (Morello Frosch et al. 2009; Dankelman 2010; Bryan and Behrman 2013; Habtezion 2013; Godfrey and Torres 2016; Walsh 2016; Flatø et al. 2017; Wilson et al. 2018; Goodrich et al. 2019; Perkins 2019; Bell et al. 2020b; Gür 2020).

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5.3 Mapping the opportunity space

Reducing global energy demand and resource inputs while improving well-being for all requires an identification of options, services and pathways that do not compromise essentials of a decent living. To identify such a solution space, this section summarises socio-cultural, technological and infrastructural interventions through the avoid/shift/improve (ASI) concept. ASI (see Section 5.1) provides a categorisation of options aimed at continuously eliminating wastes in the current systems of service provision (see Section 5.3.1.1). It also concisely presents demand side options to reduce GHG emissions by individual choices which can be leveraged by supporting policies, technologies and infrastructure. Two key concepts for evaluating the efficiency of service provision systems are: 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 (see Section 5.3.2) and higher well-being levels. They typically focus on end-use conversion and service delivery improvements as the most influential opportunities for system-wide waste reductions. Review of the state of modelling low energy and resource demand pathways in long-term climate mitigation scenarios (recognising the importance of such scenarios for illuminating technology and policy pathways for more efficient service provision) and summary of the mitigation potentials estimated from relevant scenarios to date are in Section 5.3.3. Finally, it reviews the role of three megatrends that are transforming delivery of the services in innovative ways – digitalisation, the sharing economy, and the circular economy (see Section 5.3.4). The review of megatrends 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, avoiding undesirable outcomes.

5.3.1 Efficient service provision

This section organises demand reductions under the ASI framework. It presents service-oriented demand-side solutions consistent with decent living standards (Table 5.1) (Creutzig et al. 2018). The sharing economy, digitalisation, 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 digitalisation tentatively more on the demand side (see Section 5.3.4). 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 realised in the short term, such as energy access, while others may take a longer period, such as radical and systemic eco-innovations like shared electric autonomous vehicles. It is important to understand benefits and distributional impacts of these systemic changes.

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

Assessment of service-related mitigation options within the ASI framework is aided by decomposition of emissions intensities into explanatory contributing factors, which depend on the type of service delivered. Table 5.1 shows ASI options in selected sectors and services. It summarises resource, energy, and emissions intensities commonly used by type of service (Cuenot et al. 2010; Lucon et al. 2014; Fischedick et al. 2014). Also relevant: the concepts of service provision adequacy (Arrow et al. 2004; Samadi et al. 2017), 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) (Millward-Hopkins et al. 2020); and service level efficiency (e.g., effect of occupancy on the energy intensity of public transit passenger-km travelled (Schäfer and Yeh 2020). Service-oriented solutions in this chapter are discussed in the context of Table 5.1. Implementation of these solutions requires combinations of institutional, infrastructural, behavioural, socio-cultural, and business changes that are mentioned in Section 5.2 and discussed in Section 5.4.

Table 5.1 Avoid-Shift-Improve options in selected sectors and services. Many options, such as urban form and infrastructures are systemic, and influence several sectors simultaneously. Linkages to concepts presented in sectoral chapters are indicated in parentheses in the first column.

Source: adapted from Creutzig at al. 2018

Service	Emission decomposition factors	Avoid	Shift	Improve
Mobility [passenger-km] *(Ch 8,10, 11,16)*	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 Fewer long-haul flights Local holidays	**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] *(Ch 8,9, 11)*	kg CO_2 = (square meters)*(tons material m^{-2})*(kg CO_2 ton material^{-1})	**Innovative dwellings to reduce square meters:** Smaller decent dwellings	**Material efficient housing tons material m^{-2}:** Less material-intensive dwelling designs	**Low emission dwelling design kgCO_2 ton^{-1} material:** Use wood as material

		Shared common spaces Multigenerational housing	Shift from single-family to multi-family dwellings	Use low-carbon production processes for building materials (e.g., cement and steel)
Thermal comfort [indoor temperature] *(Ch 9,16)*	kg CO_2 = (Δ°C m^3 to warm or cool) (MJ m^{-3})*(kg CO_2 MJ^{-1})	**Choice of healthy indoor temperature Δ°C m^3:** Reduce m^2 as above Change temperature set-points Change dressing code Change working times	**Design options to reduce MJ Δ°C^{-1} m^{-3}:** Architectural design (shading, natural ventilation, etc.)	**New technologies to reduce MJ Δ°C^{-1} m^{-3} and kgCO_2/MJ:** Solar thermal devices Improved insulation Heat pumps District heating
Goods [units] *(Ch 11,12)*	kg CO_2 = product units * (kg material $product^{-1}$)*(kg CO_2 kg $material^{-1}$)	**More service per product:** Reduce consumption quantities Long lasting fabric, appliances Sharing economy	**Innovative product design kg material product $^{-1}$:** 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
Nutrition [Calories consumed] *(Ch 6,12)*	kg CO_2-eq = (calories consumed)*(calories produced calories $consumed^{-1}$)*(kg CO_2-eq calorie $produced^{-1}$)	**Reduce calories produced/calories consumed and optimize calories consumed:** Keep calories in line with daily needs and health guidelines Reduce waste in supply chain and after purchase	**Add more variety in food plate to reduce kg CO_2-eq cal^{-1} produced** Dietary shifts from ruminant meat and dairy to other protein sources while maintaining nutritional quality	**Reduce kg CO_2-eq cal^{-1} produced:** Improved agricultural practices Energy efficient food processing
Lighting [lumens] *(Ch 9, 16)*	kg CO_2 = lumens*(kWh $lumen^{-1}$)*(kg CO_2 kWh^{-1})	**Minimize artificial lumen demand:** Occupancy sensors Lighting controls	**Design options to increase natural lumen supply:** Architectural designs with maximal daylighting	**Demand innovation lighting technologies kWh $lumens^{-1}$ and power supply kg CO_2 kWh^{-1}:** LED lamps

Opportunities for avoiding waste associated with the provision of services, or avoiding overprovision of or excess demand for services themselves, exist across multiple service categories. Avoid options are relevant in all end-use sectors, namely, teleworking and avoiding long-haul flights, adjusting dwelling size to household size, avoiding short life span product, and food waste. Cities and built environments can play an additional role. For example, more compact designs and higher accessibility reduce travel demand and translate into lower average floor space and corresponding heating/cooling and lighting demand, and thus between 5% to 20% of GHG emissions of end-use sectors (Creutzig et al. 2021b). Avoidance of food loss and wastage – which equalled 8–10% of total anthropogenic GHG emissions from 2010-2016 (Mbow et al. 2019), while millions suffer from hunger and malnutrition – is a prime example (see Chapter 12). A key challenge in meeting global nutrition services is therefore to avoid food loss and waste while simultaneously raising nutrition levels to equitable standards globally. Literature results indicate that in developed economies 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. 2017) and improved preservation in supply chains would reduce spoilage (Duncan and Gulbahar 2019). ~931 million tons of food waste was generated in 2019 globally, 61% of which came from households, 26% from food service and 13% from retail.

Demand side mitigations are achieved through changing ***S**ocio-cultural factors*, ***I**nfrastructure use* and ***T**echnology adoption* by various social actors in urban and other settlements, food choice and waste management (*high confidence*) (Figure 5.7). In all sectors, end-use strategies can help reduce the majority of emissions, ranging from 28.7% (4.13 $GtCO_2$-eq) emission reductions in the industry sector, to 44.2% (7.96 $GtCO_2$-eq) in the food sectors, to 66.75% (4.671 $GtCO_2$-eq) emission reductions in the land transport sector, and 66% (5.763 $GtCO_2$-eq) in the buildings sector. These numbers are median estimates and represent benchmark accounting. Estimates are approximations, as they are simple products of individual assessments for each of the three *SIT* options. If interactions were taken into account, the full mitigation potentials may be higher or lower, independent of relevant barriers to realizing the median potential estimates. See more in Supplementary Material II Chapter 5, Table SM2.

The technical mitigation potential of food loss and waste reductions globally has been estimated at 0.1-5.8 $GtCO_2$-eq (*high confidence*) (Poore and Nemecek 2018; Smith, et al. 2019) (Figure 5.7, 7.4.5, Table 12.3). 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. The estimated technical potential for GHG emissions reductions associated with shifts to sustainable healthy diets is 0.5-8 $GtCO_2$-eq (Smith et al. 2013; Jarmul et al. 2020; Creutzig et al. 2021b) (Figure 5.7, Table 12.2) (*high confidence*). Current literature on health, diets, and emissions indicates that sustainable food systems providing healthy diets for all are within reach but require significant cross-sectoral action, including improved agricultural practices, dietary shifts among consumers, and food waste reductions in production, distribution, retail, and consumption (Table 12.9) (Erb et al. 2016; Muller et al. 2017; Willett and al. 2018; Graça et al. 2019).

Reduced food waste and dietary shifts have highly relevant repercussions in the land use sector that underpin the high GHG emission reduction potential. Demand side measure lead to changes in consumption of land-based resources and can save GHG emissions by reducing or improving management of residues or making land areas available for other uses such as afforestation or bioenergy production (Smith et al. 2013; Hoegh-Guldberg et al. 2019). Deforestation is the second largest source of anthropogenic greenhouse gas emissions, caused mainly by expanding forestry and agriculture and in many cases this agricultural expansion is driven by trade demand for food e. g. across the tropics, cattle and oilseed products accounts for half of the resulted deforestation carbon-emissions, embodied in international trade to China and Europe (Creutzig et al. 2019a; Pendrill et al. 2019). Benefits from shifts in diets and resulting lowered land pressure are also reflected in reductions of land degradation and improved.

Increased demand for biomass can increase the pressure on forest and conservation areas (Cowie et al. 2013) and poses an heightened risk for biodiversity, livelihoods, and intertemporal carbon balances (Creutzig et al. 2021c; Lamb et al. 2016) requiring policy and regulations to ensure sustainable forest management which depends on forest type, region, management, climate, and ownership. This suggests that demand-side actions hold sustainability advantages over the intensive use of bioenergy and BECCS, but also enable land use for bioenergy by saving agricultural land for food.

In the transport sector, ASI opportunities exist at multiple levels, comprehensively summarised in Bongardt et al (2013), Roy et al (2021) and Sims et al (2014) (Chapter 10). Modelling based on a plethora of bottom-up insights and options reveals that a balanced portfolio of ASI 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 digitalisation, but its savings depend heavily on the modes, distances, and types of office use avoided (Hook et al. 2020) and whether additional travel is induced due to greater available time (Mokhtarian 2002) or vehicle use by other household members (Kim et al. 2015; de Abreu e Silva and Melo 2018). 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; Wiedenhofer et al. 2018), or through avoiding long-haul flights (IEA 2021). For example, reallocating road and parking space to exclusive public transit lanes, protected bike lanes and pedestrian priority streets can reduce vehicle kilometres travelled in urban areas (ITF 2021). At the vehicle level, light weighting strategies (Fischedick et al. 2014) and 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 2019b).

Figure 5.7 shows Socio-cultural factors can contribute up to 15% to land transport GHG emissions reduction by 2050, with 5% as our central estimate. Active mobility, such as walking and cycling, has 2%-10% potential in GHG emissions reduction. Well-design teleworking and telecommuting policies can at least reduce transport related GHG emissions by 1%. A systematic review demonstrates that 26 of 39 studies identified suggest that teleworking reduces energy use, induced mainly by distance traveled, and only eight studies suggest that teleworking increases or has a neutral impact on energy use (Hook et al. 2020). Infrastructure use (specifically urban planning and shared pooled mobility) has about 20-50% (on average) potential in the land transport GHG emissions reduction, especially via redirecting the ongoing design of existing infrastructures in developing countries, and with 30% as our central estimate (see also 5.3.4.2). Technology adoption, particularly banning ICEs and 100% EV targets and efficient lightweight cars, can contribute to between 30 and 70% of GHG emissions reduction in land transport in 2050, with 50% as our central estimate. For details see Supplementary Material II Chapter 5, Table SM2 and Chapter 10.

Socio-cultural factors such avoid long-haul flights and shifting to train wherever possible can contribute between 10% and 40% to aviation GHG emissions reduction by 2050 (Figure 5.7). Maritime transport (shipping) emits around 940 $MtCO_2$ annually and is responsible for about 2.5% of global GHG emissions (IMO 2020). Technology measures and management measures, such as slow steaming, weather routing, contra-rotating propellers, and propulsion efficiency devices can deliver more fuel savings between 1% and 40% than the investment required (Bouman et al. 2017). For details see Supplementary Material II Chapter 5, Table SM2.

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 (Material Economics 2018; Pauliuk et al. 2021; Hertwich et al. 2019; IEA 2019b). Emerging strategies for materials efficiency, such as 3D printing to optimise the

geometries and minimise the materials content of structural elements, may also play a key role if thermal performance and circularity can be improved (Mahadevan et al. 2020; Adaloudis and Bonnin Roca 2021). Several scenarios estimate an 'avoid' potential in the building sector, which includes reducing waste in superfluous floor space, heating and IT equipment, and energy use, of between 10 and 30%, in one case even by 50% (Nadel, Steven and Ungar 2019). For details see Chapter 9.
Socio-cultural factors and behavioral and social practices in energy saving like adaptive hearing and cooling by changing temperature can contribute about 15% to Buildings GHG emissions reduction by 2050 (Figure 5.7). Infrastructure use such as compact city and urban planning interventions, living floor space rationalization, and access to low carbon architectural design has about 20% potential in the Buildings GHG emissions reduction. Technology adoption, particularly access to energy efficient technologies, and choice for installation of renewable can contribute between 30% and 70% to GHG emissions reeducation in Buildings sector. For details see Supplementary Material II Chapter 5, Table SM2 and Chapter 8 and 9 .

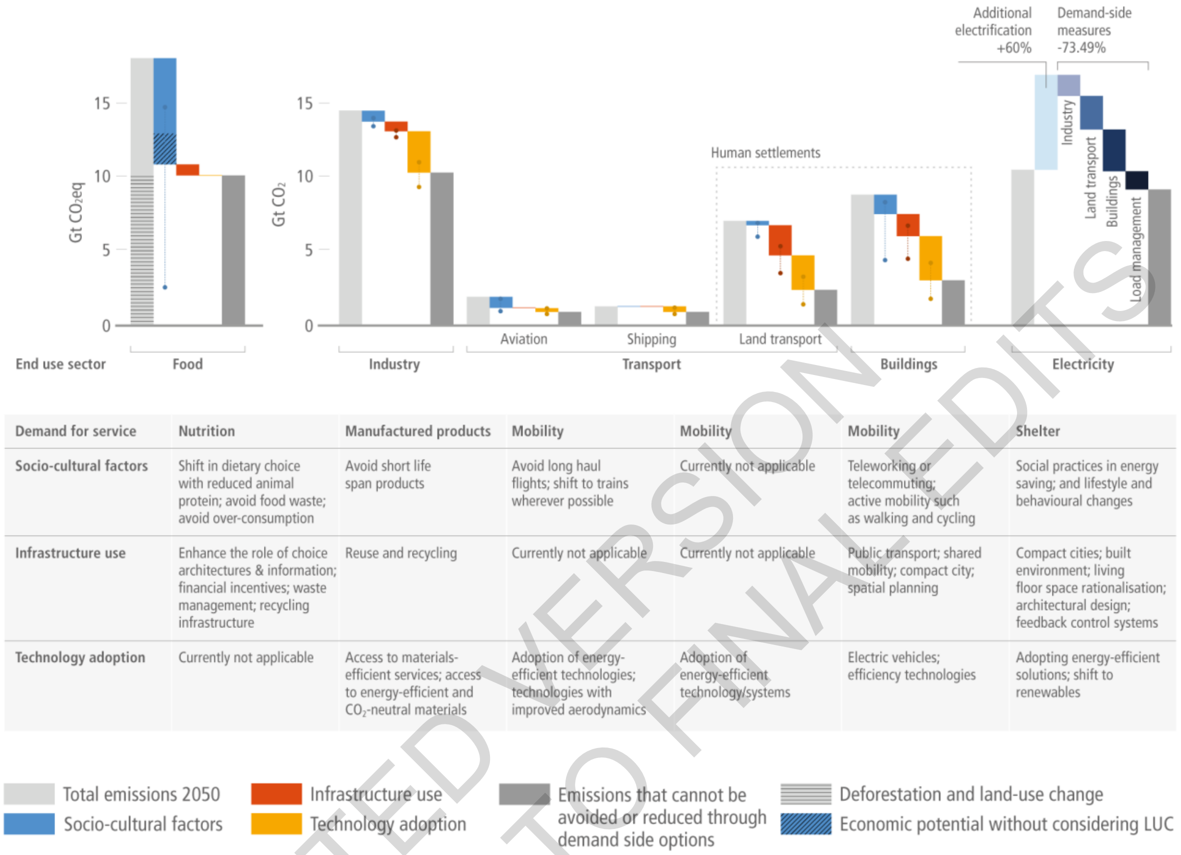
Service efficiency strategies are emerging to avoid materials demand at the product level, including dematerialisation strategies for various forms of packaging (Worrell and Van Sluisveld 2013) and the concept of "products as services," in which product systems are designed and maintained for long lifespans 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, consistent with circular economy and materials efficiency principles (see Chapter 11). Successful examples of this approach have been documented for carpets (Stubbs and Cocklin 2008), copiers (Roy 2000), kitchens (Liedtke et al. 1998), vehicles (Ceschin and Vezzoli 2010; Williams 2006) 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 (Ochsendorf et al. 2011)), 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 concrete 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; Brockway et al. 2021) as indicated in Figures 5.8, 5.12, and 5.13a, which must be carefully avoided through various regulatory and behavioural measures (Santarius et al. 2016) and in many developing country contexts rebound effects can help in accelerated provision of affordable access to modern energy and a minimum level of per capita energy consumption (Saunders et al. 2021; Chakravarty and Roy 2021). 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).

Avoid short life span products in favour of products with longer lifespan as a *socio-cultural factor*; *infrastructure use* such as increasing the re-usability and recyclability of product's components and materials; and adopting the materials-efficient services and CO_2-neutral materials have about 29% indicative potential by 2050. For details see Supplementary Material II Chapter 5, Table SM2 and Chapter 11.

In summary, sector specific demand side mitigation options reflect important role of socio-cultural, technological and infrastructural factors and interdependence among them (Figure 5.7). The assessment in Figure 5.7 shows by 2050 high emission reduction potential can be realised with demand side actions alone which can be complementary to supply side interventions with considerable impact by reducing need for capacity addition on the electricity supply system. Integrated cross sectoral actions shown through sector coupling is also important for investment decision making and policy framing going beyond sector boundaries (*high evidence and high agreement)*.



Demand for service	Nutrition	Manufactured products	Mobility	Mobility	Mobility	Shelter
Socio-cultural factors	Shift in dietary choice with reduced animal protein; avoid food waste; avoid over-consumption	Avoid short life span products	Avoid long haul flights; shift to trains wherever possible	Currently not applicable	Teleworking or telecommuting; active mobility such as walking and cycling	Social practices in energy saving; and lifestyle and behavioural changes
Infrastructure use	Enhance the role of choice architectures & information; financial incentives; waste management; recycling infrastructure	Reuse and recycling	Currently not applicable	Currently not applicable	Public transport; shared mobility; compact city; spatial planning	Compact cities; built environment; living floor space rationalisation; architectural design; feedback control systems
Technology adoption	Currently not applicable	Access to materials-efficient services; access to energy-efficient and CO_2-neutral materials	Adoption of energy-efficient technologies; technologies with improved aerodynamics	Adoption of energy-efficient technology/systems	Electric vehicles; efficiency technologies	Adopting energy-efficient solutions; shift to renewables

Figure 5.7 Demand-side mitigation options and indicative potentials

Mitigation response options related to demand for services have been categorised into three domains: 'socio-cultural factors', related to social norms, culture, and individual choices and behaviour; 'infrastructure use', related to the provision and use of supporting infrastructure that enables individual choices and behaviour; and 'technology adoption', which refers to the uptake of technologies by end users. Potentials in 2050 are estimated using the International Energy Agency's 2020 World Energy Outlook STEPS (Stated Policy Scenarios) as a baseline. This scenario is based on a sector-by-sector assessment of specific policies in place, as well as those that have been announced by countries by mid-2020. This scenario was selected due to the detailed representation of options across sectors and sub-sectors. The heights of the coloured columns represent the potentials on which there is a high level of agreement in the literature, based on a range of case studies. The range shown by the dots connected by dotted lines represents the highest and lowest potentials reported in the literature which have low to medium levels of agreement. The demand side potential of socio-cultural factor in food has two parts. Economic potential of demand reduction through socio-cultural factors alone is 1.9 $GtCO_2eq$ without considering LUC by diversion of agricultural land from food production to carbon sequestration purposes. If further changes in choice architectures and LUC due to this change in demand is considered indicative potential becomes 7 $GtCO_2eq$. The electricity panel presents separately the mitigation potential from changes in electricity demand associated with enhanced electrification in end use sectors. Electrification increases electricity demand, while it is avoided though demand-side mitigation strategies. Load management refers to demand side flexibility that can be achieved through incentive design like time of use pricing/monitoring by artificial intelligence, diversification of storage facilities etc. NZE (IEA Net Zero Emissions by 2050 Scenario) is used to compute the impact of end use sector electrification,

while the impact of demand side response options is based on bottom-up assessments. Dark grey columns show the emissions that cannot be avoided through demand-side mitigation options.

The table indicates which demand-side mitigation options are included. Options are categorised according to: socio-cultural factors, infrastructure use, and technology adoption.
(5.3, Supplementary Material 5.II)

5.3.1.2 Household consumption options to reduce GHG emissions

A systematic review of options to reduce the GHG emissions associated with household consumption activities identified 6990 peer-reviewed journal papers, with 771 options that were aggregated into 61 consumption option categories ((Ivanova et al. 2020); Figure 5.8). In consistence with previous research (Herendeen and Tanaka 1976; Pachauri and Spreng 2002; Pachauri 2007; Ivanova et al. 2016), a hierarchical list of mitigation options emerges. Choosing low-carbon options, such as car-free living, plant-based diets without or very little animal products, low-carbon sources of electricity and heating at home as well as local holiday plans, can reduce an individual's carbon footprint by up to 9tCO_2-eq. Realising these options requires substantial policy support to overcome infrastructural, institutional and socio-cultural lock-in (see Sections 5.4 and 5.6).

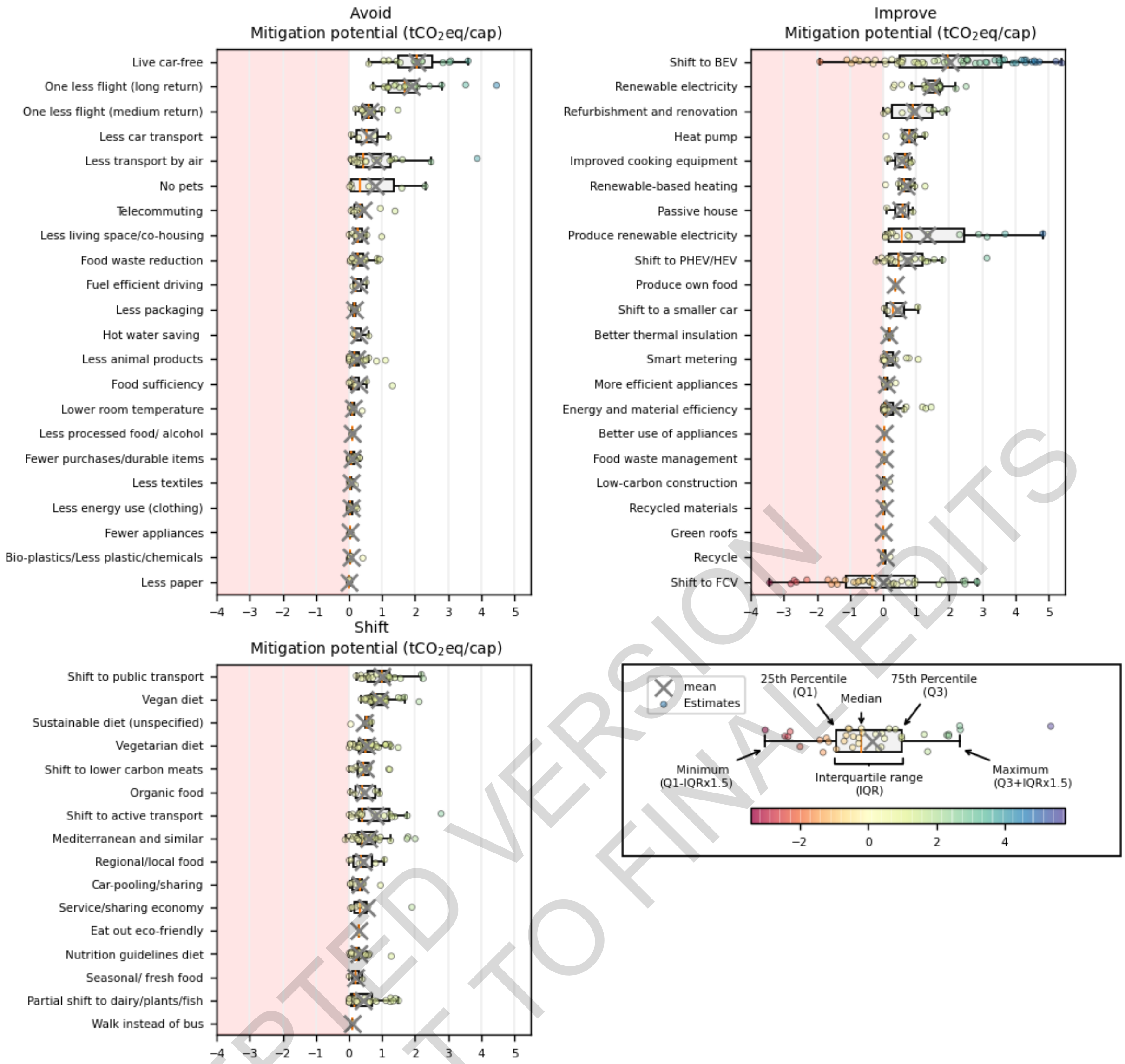


Figure 5.8 Synthesis of 60 demand side options ordered by the median GHG mitigation potential found across all estimates from the literature.
The x-s are averages. The boxes represent the 25th percentile, median and 75th percentiles of study results. The whiskers or dots show the minimum and maximum mitigation potentials of each option. Negative values (in the red area) represent the potentials for backfire due to rebound, i.e. a net-increase of GHG emissions due to adopting the option.
Source: Ivanova et al. 2020

5.3.2 Technical tools to identify Avoid-Shift-Improve options

Service delivery systems to satisfy a variety of service needs (e.g., mobility, 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 direct well-being benefits for people (Kalt et al. 2019). Illustrative examples of such resource processing systems steps and associated conversion losses drawn from the literature are shown in Figure 5.9. in the form of resource processing cascades for energy (direct energy conversion efficiencies (Nakićenović et al. 1993; De Stercke 2014)), 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 (TWI2050 2018). In other words, only between 14 to 17% of the harnessed primary resources remain at the level of ultimate service delivery.

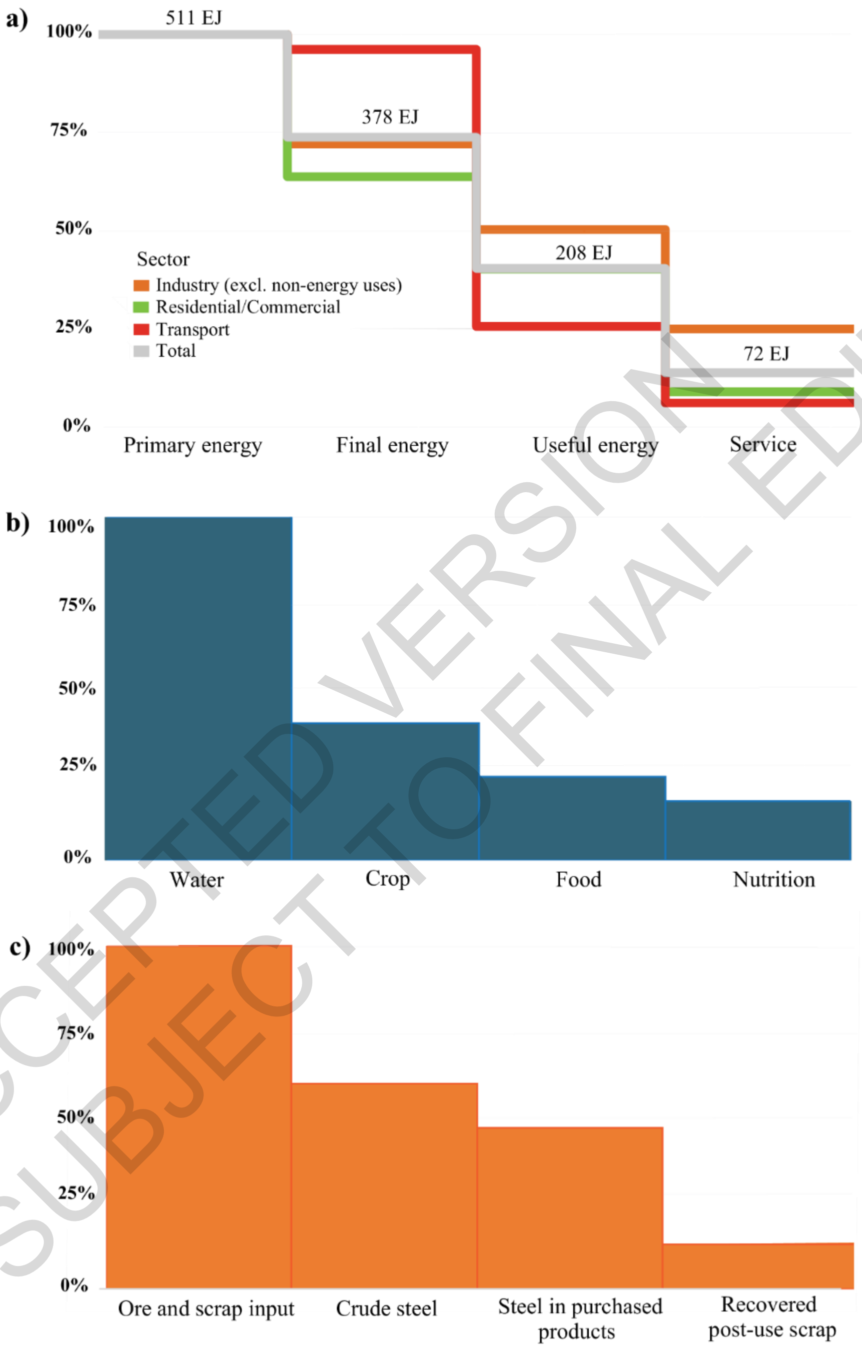


Figure 5.9 Resource processing steps and efficiency cascades (in percent of primary resource inputs [vertical axis] remaining at respective step until ultimate service delivery) for illustrative global service delivery systems for energy (top panel, disaggregated into three sectorial service types and 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

Examples of conversion losses at the supply side of resource processing systems include for instance for energy electricity generation (global output/input conversion efficiency of electric plants of 45% as shown in energy balance statistics (IEA 2020b); for water embodied in food irrigation water use efficiency (some 40% (Sadras et al. 2011)) and calorific conversion efficiency (food calories out/food calories in) in meat production of 60% (Lundqvist et al. 2008), or for materials where globally only 47% or primary iron ore extracted and recovered steel scrap end up as steel in purchased products, (i.e. a loss of 57%) (Allwood and Cullen 2012).

A substantial part of losses happen at the end-use point and in final service delivery (where losses account for 47 to 60% of aggregate systems losses for steel and energy respectively, and for 23% in the case of water embodied in food, i.e. food waste). The efficiency of service delivery (for a detailed discussion cf. (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, for a discussion of such behavioural efficiency improvement options see e.g. (Dietz et al. 2009; Laitner et al. 2009; Ehrhardt-Martinez 2015; Kane and Srinivas 2014; Lopes et al. 2017; Thaler 2015; Norton 2012). 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. Aggregated energy end-use efficiencies at the global level are estimated as low as 20% (De Stercke 2014), 13% for steel (recovered post-use scrap, Allwood and Cullen, 2012), and some 70% for food (including distribution losses and food wastes of some 30%, (Lundqvist et al. 2008).

To harness additional gains in efficiency by shifting the focus in service delivery systems to the end-user can translate into large "upstream" resource reductions. For each unit of improvement at the end-use point of the service delivery system (examples shown in Figure 5.9), primary resource inputs are reduced between a factor of 6 to 7 units (water, steel, energy) (TWI2050 2018). For example, reducing energy needs for final service delivery equivalent to 1 EJ, reduces primary energy needs by some 7 EJ. There is thus *high evidence and high agreement* in the literature that the leverage effect for improvements in end-use service delivery efficiency through behavioural, technological, and market organisational innovations is very large, ranging from a factor 6-7 (resource cascades) to up to a factor 10 to 20 (exergy analysis) with the highest improvement potentials at the end-user and service provisioning levels (for systemic reviews see (Nakićenović et al. 1996a; Grubler et al. 2012b; Sousa et al. 2017). Also the literature shows *high agreement* that current conversion efficiencies are invariably low, particularly for those components at the end-use and service delivery back end of service provisioning systems. It also suggests that efficiencies might be actually even lower than those revealed by direct input-output resource accounting as discussed above (Figure 5.9). 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. 2012b)) and 10% (global, Nakićenović 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. 2012a)) to below 25% (Japan, Italy, and Brazil, albeit with incomplete systems coverage that miss important conversion losses (Nakićenović et al. 1996b)). These findings are confirmed by more recent exergy efficiency studies that also include longitudinal time trend analysis (Cullen and Allwood 2010; Serrenho et al. 2014; Guevara et al. 2016; Brockway et al. 2014, 2015). Figure 5.10 illustrates how energy demand reductions can be realized by improving the resource efficiency cascades shown in Figure 5.9 above.

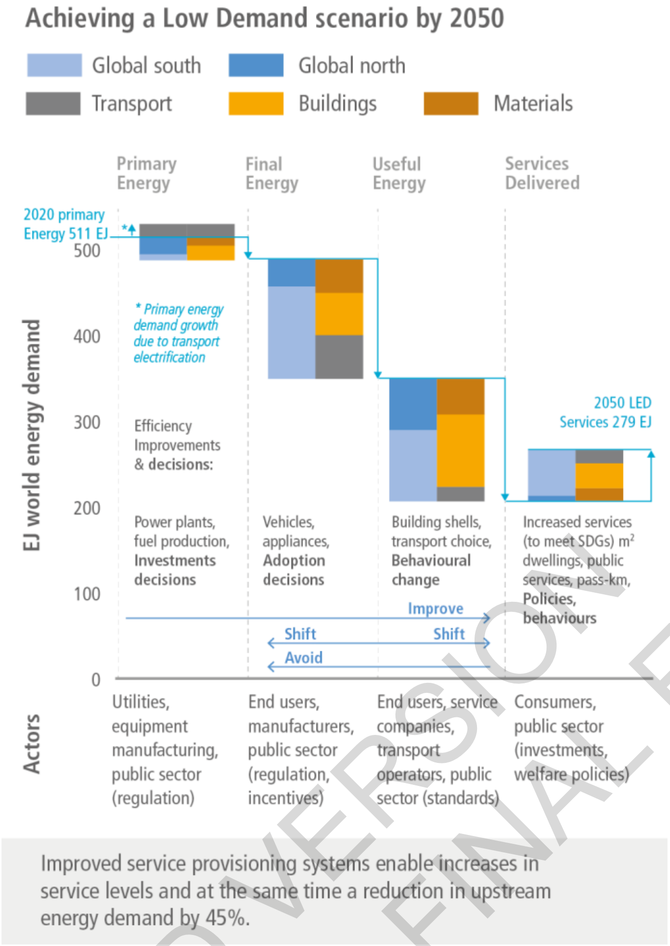


Figure 5.10 Realisable energy efficiency improvements by region and by end-use type between 2020 and 2050 in an illustrative Low Energy Demand scenario (in EJ). Efficiency improvements are decomposed by respective steps in the conversion chain from primary energy to final, and useful energy, and to service delivery and disaggregated by region (developed and developing countries) 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 system effects of transport electrification (grey bars on top of first pair in the bar charts) that counterbalance some of the efficiency improvements are also shown. Examples of options for efficiency improvements and decision involved (grey text in the chart), the relative weight of generic demand-side strategies (improve, shift, avoid blue arrows), as well as prototype actors involved are also illustrated
Data: Figure 5.9 and Grubler et al. 2018.

5.3.3 Low demand scenarios

Long-term mitigation scenarios play a crucial role in climate policy design in the near term, by illuminating transition pathways, interactions between supply-side and demand-side interventions, their timing, and the scales 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 carbon dioxide removal, particularly in 1.5ºC scenarios (Rogelj et al. 2018). Comparatively less attention has been paid to deep demand-side reductions incorporating socio-cultural change and the cascade effects (see Section 5.3.2) associated with ASI strategies, primarily due to limited past representation of such service-oriented interventions in long-term integrated assessment models (IAMs) and energy systems models (ESMs) (Napp et al. 2019; van de Ven et al. 2018; Grubler et al. 2018). There is ample evidence of savings from sector- or issue-specific bottom-up studies (see Section 5.3.1.2). However, these savings typically get lost in the dominant narrative provided by IAMs and ESMs and in their aggregate-level evaluations of combinations of ASI and efficiency strategies. As a result, their interaction effects do not typically get equal focus alongside supply-side and carbon dioxide removal options (Van den Berg et al. 2019; Van Vuuren et al. 2018; Samadi et al. 2017).

In response to 1.5ºC ambitions, and a growing desire to identify participatory pathways with less reliance on carbon dioxide removal with high uncertainty, some recent IAM and ESM mitigation scenarios have explored the role of deep demand-side energy and resource use reduction potentials at global and regional levels. Table 5.2 summarises long-term scenarios that aimed to: minimise service-level energy and resource demand as a central mitigation tenet; specifically evaluate the role of behavioural change and ASI strategies; and/or to achieve a carbon budget with limited/no carbon dioxide removal. From assessment of this emerging body of literature, several general observations arise and are presented below.

First, socio-cultural changes within transition pathways can 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 behaviour and cultural 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 roughly equivalent to those of solar PV that same year (IEA 2019a). 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). Also in Europe, a multi-regional input-output analysis suggested that adoption of low-carbon consumption practices could reduce carbon footprints by 25%, or 1.4 Gt (Moran et al. 2020). A global transport scenario suggests that transport sector emission can decline from business as usual 18 $GtCO_2$-eq to 2 $GtCO_2$-eq if ASI strategies are deployed (Gota et al. 2019), a value considerably below the estimates provided in IAM scenarios that have limited or no resolution in ASI strategies (compare with Chapter 10).

The IEA's Net Zero Emissions by 2050 (NZE) scenario, in which behavioural changes lead to 1.7 GtCO2 savings in 2030, expresses the substantial mitigation opportunity in terms of low-carbon technology equivalencies: to achieve same emissions reductions, the global share of EVs in the NZE would have to increase from 20% to 45% by 2030 or the number of installed heat pumps in homes in the NZE would have to increase from 440 to 660 million in 2030 (IEA 2021).
In light of the limited number of mitigation scenarios that represent socio-behavioural changes explicitly, there is *medium evidence* in the literature that such changes can reduce emissions at regional and global levels, but *high agreement* within that literature that such changes hold up to gigaton-scale CO_2 emissions reduction potentials.

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 (Figure 5.10) combines behavioural and technological change consistent with numerous ASI strategies that leverage digitalisation, 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 2019a), 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). Through a combination of behavioural change and energy efficient technology adoption, the IEA's NZE requires only 340 EJ of global final energy demand with universal energy access in 2050, which is among the lowest of IPCC net zero SR1.5 scenarios (IEA 2021).

Third, low demand scenarios can reduce both supply side capacity additions and the need for carbon capture and removal technologies to reach emissions targets. Of the scenarios listed in Table 5.2 one (LED-MESSAGE) reaches 2050 emissions targets with no carbon capture or removal technologies (Grubler 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. 2018; Van Vuuren et al. 2018; Napp et al. 2019), with the IEA's NZE notably requiring the least carbon dioxide removal (CDR) (1.8 Gt in 2050) and primary bioenergy (100 EJ in 2050) compared to IPCC net zero SR1.5 scenarios (IEA 2021).

Fourth, the costs of reaching mitigation targets may be 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 GCAM 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. 2018). These findings mirror earlier AIM results, which indicated lower overall mitigation costs for scenarios focused on energy service demand reductions (Fujimori et al. 2014). In the IEA's NZE, behavioural changes that avoid energy and resource demand save USD4 trillion (cumulatively 2021-2050) compared to if those emissions reductions were achieved through low-carbon electricity and hydrogen deployment (IEA 2021).

Based on the limited number of long-term mitigation scenarios that explicitly represent demand reductions enabled by ASI strategies, there is *medium evidence* but with *high agreement* within that literature that such scenarios can reduce dependence on supply-side capacity additions and carbon capture and removal technologies with opportunity for lower overall mitigation costs.

If the limitations within most IAMs and ESMs regarding non-inclusion of granular ASI strategy analysis can be addressed, it 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), much greater incorporation of rebound effects (Krey et al. 2019), including from improved efficiencies (Brockway et al. 2021) and 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; Saujot et al. 2020), improved consideration of how economic development affects service demand (Semieniuk et al. 2021), explicit representation of intersectoral linkages related to digitalisation, sharing economy, and circular economy strategies (see Section 5.3.4), and institutional, political, social, entrepreneurial, and cultural factors (van Sluisveld et al. 2018). Addressing the current significant modelling limitations will require increased investments in data generation and collection, model development, and inter-model comparisons, with a particular focus on socio-behavioural research that has been underrepresented in mitigation research funding to date (Overland and Sovacool 2020).

Covid-19 interacts with demand-side scenarios (Box 5.2). Energy demand will mostly likely be reduced between 2020 and 2030 compared to default pathway, and if recovery is steered towards low energy demand, carbon prices for a 1.5 °C-consistent pathway will be by 19%, energy supply investments until 2030 by USD1.8 trillion reduced, and the pressure to rapidly upscale renewable energy technologies will be softened (Kikstra et al. 2021a).

Table 5.2 Summary of long-term scenarios with elements that aimed to minimise service-level energy and resource demand

Global scenarios

#	**Scenario [Temp]**	**IAM/ ESM**	**Final energy**	**Focused demand reduction element(s)**			**Baseline scenario**	**Mitigation potential[c]**		
				Scope	**Sectors[a]**	**Key demand reduction measures considered (A, S, I) [b]**		**CO_2 (Gt)**	**Final energy**	**Primary energy**
a	Lifestyle change scenario [2°C]	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	2°C technology-centric scenario in 2050	1.9	-	-
b	Sustainable Development Scenario [1.8°C]	World Energy Model (WEM)	398 EJ in 2040	Behavioural 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 [1.75°C]	ETP-TIMES	377 EJ in 2050	Transport avoid/shift wedge and material efficiency wedge	T, I	A: shorter car trips, optimised truck routing and utilisation S: shifts from cars to mass transit I: plastics and metal recycling, production yield improvements	Stated policies in 2060	2.8	-	-
d	Lifestyle change scenario [1.5°C]	IMAGE	322 EJ in 2050	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	1.5°C technology-centric scenario in 2050	3.1	-	-

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, dematerialisation, reduced paper S: multi-purpose dwellings, healthier diets I: best available technologies across sectors	Final energy in 2020	-	179 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	Continuation of current trends and policies in 2050	-	260 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	1.5ºC technology-centric scenario in 2050	2.2 Gt	-	82 EJ
h	Lifestyle scenario [1.5ºC]	AIM	374 EJ in 2050	Whole scenario	T, I, F	A: reduced transport services demand, reduced demand for industrial goods S: less meat-intensive diets	1.5ºC supply technology-centric scenario in 2050	-	42 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$_2$	-	-
j	Net Zero Emissions 2050 scenario	World Energy Model (WEM)	-	Behaviour change wedge	R, T	A: Set points, line drying, reduced wash temperatures, telework, reduced air travel S: shifts to walking, cycling I: eco-driving	Stated policies in 2030	2	-	-
k	Decent living with minimum energy	Bottom-up construction	149 EJ in 2050	Whole scenario	R, T, I, F	A: activity levels for mobility, shelter, nutrition, etc. consistent with decent living standards S: shifts away from animal-based foods, shifts to public transit, more	IEA Stated Policies Scenario in 2050	-	75%	-

						I: energy efficiency consistent with best available technologies				
l	Net-Zero Emissions by 2050 Scenario (NZE)	Hybrid model based on WEM and ETP-TIMES	340 EJ in 2050	Behavioural change reductions	R, C, T, I	A: heating, air conditioning, and hot water set points, reduce international flights, line drying, vehicle light-weighting, materials-efficient construction, building lifespan extension S: shift regional flights to high-speed rail, shift cars to walking, cycling or public transport, I: eco-driving, plastics recycling	Stated policies in 2050	2.6	37 EJ	
Regional scenarios										
m	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	-
n	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	-
o	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%	-	-
p	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	-

q	EU Carbon-CAP	EXIOBASE 3 MRIO	-	Whole scenario	R, T, F	90 demand-side behaviour change opportunities spanning A-S-I including changes to consumption patterns, reducing consumption, and switching to using goods with a lower-carbon production and low-carbon use phases.	Present day consumption footprint	1.4	-	-
r	France “Negawatt” scenario	Bottom-up construction		Sufficiency wedge	R, C, T, I, F	A: increase building capacity utilisation, reduced appliance use, carsharing, telework, reduced goods consumption, less packaging S: shift to attached buildings; shift from cars and air to public transit and active mobility, carsharing, freight shift to rail and water, shift away from animal proteins I: reduced speed limits, vehicle efficiency, increased recycling	Business as usual in 2050 (~2300 TWh primary energy)	-	-	~500 TWh
s	The Netherlands households energy behavioural changes	BENCH-NLD agent-based model	-	Individual energy behavioural changes and social dynamics; considering carbon pricing	R	A: reduce energy consumption through changing lifestyle, habits and consumption patterns S: to green energy provider; investment on solar PVs (prosumers) I: investment on insulation and energy-efficient appliances	SSP2 in 2030	50%	-	-
t	The Netherlands households energy behavioural changes	BENCH-NLD agent-based model	-	Individual energy behavioural changes and social dynamics	R	A: reduce energy consumption S: investment on solar PVs (prosumers) I: investment on insulation and energy-efficient appliances	SSP2 in 2050	56%	51-71%	
u	Spain households energy behavioural changes	BENCH-ESP agent-based model	-	Individual energy behavioural changes and social dynamics	R	A: reduce energy consumption S: investment on solar PVs (prosumers) I: investment on insulation and energy-efficient appliances	SSP2 in 2050	44%	16-64%	

v	A Societal Transformation Scenario for Staying Below 1.5°C	Global calculator	187 EJ in 2050	Whole scenario	R,C,I,F	A: reduce energy, material and land use consumption	n/a	Down to 9.1 GtCO2 in 2050

Sources: a (van Sluisveld et al. 2016), b (IEA 2019a), 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. 2018), i (Gota et al. 2019), j (IEA 2020a), k (Millward-Hopkins et al. 2020), l (IEA 2021), m (Creutzig et al. 2015b), n (Millot et al. 2018), o (van de Ven et al. 2018), p (van Sluisveld et al. 2018), q (Moran et al. 2020), r (Negawatt 2018), s (Niamir et al. 2020c), t,u (Niamir et al. 2020a), v (Kuhnhenn et al. 2020)

[a] R = residential (Chapters 8, 9); C = commercial (Chapters 8, 9), T = transport (Chapters 8, 10), I = industry (Chapter 11), F = food (Chapters 6, 12),

[b] A= avoid; S = shift, I = improve

[c] Relative to indicated baseline scenario value in stated year

5.3.4 Transformative megatrends

The sharing economy, the circular economy, and digitalisation have all received much attention from the research, advocacy, business models and policy communities as potentially transformative trends for climate change mitigation (TWI2050 2019; IEA 2017a; Material Economics 2018). All are 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 scavaging and recycling comprise the core of informal economies facilitated by human interventions (Wilson et al. 2006; Asim et al. 2012; Pacheco et al. 2012). Digitalisation is now propelling sharing and circular economy concepts in developed and developing countries alike (Roy et al. 2021), and the three megatrends are highly interrelated, as seen in Figure 5.11. 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 digitalisation trend. Parts of the sharing economy are also included in some circular economy approaches, as shared resource use renders utilisation of material more efficient. Digital approaches to material management also support the circular economy, such as through waste exchanges and industrial symbiosis. Digitalisation aims more broadly to deliver services in more efficient, timely, intelligent, and less resource-intensive ways (i.e., by moving bits and not atoms), though the use of increasingly interconnected physical and digital systems in many facets of economies. With rising digitalisation also comes the risk of increased electricity use to power billions of devices and the internet infrastructure that connects them, as well as growing quantities of e-waste, presenting an important policy agenda for monitoring and balancing the carbon and resource costs and benefits of digitalisation (Malmodin and Lundén 2018; TWI2050 2019). Rebound effects and instigated consumption of digitalisation are risking to lead to a net increase in GHG emissions (Belkhir and Elmeligi 2018). The determinants and possible scales of mitigation potentials associated with each megatrend are discussed below.

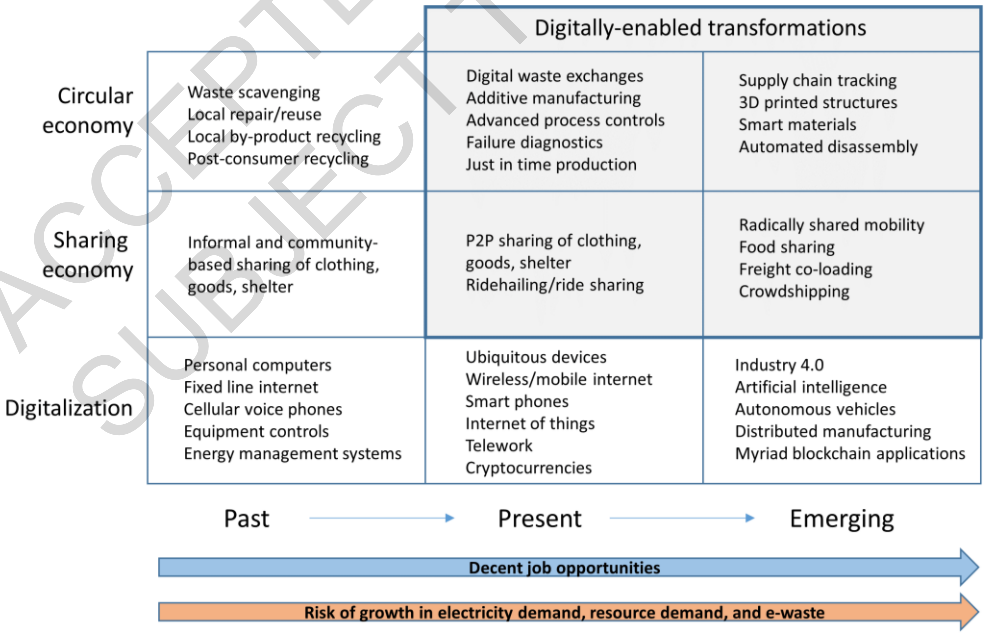


Figure 5.11 The growing nexus between digitalisation, the sharing economy, and the circular economy in service delivery systems. While these trends started mostly independently, rapid digitalisation is creating new synergistic opportunities with systemic potential to improve the quality of jobs, particularly in

developing economies. Widespread digitalisation may lead to net increases in electricity use, demand for electronics manufacturing resources, and e-waste, all of which must be monitored and managed via targeted policies

5.3.4.1 Digitalisation

In the context of service provision, there are numerous opportunities for consumers to buy, subscribe to, adopt, access, install or use digital goods and services (Wilson et al. 2020b). Digitalisation has opened up new possibilities across all domains of consumer activity, from travel and retail to domestic living and energy use. Digital platforms allow surplus resources to be identified, offered , shared, transacted and exchanged (Frenken 2017). Real-time information flows on consumers' preferences and needs mean service provision can be personalised, differentiated, automated, and optimised (TWI2050 2019). Rapid innovation cycles and software upgrades drive continual improvements in performance and responsiveness to consumer behaviour. These characteristics of digitalisation enable new business models and services that affect both service demand, from shared-ridehailing (ITF 2017a) to smart heating (IEA 2017a), and how services are provisioned, from online farmers' markets (Richards and Hamilton 2018) to peer-to-peer electricity trading to enable distributed power systems (Morstyn et al. 2018).

In many cases, digitalisation provides a 'radical functionality' that enables users to do or accomplish something that they could not do before (Nagy et al. 2016). Indeed the consumer appeal of digital innovations varies widely, from choice, convenience, flexibility and control to relational and social benefits (Pettifor and Wilson 2020). Reviewing over 30 digital goods and services for mobility, food buying and domestic living, Wilson et al. (2020b)also found shared elements of appeal across multiple innovations including (i) making use of surplus, (ii) using not owning, (iii) being part of wider networks, and (iv) exerting greater control over service provisioning systems. Digitalisation thus creates a strong value proposition for certain consumer niches. Concurrent diffusion of many digital innovations amplifies their disruptive potential (Schuelke-Leech 2018; Wilson et al. 2019b). Besides basic mobile telephone service for communication, digital innovations have been primarily geared to population groups with high purchasing power, and too little to the needs of poor and vulnerable people.

The long-term sustainability implications of digitalised services hinge on four factors: (1) the direct energy demands of connected devices and the digital infrastructures (i.e. data centres and communication networks) that provide necessary computing, storage, and communication services (Chapter 9.4.6); (2) the systems-level energy and resource efficiencies that may be gained through the provision of digital services (Wilson et al. 2020b); (3) the resource, material, and waste management requirements of the billions of ICT devices that comprise the world's digital systems (Belkhir and Elmeligi 2018; Malmodin and Lundén 2018) and (4) 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). Estimating digitalisation'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 communication 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 6% to 12% of global electricity use (Gelenbe and Caseau 2015; Cook et al. 2017; Malmodin and Lundén 2018). For example, within the literature on data centres, top-down models that project energy use on the basis of increasing demand for internet services tend to predict rapid global energy use growth, (Andrae and Edler 2015; Belkhir and Elmeligi 2018; Liu et al. 2020a), whereas bottom-up models that consider data center technology stocks and their energy efficiency trends tend to predict slower but still positive growth (Hintemann and Hinterholzer 2019; Masanet et al. 2020; Shehabi et al. 2018; Malmodin 2020). Yet there is growing concern that remaining energy 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; Masanet et al. 2020; Strubell et al. 2020). Rapid digitalization is also contributing to an expanding e-waste problem, estimated to be the fastest growing domestic waste stream globally (Forti V., Baldé C.P., Kuehr R. 2020).

As digitalisation proliferates, an important policy objective is therefore to invest in data collection and monitoring systems and energy demand models of digitalised systems to guide technology and policy investment decisions for addressing potential direct energy demand growth (IEA 2017a) and potentially concomitant growth in e-waste.

However, the net 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 (Masanet and Matthews 2010; Melville 2010; Elliot 2011; Watson et al. 2012; Gholami et al. 2013; Añón Higón et al. 2017). As shown in Figure 5.12, assessments of numerous digital service opportunities for mobility, nutrition, shelter, and education and entertainment suggest that net emissions benefits can be delivered at the systems level, although these effects are highly context-dependent. Importantly, evidence of potential negative outcomes due to rebound effects, induced demand, or life-cycle trade-offs can also be observed. For example, telework has been shown to reduce emissions where long and/or energy-intensive commutes are avoided, but can lead to net emissions increases in cases where greater non-work vehicle use occurs or only short, low-emissions commutes (e.g., via public transit) are avoided (Viana Cerqueira et al. 2020; IEA 2020a; Hook et al. 2020). Similarly, substitution of physical media by digital alternatives may lead to emissions increases where greater consumption is fuelled, whereas a shift to 3D printed structures may require more emissions-intensive concrete formulations or result in reduced thermal energy efficiency leading to life-cycle emissions increases (Mahadevan et al. 2020; Yao et al. 2020).

Furthermore, digitalisation, 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 (Figure 5.12). 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 (Wadud et al. 2016; Cohen and Cavoli 2019). On-demand electric scooters offer mobility access preferable to passenger cars, but can replace trips otherwise taken on public transit (de Bortoli and Christoforou 2020) and can come with significant additional energy requirements for night time system rebalancing (Hollingsworth et al. 2019, ITF 2020). 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; de Vries 2018; Stoll et al. 2019). For example, while it is clear that the energy requirements of global Bitcoin mining have grown significantly since 2017, recent literature indicates a wide range of estimates for 2020 (47 TWh to 125 TWh) due to data gaps and differences in modelling approaches (Lei et al. 2021). Initial estimates of the computational intensity of artificial intelligence algorithms suggest that energy requirements may be enormous without concerted effort to improve efficiencies, especially on the computational side (Strubell et al. 2020).

Efficiency gains enabled by digitalisation, in terms of reduced GHG emissions or energy use per service unit may be overcompensated by activity/scale effects.

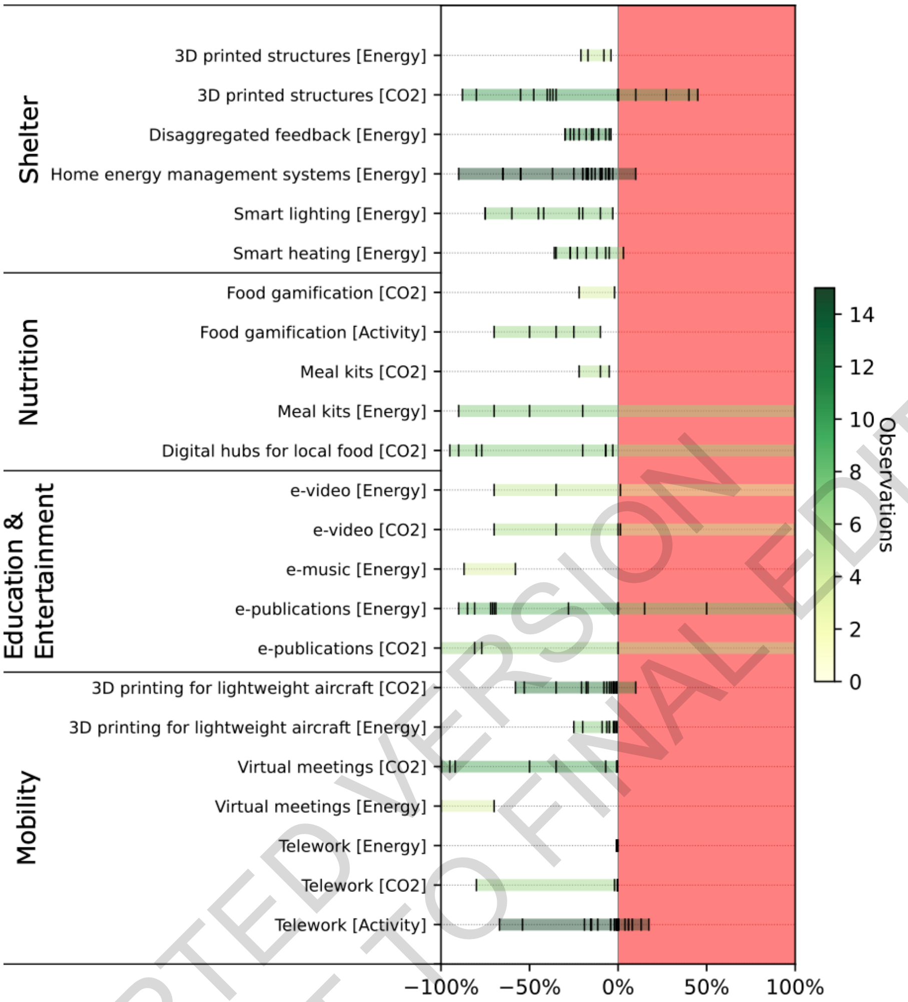


Figure 5.12 Studies assessing net changes in CO2 emissions, energy use, and activity levels indicate mitigation potentials for numerous end user-oriented digitalisation solutions, but also risk of increased emissions due to inefficient substitutions, induced demand, and rebound effects.
90 studies were assessed with 207 observations (indicated by vertical bars) including those based on empirical research, attributional and consequential life-cycle assessments, and techno-economic analyses and scenarios at different scales, which are not directly comparable but useful for indicating the directionality and determinants of net emissions, energy, and activity effects.
Sources: Erdmann and Hilty 2010; Gebler et al. 2014; Huang et al. 2016; Verhoef et al. 2018; Alhumayani et al. 2020; Court and Sorrell 2020; Hook et al. 2020; IEA 2020a; Saade et al. 2020; Torres-Carrillo et al. 2020; Yao et al. 2020; Wilson et al. 2020c; Muñoz et al. 2021

Maximising the mitigation potential of digitalisation trends involves 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; Avgerinou et al. 2017; IEA 2017a; Koronen et al. 2020). Shifts to low-carbon power are a particularly important strategy being undertaken by data centre and network operators (Cook et al. 2014; Huang et al. 2020), which might be adopted across the digital device spectrum as a proactive mitigation strategy where data demands outpace hardware efficiency gains, which may be approaching limits in the near future (Koomey et al. 2011). Most recently, data centres are being investigated as a potential resource for demand response and load balancing in renewable power grids (Zheng et al. 2020; Koronen et al. 2020), while a large bandwidth for improving software efficiency has been suggested for overcoming slowing hardware efficiency gains (Leiserson et al. 2020). Ensuring efficiency benefits of digital services while avoiding potential rebound effects and demand surges will require early and proactive public policies to avoid excess energy use (WBGU 2019; TWI2050 2019), which will also necessitate investments in data collection and monitoring systems to ensure that net mitigation benefits are realised and that unintended consequences can be identified early and properly managed (IEA 2017a).

Within a small but growing body of literature on the net effects of digitalisation, there is *medium evidence* that digitalised consumer services can reduce overall emissions, energy use, and activity levels, with *medium agreement* on the scale of potential savings with the important caveat that induced demand and rebound effects must be managed carefully to avoid negative outcomes.

5.3.4.2 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. Hence, consumable products become durable goods delivering a "product service", which potentially could provide the same level of service with fewer products (Fischedick, M. et al. 2014).The sharing economy is an old practice of sharing assets between many without transferring ownership, which has been made new through focuses on sharing underutilised products/assets in ways that promotes flexibility and convenience, often in a highly developed context via gig economy/ online platforms. However, sharing economy offers the potential to shift from 'asset-heavy' ownership to 'asset-light' access, especially in developing countries (Retamal 2019). 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). See more in Supplementary Material I Chapter 5, SM.5.4.3.

Shared mobility

Shared mobility is characterised 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. Even though most shared mobility providers operate privately, their services can be considered as part of a public transport system in so far as it is accessible to most transport users and does not require private asset ownership. 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).

Demand is an important driver for energy use and emissions because decreased cost of travel time by sharing an asset (e.g. vehicle) could lead to an increase in emissions, but a high level of vehicle sharing could reduce negative impacts associated with this (Brown and Dodder 2019). One example is the megacity Kolkata, India, which has as many as twelve different modes of public transportation options that co-exist and offer means of mobility to its 14 million citizens (see Box 5.7). Most public transport modes are shared mobility options ranging from sharing between two people in a rickshaw or between a few hundred in metro or sub-urban trains. Sharing also happens informally as daily commuters avail shared taxis and neighbours borrow each other's car or bicycle for urgent or day trips.

Shared mobility using private vehicle assets is categorised into four models (Santos et al. 2018): peer-to-peer (P2P) platforms 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 ridehailing services (Wallsten 2015; Angrist et al. 2017); and ride pooling using private vehicles shared by passengers to a common destination (Liyanage et al. 2019; Shaheen and Cohen 2019). The latest model – ride pooling – is promising in terms of congestion and per capita CO_2 emissions reductions and is a common practice in developing countries, 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 three models often yield profits to private parties, but remain mostly unrelated to reduction in CO_2 emissions (Santos et al. 2018). Shared travel models, especially Uber-like models, are criticised because of the flexibilisation of labour, especially in developing countries, in which unemployment rates and unregulated labour markets lie a foundation of precarity that lead many workers to seek out wide-ranging means towards patching together a living (Ettlinger 2017; Wells et al. 2020). Despite the advantages of the shared mobility such as convenience and affordability, consumers may also perceive risk formed by possible physical injury from strangers or unexpected poor service quality (Hong et al. 2019).

From a mitigation perspective, the current state of shared mobility looks at best questionable (Fishman et al. 2014; Ricci 2015; Zhang et al. 2019; Zhang and Mi 2018; Creutzig et al. 2019b; Martin 2016; Mi and Coffman 2019). Transport entrepreneurs and government officials often conflate 'smart' and "shared' vehicle with 'sustainable' mobility, a conflation not withstanding scrutiny (Noy and Givoni 2018). Surveys demonstrate that many users take free-floating car sharing instead of public transit, rather than to replace their private car (Herrmann et al. 2014); while in the United States, ride hailing and sharing data indicate that these services have increased road congestion and lowered transit ridership, with an insignificant change in vehicle ownership, and may further lead to net increases in energy use and CO2 emissions due to deadheading (Diao et al. 2021; Ward et al. 2021). If substitution effects and deadheading, which is the practice of allowing employees of a common carrier to use a vehicle as a non-revenue passenger, are accounted for, flexible motor-cycle sharing in Djakarta is at best neutral to overall GHG emissions (Suatmadi et al. 2019). Passenger surveys conducted in Denver indicated that 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).

Positive effects can be realised directly in bike sharing due to its very low marginal transport emissions. For example, in 2016, bike sharing in Shanghai reduced CO_2 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 optimised 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 can be substantial when mobility systems and digitalisation is regulated. Some studies model that ride pooling with electric cars (6 to 16 seats, which shifts the service to a more efficient transport mode (e.g., electric vehicle) and improves its carbon intensity by cutting 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 realises 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. 2019b). 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.

Evidence from attributional life-cycle assessments (LCAs) of ride-hailing, whether Uber-like or by taxi, suggests that the key determinants of net emissions effects are average vehicle occupancy and vehicle powertrain, with high-occupancy and electric drivetrain cars deliver the greatest emissions benefits, even rivalling traditional metro/urban rail and bus options (Figure 5.13b). 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). 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 many countries, 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 Box 5.7). 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 holds potential for prioritizing public transit and the use of public spaces for human activities, managing the data as a digital sustainable commons (e.g., via the installation of a Central Information Officer, as in Tel Aviv), and managing the social and environmental risks of smart mobility to realise its benefits (Creutzig et al. 2019b). Pricing of energy use and GHG emissions will be helpful to achieve these goals. The governance of shared mobility is complicated, as it involves many actors, and is key to realise wider benefits of shared mobility (Akyelken et al. 2018). New actors, networks and technologies enabling shared mobility are already fundamentally challenging how transport is governed worldwide. This is not a debate about state versus non-state actors but instead about the role the state takes within these new networks to steer, facilitate and also reject different elements of the mobility system (Docherty et al. 2018).

Shared accommodation

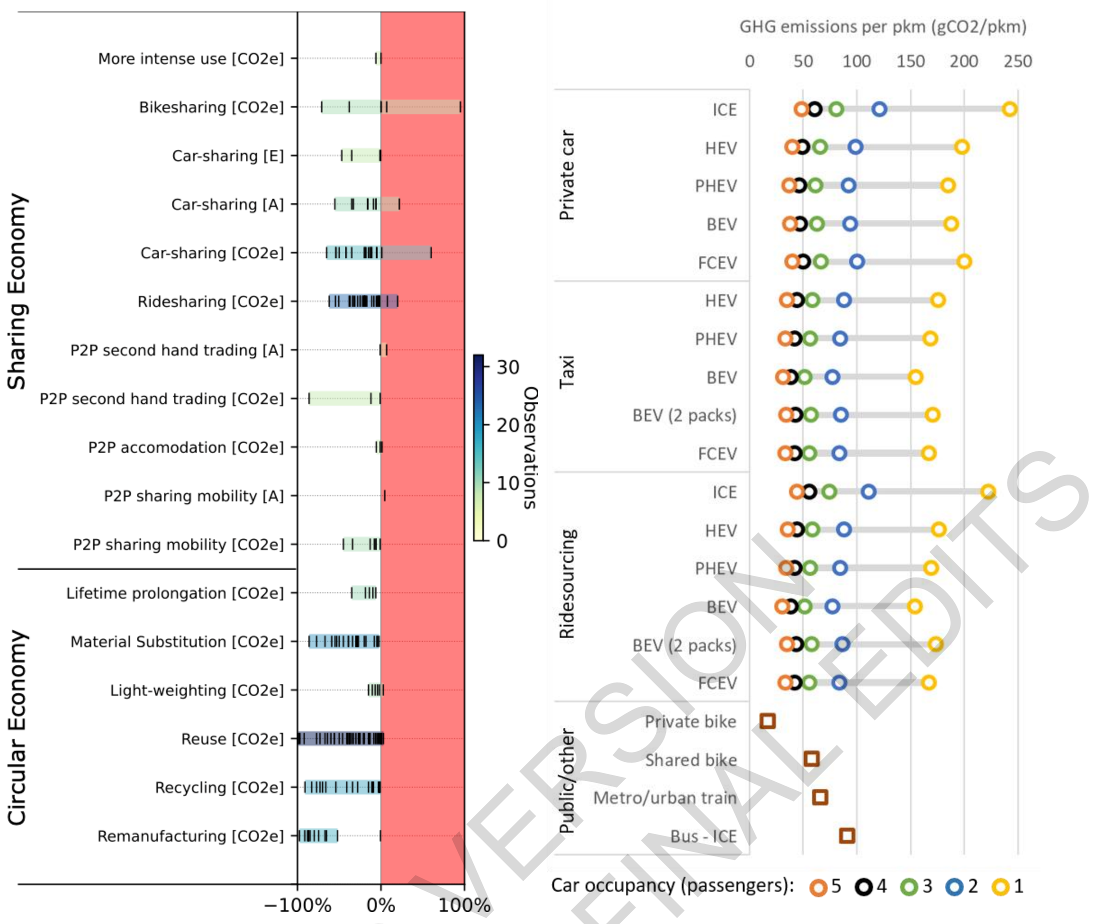
In developing countries and in many student accommodations globally, shared accommodation allows affordable housing for a large part of the population. For example, living arrangements are built expressly around the practice of sharing toilets, bathrooms and kitchens. While the sharing of such facilities does connote a lower level of service provision and quality of life, it provides access to a consumer base with very low and unreliable incomes. Thus, sharing key facilities can help guarantee the provision of affordable housing (Gulyani et al. 2018). In developed countries, large-scale developments are targeting students and 'young professionals' by offering shared accommodation and services. Historically shared accommodation has been part of the student life due to its flexible and affordable characteristics. However, the expansion of housing supply through densification can use shared facilities as an instrument to *"commercialize small housing production, while housing affordability and accessibility are threatened"* (Uyttebrouck et al. 2020).

With respect to travel accommodations, several models are emerging in which accommodation is offered to, or shared with, travellers by private people organised 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 (Voytenko Palgan et al. 2017; Möhlmann 2015).

With shared accommodation services via the platform economy, there may be risks of 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 long-term rental markets, thus indirectly inducing construction activities, with substantial GHG emissions on their own. However, 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). Given the nascence of shared accommodation via the platform economy, quantifications of its systems-level energy and emissions impacts are lacking in the literature, representing an important area for future study.

Mitigation potentials of sharing economy strategies

Sharing economy initiatives play a central role in enabling individuals to share underutilised products. While the literature on the net effects of sharing economy strategies is still limited, available studies have presented different mitigation potentials to date, as shown in Figure 5.13. For many sharing economy strategies, there is a risk of negative rebound and induced demand effects, which may occur by changing consuming patterns, e.g., if savings from sharing housing are used to finance air travel. Thus, the mitigation potentials of sharing economy strategies will depend on stringent public policy and consumer awareness that reigns in run-away consumption effects. Shared economy solutions generally relate to the “Avoid” and “Shift” strategies (see Sections 5.1 and 5.3.2). On the one hand, they hold potential for providing similar or improved services for well-being (mobility, shelter) at reduced energy and resource input, with the proper policy signals and consumer responses. On the other hand, shared economy strategies may increase emissions, e.g., shared mobility may shift activity away from public transit and lead to lower vehicle occupancy, deadheading, and use of inefficient shared vehicles (Merlin 2019; Jones and Leibowicz 2019; Bonilla-Alicea et al. 2020; Ward et al. 2021). Similarly to digitalisation, there is *medium evidence* that sharing economy can reduce overall emissions, energy use, and activity levels, with *medium agreement* on the scale of potential savings if induced demand and rebound effects can be carefully managed to avoid negative outcomes.



(a) **(b)**

Figure 5.13

(a) Published estimates from 72 studies with 185 observations (indicated by vertical bars) of the relative mitigation potential of different shared and circular economy strategies, demonstrating limited observations for many emerging strategies, a wide variance in estimated benefits for most strategies, and within the sharing economy risk of increased emissions due to inefficient substitutions, induced demand, and rebound effects. Mitigation potentials are conditional on corresponding public policy and/or regulation. (b) Attributional LCA comparisons of ridesharing mobility options, which highlight the large effects of vehicle occupancy and vehicle technology on total CO2 emissions per passenger-km and the preferability of high-occupancy and non-ICE configurations for emissions reductions compared to private cars. Also indicated are possible emissions increases associated with shared car mobility when it substitutes for non-motorised and public transit options.

BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; HEV = hybrid electric vehicle; ICE=internal combustion engine; PHEV = plug-in hybrid electric vehicle.

Sources: Jacobson and King 2009; Firnkorn and Müller 2011; Baptista et al. 2014; Liu et al. 2014; Nijland et al. 2015; Namazu and Dowlatabadi 2015; IEA 2016; Koh 2016; Martin and Shaheen 2016; Rabbitt and Ghosh 2016; Bruck et al. 2017; Bullock et al. 2017; Clewlow and Mishra 2017; Fremstad 2017; ITF 2017a,b,c; Nijland and van Meerkerk 2017; Nasir et al. 2017; Skjelvik et al. 2017; Yin et al. 2017; Campbell 2018; Ghisellini et al. 2018; Favier et al. 2018; Hopkinson et al. 2018; IEA 2018; ITF 2018; Lokhandwala and Cai 2018; Malmqvist et al. 2018; Makov and Font Vivanco 2018; Material Economics 2018; Rademaekers et al. 2017; Nasr et al. 2018; Yu et al. 2018; Zhang and Mi 2018; Brambilla et al. 2019; Brütting et al. 2019; Buyle et al. 2019; Castro and Pasanen 2019; Coulombel et al. 2019; Eberhardt et al. 2019; IEA 2019b; ITF 2019; Jones and Leibowicz 2019; Ludmann 2019; Merlin 2019; Nußholz et al. 2019; Bonilla-Alicea et al. 2020; Cantzler et al. 2020; Churkina et al. 2020; Gallego-Schmid et al. 2020; Hertwich et al. 2020; ITF 2020a,b; Liang et al. 2020; Miller 2020; Wilson et al. 2020c; Yan et al. 2020; Cordella et al. 2021; Diao et al. 2021; Pauliuk et al. 2021; Ward et al. 2021; Wolfram et al. 2021

The circular economy

While the demands for energy and materials will increase until 2060 following the traditional linear model of production and consumption, resulting in serious environmental consequences (OECD 2019b), the circular economy (CE) provides strategies for reducing societal needs for energy and primary materials to deliver the same level of service with lower environmental impacts. The CE framework embodies multiple schools of thought with roots in 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), green economy (Loiseau et al. 2016) and industrial ecology (Saavedra et al. 2018). As a result, there are also many definitions of CE: a systematic literature review identified 114 different definitions (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), and Recover energy (R9). Overall, the definition of CE is contested, with varying boundary conditions chosen. As illustrated in Figure 5.11, the CE overlaps with both the sharing economy and digitalisation megatrends.

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 in a given application (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 life-cycle emissions through harnessing the leverage effect (Creutzig et al. 2018). The development of closed-loop models in service-oriented businesses can increase resource and energy efficiency, reducing emissions and contributing to 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 primary materials and construction processes (Shanks et al. 2019), and improved recycling to reduce upstream resource pressures (IEA 2019b, 2017b).

Among the many schools of thought on the CE and climate change mitigation, two different trends can be distinguished from the literature to date. First, there are publications, many of them non peer-reviewed, that eulogize the perceived benefits of the CE, but in many cases stop short of providing a quantitative assessment. Promotion of CE from this perspective has been criticised as a greenwashing attempt by industry to avoid serious regulation (Isenhour 2019). Second, there are more methodologically rigorous publications, mostly originating in the industrial ecology field, but sometimes investigating only limited aspects of the CE (Bocken et al. 2017; Cullen 2017; Goldberg 2017). Conclusions on CE’s mitigation potential also differ with diverging definitions of the CE. A systematic review identified 3244 peer-reviewed articles addressing CE and climate change , but only 10% of those provide insights on how the CE can support mitigation, and most of them found only small potentials to reduce GHG emissions (Cantzler et al. 2020). Recycling is the CE category most investigated, while reuse and reduce strategies have seen comparatively less attention (Cantzler et al. 2020). However, mitigation potentials were also context- and material-specific, as illustrated by the ranges shown in Figure 5.13a.

There are three key concerns relating to the effectiveness of the CE concept. First, many proposals on the CE insufficiently reflect on thermodynamic constraints that limit the potential of recycling from both mass conservation and material quality perspectives 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}. As long as long-lived material stocks (e.g., in buildings and infrastructure) continue to grow, strategies targeting end-of-pipe materials cannot keep pace with primary materials demand (Krausmann et al. 2017; Haas et al. 2020). Instead, a significant reduction of societal stock growth, and decisive eco-design is suggested to advance the CE (Haas et al. 2015). Third, cost-effectiveness underlying CE activities may concurrently also increase energy intensity and reduce labour intensity, causing systematically undesirable effects. To a large extent, the distribution of costs and benefits of material and energy use depends on institutions in order to include demand-side solutions. Thus, institutional conditions have an essential role to play in setting rules differentiating profitable from nonprofitable activities in CE (Moreau et al. 2017). Moreover, the prevalence CE practices such as reuse, refurbishment, and recycling can differ substantially between developed and developing economies, leading to highly context-specific mitigation potentials and policy approaches (McDowall et al. 2017).

One report estimates that the CE can contribute to more than 6 $GtCO_2$ emission reductions in 2030, including strategies such as 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 effects tends to take back a high share of marginal CE efforts. A 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 generally correspond to the “Avoid” strategy for primary materials (see Sections 5.1 and 5.3.2). CE strategies in industrial settings improve well-being mostly indirectly, via the reduction of environmental harm and climate impact. They can also save monetary resources of consumers by reducing the need for consumption. It may seem counterintuitive, but reducing consumers' need for consumption of a particular product/service (e.g. reducing energy consumption) may increase a consumption of another one (e.g. travels) associated with some type of energy use, or lead to greater consumption if additional secondary markets are created. Hence, carbon emissions could rise if the rebound effect is not considered (Chitnis et al. 2013; Zink and Geyer 2017).

Looking at “Shift” strategy (see Sections 5.1 and 5.3.2), the role of individuals as consumers/users has received less attention than other aspects of the CE (e.g. technological interventions as “Improve” strategy and waste minimisation as “Avoid” strategy) within mainstream debates to date. One explanation is CE has roots in the field of Industrial Ecology, which has historically emphasized materials systems more than the end-user. By shifting this perspective from the supply-side to the demand-side in the CE, users are, for the most part, discussed as social entities that now must form new relations with businesses to meet their needs. That is, the demand-side approach largely replaces the concept of a consumer with that of a user, who must either accept or reject new business models for service provision, stimulated by the pushes and pulls of prices and performance (Hobson 2019).
Relevant contributions to climate change mitigation at Gigaton scale by the CE will remain out of scope if decision makers and industry fail to reduce primary inputs (*high confidence*). Systemic

(consequential) analysis is required to avoid the risk that scaling effects negate efficiency gains; such analysis is however rarely applied to date. For example, material substitution or refurbishment of buildings brings risk of increasing emissions despite improving or avoiding current materials (Eberhardt et al. 2019; Castro and Pasanen 2019) Besides, 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. In spite of presenting a large body of literature on CE in general, only a small but growing body of literature exists on the net effects of its strategies from a quantitative perspective, with key knowledge gaps remaining on specific CE strategies. There is *medium evidence* that CE can reduce overall emissions, energy use, and activity levels, with *medium evidence* that sharing economy can reduce overall emissions, energy use, and activity levels, with *medium agreement* on the scale of potential savings.

5.4 Transition toward high well-being and low-carbon demand societies

Demand-side mitigation involves individuals (e.g. consumption choices), culture (e.g. social norms, values), corporate (e.g. investments), institutions (e.g. political agency), and infrastructure change (*high evidence, high agreement*). These five drivers of human behaviour either contribute to the status-quo of a global high-carbon, consumption, and GDP growth oriented economy or help generate the desired change to a low-carbon energy-services, well-being, and equity oriented economy (Jackson 2017; Cassiers et al. 2018; Yuana et al. 2020)(Figure 5.14). Each driver has novel implications for the design and implementation of demand-side mitigation policies. They show important synergies, making energy demand mitigation a dynamic problem where the packaging and/or sequencing of different policies play a role in their effectiveness, demonstrated in Sections 5.5 and 5.6. The Social Science Primer (Supplementary Material I Chapter 5) describes theory and empirical insights about the interplay between individual agency, the social and physical context of demand-side decisions in the form of social roles and norms, infrastructure and technological constraints and affordances, and other formal and informal institutions. Incremental interventions on all five fronts change social practices, effecting simultaneously energy and well-being (Schot and Kanger 2018). Transformative change will require coordinated use of all five drivers, as described in Figure 5.14 and Table 5. using novel insights about behaviour change for policy design and implementation (*high evidence, high agreement)*. In particular, socio-economic factors, such as equity, public service quality, electricity access and democracy are found to be highly significant in enabling need satisfaction at low energy use, whereas economic growth beyond moderate incomes and extractive economic activities are observed to be prohibiting factors (Vogel et al. 2021).

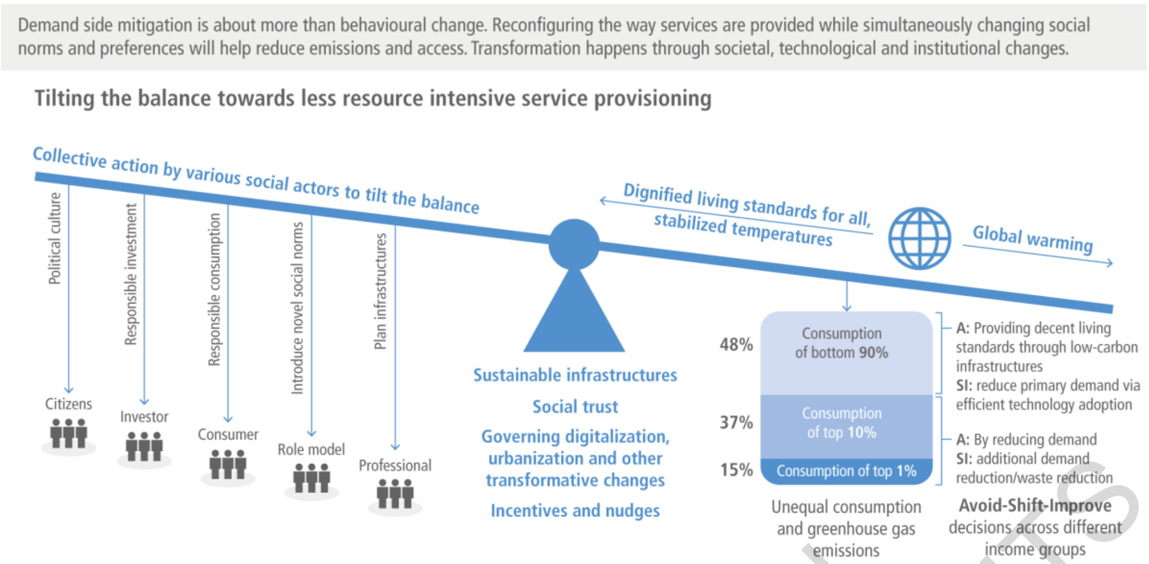


Figure 5.14 Role of people, demand-side action and consumption in reversing a planetary trajectory to a warming Earth towards effective climate change mitigation and dignified living standards for all

5.4.1 Behavioural Drivers

Behaviour change by individuals and households requires both *motivation* to change and *capacity* for change (option availability/knowledge; material/cognitive resources to initiate and maintain change) (Moser and Ekstrom 2010; Michie et al. 2011) and is best seen as part of more encompassing collective action. Motivation for change for collective good comes from economic, legal, social incentives, regard for deeper intrinsic value of concern for others over extrinsic values. Capacity for change varies; people in informal settlements or rural areas are incapacitated by socio-political realities and have limited access to new energy-service options.

Motivation and effort required for behaviour change increase from Improve to Shift to Avoid decisions. 'Improve' requires changes in personal purchase decisions, 'shift' involves changes in behavioural routines, 'avoid' also involves shifts in deeper values or mindsets. People set easy goals for themselves and more difficult ones for others (Attari et al. 2016) and underestimate the energy savings of behaviour changes that make a large difference (Attari et al. 2010). Most personal actions taken so far have small mitigation potential (recycling, ecodriving), and people refrain from options advocated more recently with high impact (less flying, living car free) (Dubois et al. 2019).

As individuals pursue a broad set of goals and use calculation-, emotion-, and rule-based processes when they make energy decisions, demand-side policies can use a broad range of behavioural tools that complement subsidies, taxes, and regulations (Chakravarty and Roy 2016; Mattauch et al. 2016; Niamir 2019) *(high evidence, high agreement*). The provision of targeted information, social advertisements, and influence of trusted in-group members and/role models or admired role models like celebrities can be used to create better climate change knowledge and awareness (Niamir et al. 2020c,b; Niamir 2019). Behavioural interventions like communicating changes in social norms can accelerate behaviour change by creating tipping points (Nyborg et al. 2016). When changes in energy-demand decisions (such as switching to a plant-based diet, Box 5.5) are motivated by the creation and activation of a social identity consistent with this and other behaviours, positive spillover can accelerate behaviour change (Truelove et al. 2014), both within a domain or across settings, e.g., from work to home (Maki and Rothman 2017).

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Box 5.5 Dietary shifts in UK society towards lower emission foods

Meat eating is declining in the UK, alongside a shift from carbon-intensive red meat towards poultry. This is due to the interaction of behavioural, socio-cultural and organisational drivers (Vinnari and Vinnari 2014). Reduced meat consumption is primarily driven by issues of personal health and animal welfare, instead of climate or environment concerns (Latvala et al. 2012; Dibb and Fitzpatrick 2014; Hartmann and Siegrist 2017; Graça et al. 2019). Social movements have promoted shifts to a vegan diet (Morris et al. 2014; Laestadius et al. 2016) yet their impact on actual behaviour is the subject of debate (Taufik et al. 2019; Harguess et al. 2020; Sahakian et al. 2020). Companies have expanded new markets in non-meat products (MINTEL 2019). Both corporate food actors and new entrants offering more innovative 'meat alternatives' view consumer preferences as an economic opportunity, and are responding by increasing the availability of meat replacement products. No significant policy change has taken place in the UK to enable dietary shift (Wellesley and Froggatt 2015); however the Committee on Climate Change has recommended dietary shift in the Sixth Carbon Budget(Climate Change Committee 2020), involving reduced consumption of high-carbon meat and dairy products by 20% by 2030, with further reductions in later years in order to reach net zero by 2050. Agricultural policies serve to support meat production with large subsidies that lower production cost and effectively increase the meat intensity of diets at a population level (Simon 2003; Godfray et al. 2018). Deeper, population wide reductions in meat consumption are hampered by these lock-in mechanisms which continue to stabilise the existing meat production-consumption system. The extent to which policymakers are willing to actively stimulate reduced meat consumption thus remains an open question (Godfray et al. 2018). See more in Supplementary Material I Chapter 5, SM5.6.4.

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People's general perceptions of climate risks, first covered in AR5, motivate behaviour change; more proximate and personal feelings of being at risk triggered by extreme weather and climate-linked natural disasters will increase concern and willingness to act (Bergquist et al. 2019), though the window of increased support is short (Sisco et al. 2017). 67% of individuals in 26 countries see climate change as a major threat to their country, an increase from 53% in 2013, though 29% also consider it a minor or no threat (Fagan and Huang 2019). Concern that the COVID-19 crisis may derail this momentum due to a finite pool of worry (Weber 2006) appears to be unwarranted: Americans' positions on climate change in 2020 matched high levels of concern measured in 2019 (Leiserowitz et al. 2020). Younger, female, and more educated individuals perceive climate risks to be larger (Weber 2016; Fagan and Huang 2019). Moral values and political ideology influence climate risk perception and beliefs about the outcomes and effectiveness of climate action (Maibach et al. 2011). Motivation for demand-side solutions can be increased by focusing on personal health or financial risks and benefits that clearly matter to people (Petrovic et al. 2014). Consistent with climate change as a normally distant, non-threatening, statistical issue (Gifford 2011; Fox-Glassman and Weber 2016), 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) when plausible mediators and moderators are considered (Brügger et al. 2021), confirmed in all 24 countries studied by Broomell et al (2015)(Broomell et al. 2015). Discounting the future matters (Hershfield et al. 2014): across multiple countries, individuals more focused on future outcomes more likely engage in environmental actions (Milfont et al. 2012).

There is *medium evidence and high agreement* that demographics, values, goals, personal and social norms differentially determine ASI behaviours, in the Netherlands and Spain (Abrahamse and Steg

2009; Niamir 2019; Niamir et al. 2020b), the OECD (Ameli and Brandt 2015), and 11 European countries (Mills and Schleich 2012; Roy et al. 2012). Education and income increase Shift and Improve behaviour, whereas personal norms help to increase the more difficult Avoid behaviours (Mills and Schleich 2012). Sociodemographic variables (household size and income) predict energy use, but psychological variables (perceived behavioural control, perceived responsibility) predict *changes* in energy use; younger households are more likely to adopt Improve decisions, whereas education increases Avoid decisions (Ahmad et al. 2015). In India and developing countries, Avoid decisions are made by individuals championing a cause, while Improve and Shift behaviour are increases by awareness programmes and promotional materials highlighting environmental and financial benefits (Roy et al. 2018a; Chakravarty and Roy 2016). Cleaner cookstove adoption (see Box 5.6), a widely studied Improve solution in developing countries (Nepal et al. 2010; Pant et al. 2014), goes up with income, education, and urban location. Female education and investments into reproductive health are evident measures to reducing world population growth (Abel et al. 2016).

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Box 5.6 Socio-behavioural aspects of deploying cookstoves

Universal access to clean and modern cooking energy could cut premature death from household air pollution by two-thirds, 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). 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). Studies reveal that a combination of drivers influence adoption of new cookstove appliances including affordability, behavioural and cultural aspects (lifestyles, social norms around cooking and dietary practices), information provision, availability, aesthetic qualities of the technology, perceived health benefits and infrastructure (spatial design of households and cooking areas). The increasing efficiency *improvements* in electric cooking 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), Ecuador (Martínez et al. 2017; Gould et al. 2018) and Ethiopia (Tesfamichael et al. 2021); and *improved* biomass stoves in China (Smith et al. 1993). Significant subsidy, information (Dendup and Arimura 2019), social marketing and availability of technology in the local markets are some of the key policy instruments helping to adopt ICS (Pattanayak et al. 2019). There is no one-size-fits-all solution to household air pollution – different levels of shift and improvement occur in different cultural contexts, indicating the importance of socio-cultural and behavioural aspects in shifts in cooking practices. See more in Supplementary Material Chapter 5, SM5.6.2.

END BOX 5.6 HERE

There is *high agreement* in the literature that the updating of educational systems from a commercialised, individualised, entrepreneurial training model to an education cognizant of planetary health and human well-being can accelerate climate change awareness and action (Mendoza and Roa 2014; Dombrowski et al. 2016) (also see Supplementary Material Chapter 5).

There is *high evidence and high agreement* that people's core values affect climate-related decisions and climate policy support by shaping beliefs and identities (Dietz 2014; Steg 2016; Hayward and Roy 2019). People with altruistic and biospheric values are more likely to act on climate change and support climate policies than those with hedonic or egoistic values (Taylor et al. 2014), because these values are associated with higher awareness and concern about climate change, stronger belief that personal actions can help mitigating climate change, and stronger feelings of responsibility for taking climate action (Dietz 2014; Steg 2016). Research also suggest that egalitarian, individualistic, and hierarchical worldviews (Wildavsky and Dake 1990) have their role, and that successful solutions require policy makers of all three worldviews to come together and communicate with each other (Chuang et al. 2020).

Core values also influence which costs and benefits are considered (Hahnel et al. 2015; Gölz and Hahnel 2016; Steg 2016). Information provision and appeals are thus more effective when tailored to those values (Bolderdijk et al. 2013; Boomsma and Steg 2014), as implemented by the energy-cultures framework (Stephenson et al. 2015; Klaniecki et al. 2020). Awareness, personal norms, and perceived behavioural control predict willingness to change energy-related behaviour above and beyond traditional sociodemographic and economic predictors (Schwartz 1977; Ajzen 1985; Stern 2000), as do perceptions of self-efficacy (Bostrom et al. 2019). However, such motivation for change is often not enough, as actors also need capacity for change and help to overcome individual, institutional and market barriers (Young et al. 2010; Carrington et al. 2014; Bray et al. 2011).

Table 5.4 describes common obstacles to demand-side energy behaviour change, from loss aversion to present bias (for more detail see Supplementary Material Chapter 5). Choice architecture refers to interventions (“nudges”) that shape the choice context and how choices are presented, with seemingly-irrelevant details (e.g., option order or labels) often more important than option price (Thaler and Sunstein 2009). There is *high evidence and high agreement* that choice architecture nudges shape energy decisions by capturing deciders’ attention; engaging their desire to contribute to the social good; facilitating accurate assessment of risks, costs, and benefits; and making complex information more accessible (Yoeli et al. 2017; Zangheri et al. 2019). Climate-friendly choice architecture includes the setting of proper defaults, the salient positioning of green options (in stores and online), forms of framing, and communication of social norms (Johnson et al. 2012). Simplifying access to greener options (and hence lowering effort) can promote ASI changes (Mani et al. 2013). Setting effective “green” defaults may be the most effective policy to mainstream low-carbon energy choices (Sunstein and Reisch 2014), adopted in many contexts (Jachimowicz et al. 2019) and deemed acceptable in many countries (Sunstein et al. 2019). Table 5.3a lists how often different choice-architecture tools were used in many countries over the past 10 years to change ASI behaviours, and how often each tool was used to enhance an economic incentive. These tools have been tested mostly in developed countries. Reduction in energy use (typically electricity consumption) is the most widely studied behaviour (because metering is easily observable). All but one tool was applied to increase this Avoid behaviour, with demand-side reductions from 0% to up to 20%, with most values below 3% (see also meta-analyses by (Hummel and Maedche 2019; Nisa et al. 2019; van der Linden and Goldberg 2020; Stankuniene et al. 2020; Khanna et al. 2021). Behavioural, economic, and legal instruments are most effective when applied as an internally consistent ensemble where they can reinforce each other, a concept referred to as “policy packaging” in transport policy research (Givoni 2014). A meta-analysis, combining evidence of psychological and economic studies, demonstrates that feedback, monetary incentives and social comparison operates synergistically and is together more effective than the sum of individual interventions (Khanna et al. 2021). The same meta-analysis also shows that combined with monetary incentives, nudges and choice architecture can reduce global GHG emissions from household energy use by 5-6% (Khanna et al. 2021).

Choice architecture has been depicted as an anti-democratic attempt at manipulating the behaviour of actors without their awareness or approval (Gumbert 2019). Such critiques ignore the fact that there is no neutral way to present energy-use related decisions, as every presentation format and choice environment influences choice, whether intentionally chosen or not. Educating households and policy makers about the effectiveness of choice architecture and adding these behavioural tools to existing market- and regulation-based tools in a transparent and consultative way can provide desired outcomes with increased effectiveness, while avoiding charges of manipulation or deception. People consent to choice architecture tools if their use is welfare-enhancing, policymakers are transparent about their goals and processes, public deliberation and participation is encouraged, and the choice architect is trusted (Sunstein et al. 2019).

Table 5.3a Inventory of behavioural interventions experimentally tested to change energy behaviours

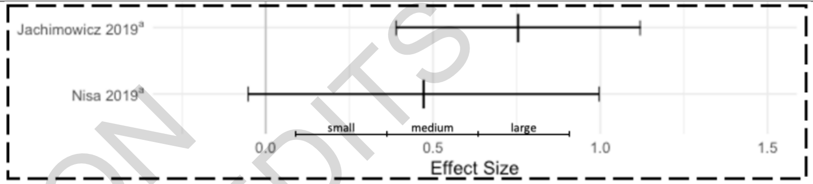
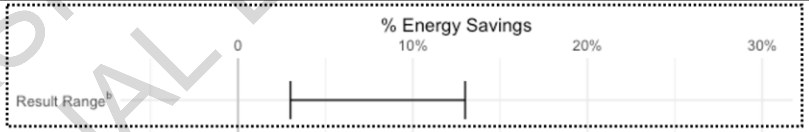
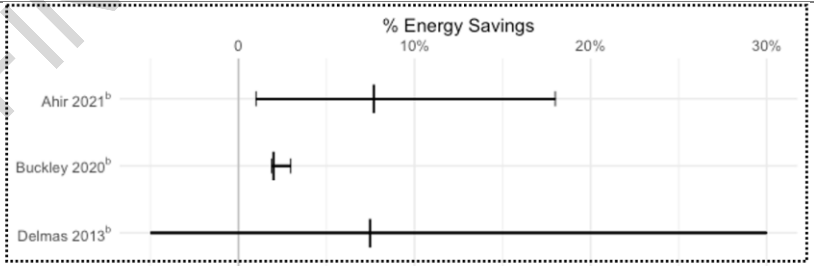
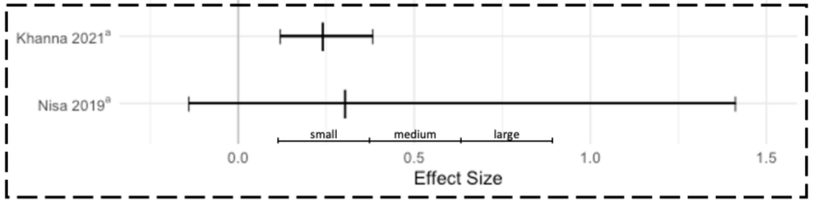
Behavioural Tool	# of Papers	# in Developed Countries	# in Other Countries	Energy Demand Behaviour	Avoid	Shift	Improve	Economic Incentive
Set the Proper Defaults	27	26	1	Carbon Offset Program (3) (Löfgren et al. 2012; Araña and León 2013) Energy Source (4) (Kaiser et al. 2020); (Wolske et al. 2020)* Energy Use (16) (Jachimowicz et al. 2019; Nisa et al. 2019; Grilli and Curtis 2021)* Investment in Energy Efficiency (7) (Theotokis and Manganari 2015; Ohler et al. 2020) Mode of Transportation (1) (Goodman et al. 2013)	11	12	9	6
Reach Out During Transitions	10	9	1	Energy Use (4) (Verplanken 2006; Jack and Smith 2016); (Iweka et al. 2019)* Investment in Energy Efficiency (4) (Gimpel et al. 2020) Mode of Transportation (2) (Verplanken et al. 2008)	1	3	7	1
Provide Timely Feedback & Reminders	256	246	10	Energy Use (252) (Darby 2006; Buckley 2019)* (Abrahamse et al. 2005; Fischer 2008; Steg 2008; Faruqui et al. 2010; Delmas et al. 2013; McKerracher and Torriti 2013; Karlin et al. 2015; Andor and Fels 2018; Bergquist et al. 2019; Iweka et al. 2019; Nisa et al. 2019; Zangheri et al. 2019; Ahir and Chakraborty 2021; Grilli and Curtis 2021; Khanna et al. 2021)* Mode of Transportation (3) (Steg 2008; Sanguinetti et al. 2020)*	244	6	7	33

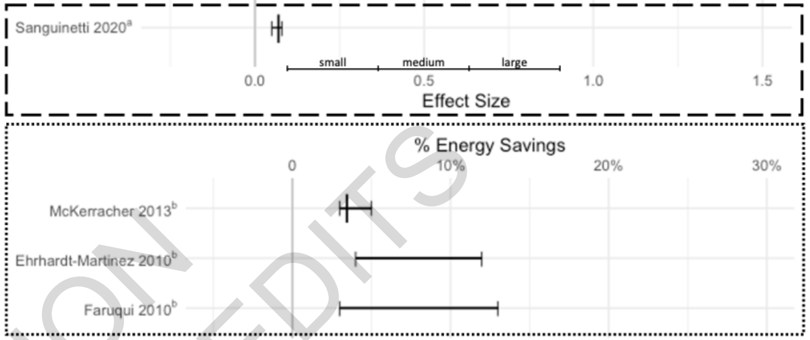
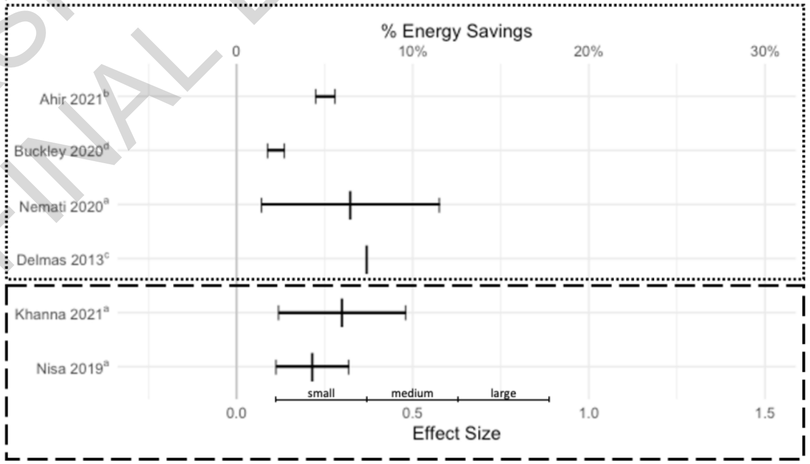
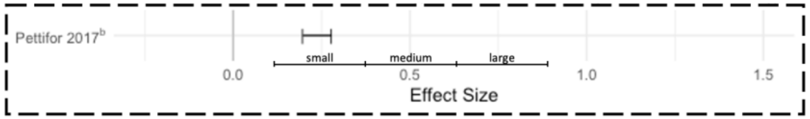
Make Information Intuitive & Easy to Access	247	235	12	Energy Source (3) (Havas et al. 2015; Jagger et al. 2019) Energy Use (202) (Henryson et al. 2000; Darby 2006; Carlsson-Kanyama and Lindén 2007; Chen et al. 2017; Iwafune et al. 2017; Burkhardt et al. 2019; Henry et al. 2019; Wong-Parodi et al. 2019; Mi et al. 2020; Stojanovski et al. 2020) (Abrahamse et al. 2005; Ehrhardt-Martinez and Donnelly 2010; Delmas et al. 2013; Andor and Fels 2018; Bergquist et al. 2019; Buckley 2019; Iweka et al. 2019; Nisa et al. 2019; Zangheri et al. 2019; Wolske et al. 2020; Ahir and Chakraborty 2021; Grilli and Curtis 2021; Khanna et al. 2021)* Investment in Energy Efficiency (30) (Larrick and Soll 2008); (Steg 2008; Andor and Fels 2018)* Mode of Transportation (19) (Steg 2008; Pettifor et al. 2017)*	197	38	24	33
Make Behaviour Observable & Provide Recognition	58	53	5	Energy Use (24) (Abrahamse et al. 2005; Delmas et al. 2013; Bergquist et al. 2019; Iweka et al. 2019; Nisa et al. 2019; Grilli and Curtis 2021)* Investment in Energy Efficiency (30) (Pettifor et al. 2017)* Mode of Transportation (4) (Pettifor et al. 2017)*	27	28	5	6
Communicate a Norm	138	131	7	Energy Source (1) (Hafner et al. 2019) Energy Use (116) (Nolan et al. 2008; Ayers and Forsyth 2009; Allcott 2011; Costa and Kahn 2013; Allcott and Rogers 2014) (Abrahamse et al. 2005; Abrahamse and Steg 2013; Delmas et al. 2013; Andor and Fels 2018; Bergquist et al. 2019; Buckley 2019; Iweka et al. 2019; Nisa et al. 2019; Ahir and Chakraborty 2021; Khanna et al. 2021)* Investment in Energy Efficiency (15) (Niamir et al. 2020b); (Pettifor et al. 2017; Grilli and Curtis 2021)* Mode of Transportation (7) (Bamberg et al. 2007); (Bergquist et al. 2019)*	106	21	16	15
Reframe Consequences	74	68	6	Energy Source (5)	41	18	19	18

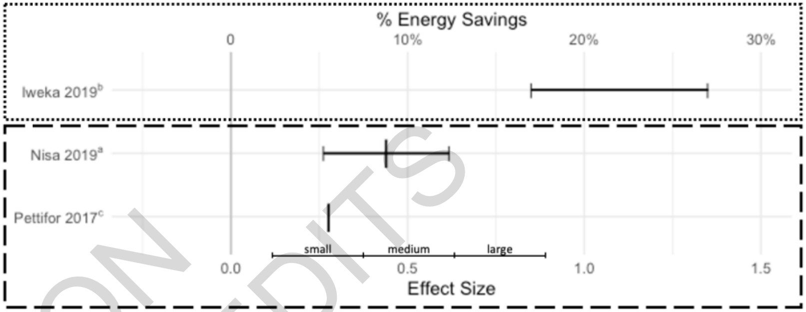
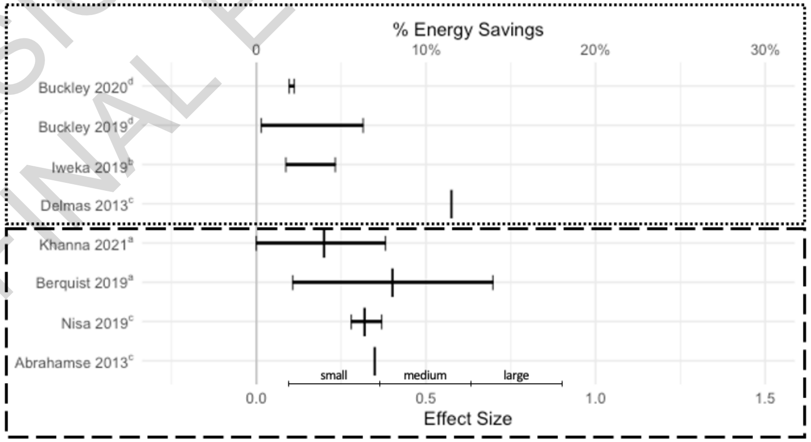
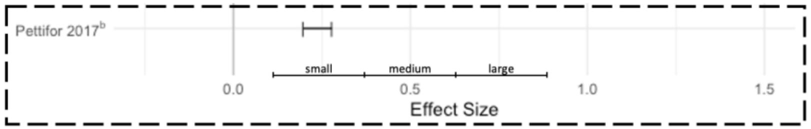
in Terms People Care About				(Wolske et al. 2018; Hafner et al. 2019); (Grilli and Curtis 2021)* Energy Use (47) (Chen et al. 2017; Eguiguren-Cosmelli 2018; Ghesla et al. 2020; Mi et al. 2020) (Abrahamse et al. 2005; Darby 2006; Delmas et al. 2013; Bergquist et al. 2019; Khanna et al. 2021)* Investment in Energy Efficiency (22) (Forster et al. 2021); (Andor and Fels 2018)* Mode of Transportation (2) (Nepal et al. 2010; Mattauch et al. 2016)				
Obtain a Commitment	52	47	5	Energy Source (1) (Jagger et al. 2019) Energy Use (47) (Ghesla et al. 2020) (Abrahamse et al. 2005; Steg 2008; Delmas et al. 2013; Andor and Fels 2018; Iweka et al. 2019; Nisa et al. 2019; Grilli and Curtis 2021; Khanna et al. 2021)* Investment in Energy Efficiency (1) (Steg 2008)* Mode of Transportation (5) (Matthies et al. 2006); (Steg 2008)*	45	4	4	10

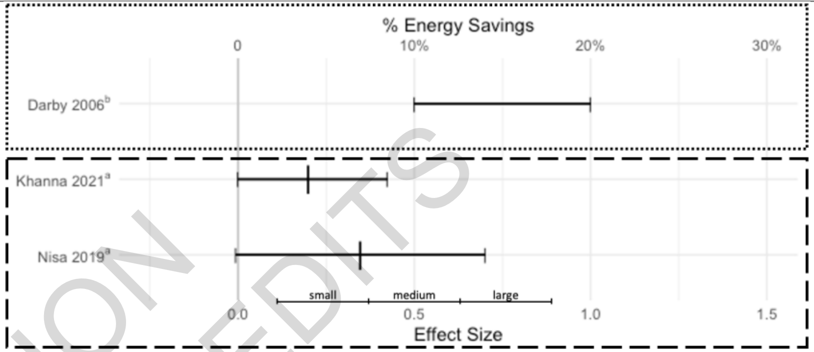
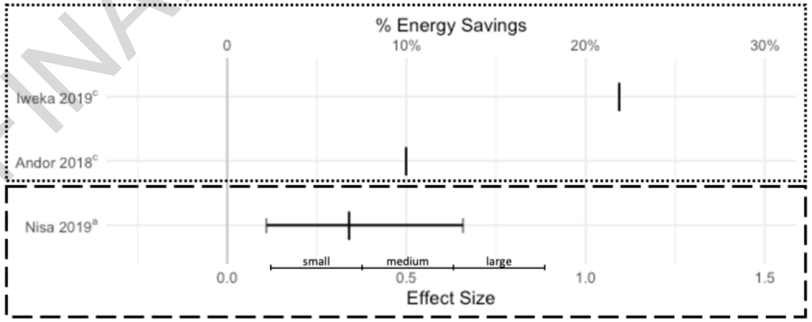
Note: Papers in this review of behavioural interventions to reduce household energy demand were collected through a systemic literature search up to August 2021. Studies are included in the reported counts if they are (1) experimental, (2) peer-reviewed or highly cited reports, (3) the intervention is behavioural, and (4) the targeted behaviour is household energy demand. 559 papers are included in the review. Each paper was coded for: type of behavioural intervention, country of study, energy demand behaviour targeted, whether the target is an avoid, shift, or improve behaviour, and whether the intervention includes an economic incentive. Some papers do not report all elements. The energy demand behaviour column provides the count of papers that focus on each behaviour type (in parentheses after the behaviour). The citations that follow are not exhaustive but exemplify papers in the category, selected for impact, range, and recency. The asterisk (*) indicates references that are meta-analyses or systematic reviews. Papers within meta-analyses and systematic reviews that meet the inclusion criteria are counted individually in the total counts. The full reference list is available at https://osf.io/9463u/.

Table 5.3b Summary of effects of behavioural interventions in Table 5.3a.

Behavioural Tool	Results (expressed in household energy savings, unless otherwise stated)	Results Summary
Set Proper Default	Meta-analyses find a medium to strong effect of defaults on environmental behaviour. Jachimowicz et al. (2019) report a strong average effect of defaults on environmental behaviour (Cohen's d=.75, confidence interval 0.39 - 1.12), though not as high as for consumer decisions. They find that defaults, across domains, are more effective when they reflect an endorsement (recommendation by a trusted source) or endowment (reflecting the status quo). Nisa et al. (2019)* report a medium average effect size (Cohen's d = 0.35; range 0.04 - 0.55).	
Reach Out During Transitions	The few interventions that focus on transitions and measure behaviour change (rather than energy savings) report mixed, moderate effect sizes. People were unwilling to change their behaviour if they are satisfied with current options (Mahapatra and Gustavsson 2008). Iweka et al. (2019)find that effective messages can prompt habit disruption.	
Timely Feedback & Reminders	The average effects of meta-analyses of feedback interventions on household energy use reductions range from 1.8% to 7.7%, with large variations (Delmas et al. 2013; Buckley 2019; Nisa et al. 2019; Buckley 2020; Ahir and Chakraborty 2021; Khanna et al. 2021). The same is true for two literature reviews (Abrahamse et al. 2005; Bergquist et al. 2019). Most studies find a 4% - 10% average reduction during the intervention; some studies find a non-significant result (Dünnhoff and Duscha 2008) or a negative reduction (Winett et al. 1978). Real-time feedback is most effective, followed by personalized feedback (Buckley 2019, 2020). A review by Darby et al. (2006) finds direct feedback (from the meter or display monitor) is more effective than indirect feedback (via billing) (5 - 15% savings vs. 0 - 10% savings). Feedback effects (Cohen's d= .241) are increased when combined with a monetary incentive (Cohen's d=.96) and with a social comparison and a monetary incentive (Cohen's d=.714) (Khanna et al. 2021) Sanguinetti et al. (2020) find that onboard feedback results in a 6.6% improvement in the fuel economy of cars (Cohen's d: .07, [.05,.08]).	 

	The effectiveness of feedback from in home displays (IHDs) is highly studied. Two reviews find them to have a 2 - 14% energy saving (Ehrhardt-Martinez and Donnelly 2010; Faruqui et al. 2010). A meta-analysis by McKerracher and Torriti (2013)finds a smaller range of results, with 3 - 5% energy savings.	
Make Information Intuitive & Easy to Access	Meta-analyses of information interventions on household energy use find average energy savings between 1.8 - 7.4% and Cohen's d effect sizes between .05 and .30 (Delmas et al. 2013; Buckley 2019, 2020; Nemati and Penn 2020; Ahir and Chakraborty 2021; Khanna et al. 2021); (Nisa et al. 2019)*. Study quality affects the measured effect—small sample sizes, shorter measurement windows, and self-selection are correlated with larger effects (Nisa et al. 2019; Nemati and Penn 2020). RCTs have a smaller effect size, 5.2% savings (95% CI [0.5%,9.5%]) (Nemati and Penn 2020). Information combined with comparative feedback is more effective than information alone (d=.34 vs. .30, (Khanna et al. 2021); 8.5% vs. 7.4%, Delmas et al. 2013). Monetary incentives make information interventions more effective (Khanna et al. 2021). Energy efficiency labeling has a heterogenous effect on investment in energy efficiency(Abrahamse et al. 2005; Andor and Fels 2018). Efficiency labels on houses lead to higher price mark ups (Jensen et al. 2016) and house prices (Brounen and Kok 2011). Energy star labels lead to significantly higher willingness to pay for refrigerators (Houde et al. 2013), but energy and water conservation varies by appliance from 0 - 23% (Kurz et al. 2005). A meta-analysis of interventions to increase alternative fuel vehicle adoption find a small effect (d=.20 - .28) (Pettifor et al. 2017).	 

Make Behaviour Observable & Provide Recognition	Making behaviour observable and recognition lead to 6-7% energy savings (Winett et al. 1978; Handgraaf et al. 2013; Nemati and Penn 2020) and a large effects size (Cohen's d = [.79,1.06); Nisa et al. 2019*). Community-wide interventions result in 17-27% energy savings (Iweka et al. 2019). Neighborhood social influence has a small (d=.28) effect on alternative fuel vehicle adoption (Pettifor et al. 2017).	
Communicate a Norm	The effect of social norm information on household energy savings ranges from 1.7-11.5% (Delmas et al. 2013; Buckley 2020) and Cohen's d from .08-.32,(Abrahamse and Steg 2013; Bergquist et al. 2019; Khanna et al. 2021); (Nisa et al. 2019)*, with similar effects on choice of mode of transportation. Pettifor et al. (2017) report a small effect (d=.20-.28) on selecting a more energy efficient car. The Opower study (Allcott 2011), prototypical for the impact of social norms on household energy consumption, finds 2% reduction in long-term energy use and 11-20% energy reduction in the short run (Allcott 2011; Ayres et al. 2013; Costa and Kahn 2013; Allcott and Rogers 2014). Impact decays over time (Allcott and Rogers 2012). Norm interventions are less effective for low energy users (Schultz et al. 2007; Andor et al. 2017). Moral licensing and negative spillover can reduce the overall positive feedback of normative feedback (Tiefenbeck et al. 2013). Interventions are more effective when the norm is implicitly inducted, in individualistic countries, and when people care about the norm (Nolan et al. 2008; Bergquist et al. 2019; Khanna et al. 2021). Descriptive norm interventions (social comparisons) are more effective when communicated online/email or through in-home displays compared to billing letters (Andor and Fels 2018), when the reference group is more specific (Shen et al. 2015). Dolan and Metcalfe (2013) find conservation increased from 4% to 11% when energy savings tips are added.	 

Reframe Consequences in Terms People Care About	A meta-analysis by Khanna et al. (Khanna et al. 2021) finds a small and variable effect of motivational interventions that reframe consequences (Cohens's d = [0,.423]); Effect are larger when reframing is combined with monetary incentives and feedback (d = .96). Darby et al. (2006) report 10-20% savings for US pay-as-you-go systems. Providing lifecycle cost information increases likelihood of purchasing eco-innovative products (Kaenzig and Wüstenhagen 2010). Long term (10-year) operating cost information leads to higher WTP for energy efficiency compared to short term (1-year) cost information (Heinzle and Wüstenhagen 2012). Monetary information increases the success of energy reduction interventions (Newell and Siikamäki 2014; Andor and Fels 2018). Reframing interventions are more effective when combined with feedback (d = .24-.96) and with social comparisons and feedback (d = .42) (Khanna et al. 2021)	
Obtain a Commitment	Commitment and goal interventions result in significant energy reduction in half of studies(Abrahamse et al. 2005; Andor and Fels 2018); (Nisa et al. 2019)*. Nisa et al. (2019) report a moderate average effect (Cohen's d = 0.34, [.11, .66]). When results are significant, the energy savings are around 10% (Andor and Fels 2018). Self-set goals perform better than assigned goals (van Houwelingen and van Raaij 1989; McCalley and Midden 2002; Andor and Fels 2018) and reasonable goals perform better than unreasonably high or low goals (van Houwelingen and van Raaij 1989; Abrahamse et al. 2007; Harding and Hsiaw 2014). Interventions are more effective when the commitment is public (Pallak and Cummings 1976) and when combined with information and rewards (Slavin et al. 1981; Völlink and Meertens 1999).	

Note: The second column describes the effects of each of the eight behavioural tools. The third column plots the results of meta-analyses and reviews that focus on each tool. Effects are reported as described in the referenced paper, either as percentage of energy saved (dotted box) or by the effect size, measured as Cohen's D (dashed box).

*Two responses to Nisa et al. (2019) challenge their conclusion that behavioural interventions have a small impact on household energy use (Stern 2020; van der Linden & Goldberg, 2020). We report the raw data collected and used in Nisa et al. (2019). Our data summary supports the arguments by Stern (2020) and van der Linden (2020) that interventions should be evaluated in combination, as well as individually, and that the results are highly sensitive to the chosen estimator.

[a] Range reported as 95% confidence interval of results used in the meta-analysis or review.

[b] Range reported as all results included in the meta-analysis or review.

[c] No range reported.

[d] Range indicates the reported results within a meta-analysis; this applies when multiple intervention types in a meta-analysis are classified as a single behavioural tool.

5.4.2 Socio-cultural drivers of climate mitigation

Collective behaviours and social organisation is part of everyday life, and feeling part of active collective action renders mitigation measures efficient and pervasive (Climact 2018). Social and cultural processes play an important role in shaping what actions people take on climate mitigation, interacting with individual, structural, institutional and economic drivers (Barr and Prillwitz 2014). Just like infrastructures, social and cultural processes can 'lock-in' societies to carbon-intensive patterns of service delivery. They also offer potential levers to change normative ideas and social practices in order to achieve extensive emissions cuts (*high confidence*, see Table 5.4).

In terms of cultural processes, we can distinguish two levels of analysis: specific meanings associated with particular technologies or practices, and general narratives about climate change mitigation. Specific **meanings** (e.g. comfort, status, identity and agency) are associated with many technologies and everyday social practices that deliver energy services, from driving a car to using a cookstove (*high evidence*, *high agreement*, see Section 5.5). Meanings are symbolic and influence the willingness of individuals to use existing technologies or shift to new ones (Wilhite and Ling 1995; Wilhite 2009; Sorrell 2015). Symbolic motives are more important predictors of technology adoption than instrumental motives (Steg 2005; Noppers et al. 2014, 2015, 2016) (see mobility case study on app-cabs in Kolkata, Box 5.8). If an invidiual's pro-environmental behavior is associated with personal meaning than it also increases subjective wellbeing (Zawadzki et al. 2020). Status consciousness is highly relevant in high GHG emission intensive consumption choices (cars, houses). However, inversely framing energy saving behaviour as high status is a promising strategy for emission reduction (Ramakrishnan and Creutzig 2021).

At a broader level, **narratives** about climate mitigation circulate within and across societies, as recognised in SR15, and are broader than the meanings associated with specific technologies (*high evidence, high agreement)*. Narratives enable people to imagine and make sense of the future through processes of interpretation, understanding, communication and social interaction (Smith et al. 2017). Stories about climate change are relevant for mitigation in numerous ways. They can be utopian or dystopian (e.g. The great derangement by Amitav Ghosh) (Ghosh 2016), for example presenting apocalyptic stories and imagery to capture people's attention and evoke emotional and behavioural response (O'Neill and Smith 2014). Reading climate stories has been shown to cause short-term influences on attitudes towards climate change, increasing the belief that climate change is human caused and increasing its issue priority (Schneider-Mayerson et al. 2020). Climate narratives can also be used to justify scepticism of science, drawing together coalitions of diverse actors into social movements that aim to prevent climate action (Lejano and Nero 2020). Narratives have been used by indigenous communities to imagine climate futures divergent from top-down narratives (Streeby 2018). Narratives are also used in integrated assessment and energy system models that construct climate stabilisation scenarios, for example in the choice of parameters, their interpretation and model structure (Ellenbeck and Lilliestam 2019). One important narrative choice of many models involves framing climate change as market failure (which leads to the result that carbon pricing is required). While such a choice can be justified, other model framings can be equally justified (Ellenbeck and Lilliestam 2019). Power and agency shape which climate narratives are told and how prevalent they are (O'Neill and Smith 2014; Schneider-Mayerson et al. 2020). For example, narratives have been used by indigenous communities to imagine climate futures divergent from top-down, government-led narratives (Streeby 2018). The uptake of new climate narratives is influenced by political beliefs and trust. Policy makers can enable emissions reduction by employing narratives that have broad societal appeal, encourage behavioural change and complement regulatory and fiscal measures (Terzi 2020). Justice narratives may not have universal appeal - in a UK study, justice narratives polarised individuals along ideological lines, with lower support amongst individual with right-wing beliefs; by contrast, narratives centred on saving energy, avoiding waste and patriotic values were more widely supported across society

(Whitmarsh and Corner 2017). More research is needed to assess if these findings are prevalent in diverse socio-cultural contexts, as well the role played by social media platforms to influence emerging narratives of climate change (Pearce et al. 2019).

Trust in organisations is a key predictor of the take-up of novel energy services (Lutzenhiser 1993), particularly when financial incentives are high (Stern et al. 1985; Joskow 1995). Research has shown that, if there is low public trust in utility companies, service delivery by community-based non-profit organisations in the US (Stern et al. 1985) or public/private partnerships in Mexico (Friedmann and Sheinbaum 1998), offer more effective solutions, yet only if public trust is higher in these types of organisations. UK research shows that acceptance of shifts to less-resource intensive service provision (e.g. more resource efficient products, extending product lifetimes, community schemes for sharing products) varies depending on factors including trust in suppliers and manufacturers, affordability, quality and hygiene of shared products, and fair allocation of responsibilities (Cherry et al. 2018). Trust in other people plays an important role in the sharing economy (Li and Wang 2020), for example predicting shifts in transport mode, specifically car-sharing involving rides with strangers (Acheampong and Siiba 2019) (sharing economy see Section 5.3.4.2).

Action on climate mitigation is influenced by our perception of what other people commonly do, think or expect, known as social norms *(high evidence, high agreement)* (Cialdini 2006) (see Table 5.3), even though people often do not acknowledge this (Nolan et al. 2008; Noppers et al. 2014). Changing social norms can encourage societal transformation and social tipping points to address climate mitigation(Nyborg et al. 2016; Otto et al. 2020). Providing feedback to people about how their own actions compare to others can encourage mitigation (Delmas et al. 2013), although the overall effect size is not strong (Abrahamse and Steg 2013). Trending norms are behaviours that are becoming more popular, even if currently practised by a minority. Communicating messages that the number of people engaging in a mitigation behaviour (e.g. giving a financial donation to an environmental conservation organisation) is increasing – a simple low cost policy intervention - can encourage shifts to the targeted behaviour, even if the effect size is relatively small (Mortensen et al. 2019).

Socially comparative feedback seems to be more effective when people strongly identify with the reference group (De Dominicis et al. 2019). Descriptive norms (perceptions of behaviours common in others) are more strongly related to mitigation actions when injunctive norms (perceptions of whether certain behaviours are commonly approved or disapproved) are also strong, when people are not strongly personally involved with mitigation topics (Göckeritz et al. 2010), when people are currently acting inconsistently with their preferences, when norm-based interventions are supported by other interventions and when the context supports norm-congruent actions (Miller and Prentice 2016). A descriptive norm prime ("most others try to reduce energy consumption") together with injunctive norm feedback ("you are very good in saving energy") is a very effective combination to motivate further energy savings (Bonan et al. 2020). Second-order beliefs (perceptions on what others in the community believe) are particularly important for leveraging descriptive norms (Jachimowicz et al. 2018).

Behavioural contagion, which describes how ideas and behaviours often spread like infectious diseases, is a major contributor to the climate crisis (Sunstein 2019). But harnessing contagion can also mitigate warming. Carbon-heavy consumption patterns have become the norm only in part because we're not charged for environmental damage we cause (Pigou 1920). The deeper source of these patterns has been peer influence (Frank 1999), because what we do influences others. A rooftop solar installation early in the adoption cycle, for example, spawns a copycat installation in the same neighbourhood within four months, on average. With such installations thus doubling every four months, a single new order results in 32 additional installations in just two years. And contagion doesn't stop there, since each family also influences friends and relatives in distant locations.

Harnessing contagion can also underwrite the investment necessary for climate stability. If taxed more heavily, top earners would spend less, shifting the frames of reference that shape spending of those just below, and so on—each step simultaneously reducing emissions and liberating resources for additional green investment (Frank 2020). Many resist, believing that higher taxes would make it harder to buy life's special extras. But that belief is a cognitive illusion (Frank 2020). Acquiring special things, which are inherently in short supply, requires outbidding others who also want them. When top tax rates rise in tandem, relative bidding power is completely unchanged, so the same penthouse apartments would end up in the same hands as before. More generally, behavioural contagion is important to leverage all relevant social tipping points for stabilising Earth's climate (Otto et al. 2020).

For new climate policies and mitigation technologies to be rapidly and extensively implemented, they must be socially acceptable to those who are directly impacted by those policies and technologies (*medium evidence, high agreement*). Policies that run counter to social norms or cultural meanings are less likely to be effective in reducing emissions (Demski et al. 2015; Perlaviciute et al. 2018; Roy et al. 2018b). More just and acceptable implementation of renewable energy technologies requires taking account of the cultural meanings, emotional attachments and identities linked to particular landscapes and places where those technologies are proposed (Devine-Wright 2009) and enabling fairness in how decisions are taken and costs and benefits distributed (Wolsink 2007). This is important for achieving the goal of SDG7 (i.e. increased use of renewable energy resources) in deveolping countries while achieving energy justice (Calzadilla and Mauger 2017). 'Top-down' imposition of climate policies by governments can translate into local opposition when perceived to be unjust and lacking transparency (*high evidence, high agreement*). Policy makers can build trust and increase the legitimacy of new policies by implementing early and extensive public and stakeholder participation, avoiding 'NIMBY' (Not In My Back Yard) assumptions about objectors and adopting 'Just Transition' principles (Owens 2000; Wolsink 2007; Wüstenhagen et al. 2007; Dietz and Stern 2008; Devine-Wright 2011; Heffron and McCauley 2018). Participatory mechanisms that enable deliberation by a representative sample of the public (Climate Assembly UK 2020) can inform policy making and increase the legitimacy of new and difficult policy actions (Dryzek et al. 2019).

Collective action by civil society groups and social movements can work to enable or constrain climate mitigation. Civil society groups can advocate policy change, provide policy research and open up opportunities for new political reforms (high evidence, high agreement) as recognised in previous IPCC reports (IPCC 2007). Grassroots environmental initiatives, including community energy groups, are collective responses to, and critiques of, normative ways that everyday material needs (e.g. food, energy, making) are produced, supplied and circulated (Schlosberg and Coles 2016). Such initiatives can reconcile lower carbon footprints with higher life satisfaction and higher incomes(Vita et al. 2020). Local initiatives such as Transition Towns and community energy can lead to improvements in energy efficiency, ensure a decent standard of living and increase renewable energy uptake, while building on existing social trust, and in turn, building social trust and initiating engagement, capacity building, and social capital formation(Hicks and Ison 2018). Another example are grassroot initiatives that aim to reduce food loss and waste, even as overall evidence on their effectiveness remains limited (Mariam et al. 2020). However, community energy initiatives are not always inclusive and require policy support for widespread implementation across all socio-economic groups (Aiken et al. 2017) In addition, more evidence is required of the impacts of community energy initiatives (Creamer et al. 2018; Bardsley et al. 2019).

Civil society social movements are a primary driver of social and institutional change (high evidence, high agreement) and can be differently positioned as, on the one hand, 'insider' social movements (e.g. World Wildlife Fund) that seek to influence existing state institutions through lobbying, advice and research and, on the other hand, 'outsider' social movements (e.g. Rising Tide, Extinction Rebellion) that advocate radical reform through protests and demonstrations(Newell 2005; Caniglia et al. 2015). Civil society social movements frame grievances that resonate with society, mobilise resources to coordinate and sustain mass collective action, and operate within – and seek to influence - external conditions that enable or constrain political change (Caniglia et al. 2015). When successful, social movements open up windows of opportunity (so called 'Overton Windows') to unlock structural change (high evidence, high agreement) (Szałek 2013; Piggot 2018).

Climate social movements advocate new narratives or framings for climate mitigation (e.g. climate 'emergency') (della Porta and Parks 2014); criticise positive meanings associated with high emission technologies or practices (see Diet and Solar PV Case Studies, Box 5.5 and 5.7); show disapproval for high emission behaviours (e.g. through 'flight shaming'); model behaviour change (e.g. shifting to veganism or public transport – see Case Study on Mobility in Kolkata, Box 5.8); demonstrate against extraction and use of fossil-fuels(Cheon and Urpelainen 2018); and aim to increase a sense of agency amongst certain social groups (e.g. young people or indigenous communities) that structural change is possible. Climate strikes have become internationally prevalent, for example the September 2019 strikes involved participants in more than 180 countries (Rosane 2019; Fisher and Nasrin 2020; Martiskainen et al. 2020). Enabled by digitalisation, these have given voice to youth on climate (Lee et al. 2020) and created a new cohort of active citizens engaged in climate demonstrations (Fisher 2019). Research on bystanders shows that marches increase positive beliefs about marchers and collective efficacy (Swim et al. 2019).

Countermovement coalitions work to oppose climate mitigation *(high confidence)*. Examples include efforts in the US to oppose mandatory limits on carbon emissions supported by organisations from the coal and electrical utility sectors (Brulle 2019) and evidence that US opposition to climate action by carbon-connected industries is broad-based, highly organized, and matched with extensive lobbying (Cory et al., 2021). Social movements can also work to prevent policy changes, for example in France the Gilet Jaunes objected to increases in fuel costs on the grounds that they unfairly distributed the costs and benefits of price rises across social groups, for example between urban, peri-urban and rural areas (Copland 2019).

Religion could play an important role in enabling collective action on climate mitigation by providing cultural interpretations of change and institutional responses that provide resources and infrastructure to sustain collective actions (Roy et al. 2012; Haluza-DeLay 2014; Caniglia et al. 2015; Hulme 2015). Religion can be an important cultural resource towards sustainability at individual, community and institutional levels(Ives and Kidwell 2019) , providing leverage points for inner transformation towards sustainability (Woiwode et al. 2021). Normative interpretations of climate change for and from religious communities are found in nearly every geography, and often observe popular movements for climate action drawing on religious symbols or metaphors (Jenkins et al. 2018). This suggests the value for policy makers of involving religious constituencies as significant civil society organisations in devising and delivering climate response.

START BOX 5.7 HERE

Box 5.7 Solar PV and the agency of consumers

As an innovative technology, solar PV was strongly taken up by consumers (Nemet 2019). Several key factors explain its success. First, modular design made it applicable to different scales of deployment in different geographical contexts (e.g. large-scale grid-connected projects and smaller-scale off-grid projects) and allowed its application by companies taking advantage of emerging markets (Shum and Watanabe 2009). Second, culturally, solar PV symbolised an environmentally progressive technology that was valued by users (Morris and Jungjohann 2016). Large-scale adoption led to policy change (i.e. the introduction of feed-in tariffs that guaranteed a financial return) that in turn enabled improvements to the technology by companies. Over time, this has driven large-scale reductions in cost and increase in deployment worldwide. The relative importance of drivers varied across contexts. In Japan, state subsidies were lower yet did not hinder take-up because consumer behaviour was motivated by non-cost symbolic aspects. In Germany, policy change arose from social movements that campaigned for environmental conservation and opposed nuclear power, making solar PV policies politically acceptable. In summary, the seven-decade evolution of solar PV shows an evolution in which the agency of consumers has consistently played a key role in multiple countries, such that deriving 30-50% of global electricity supply from solar is now a realistic possibility (Creutzig et al. 2017). See more in Supplementary Material Chapter 5, SM5.6.1.

END BOX 5.7 HERE

5.4.3 Business and Corporate Drivers

Businesses and corporate organisations play a key role in the mitigation of global warming, through their own commitments to zero-carbon footprints (Mendiluce 2021) decisions to invest in researching and implementing new energy technologies and energy efficient measures, and the supply side interaction with changing consumer preferences and behaviours, e.g. via marketing. Business models and strategies work both as a barrier to and as accelerator of decarbonisation. Still existing lock-in in infrastructures and business models advantages fossil fuel industry over renewable and energy efficient end use industry (Klitkou et al. 2015). The fossil fuel energy generation and delivery system therefore epitomises a barrier to the acceptance and implementation of new and cleaner renewable energy technologies (Kariuki 2018). A good number of corporate agents have attempted to derail climate change mitigation by targeted lobbying and doubt-inducing media strategies (Oreskes and Conway 2011). A number of corporations that are involved in the supply chain of both upstream and downstream of fossil fuel companies, make up the majority of organizations opposed to climate action (Dunlap and McCright 2015; Cory et al. 2021; Brulle 2019). Corporate advertisement and brand building strategies also attempt to deflect corporate responsibility to individuals, and/or to appropriate climate care sentiments in their own brand building; climate change mitigation is uniquely framed through choice of products and consumption, avoiding the notion of the political collective action sphere (Doyle 2011; Doyle et al. 2019).

Business and corporations are also agents of change towards decarbonisation, as demonstrated in the case of PV and battery electric cars (Teece 2018). Beyond new low-carbon technologies, strong sustainability business models (SSBM) are characterised by identifying nature as the primary stakeholder, strong local anchorage, the creation of diversified income sources, and deliberate limitations on economic growth (Brozovic 2019). However, SSBM are difficult to maintain if generally traditional business models prevail, requiring short-term accounting.

Liability of fossil fuel business models and insurance against climate damages are key concerns of corporations and business. Limitations and regulation on GHG emissions will compel the demand for fossil fuel companies' products (Porter and Kramer 2006). 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. The divestment movement adds additional pressure on fossil fuel related investments (Braungardt et al. 2019), even though fossil fuel financing remains resilient (Curran 2020). Companies, businesses and organisations might face liability claims for their contribution to changes especially in the carbon intensive energy sector. A late transition to a low-carbon economy would exacerbate the physical costs of climate change on governments, businesses and corporations (ESRB 2016).

Despite these seemingly positive roles that Businesses and corporate organisations tend to play towards sustainable transitions, there is a need to highlight the dynamic relationship between sustainable and unsustainable trends (Antal et al. 2020). For example, the production of Sports Utility Vehicles (SUVs) in the automobile market at the same time that car manufacturers are producing electric vehicles. An analysis of the role of consumers as drivers of unsustainability for Businesses and Corporate organisations is very important here as this trend will offset the sustainability progress being made by these businesses and organisations (Antal et al. 2020).

Professional actors, such as building managers, landlords, energy efficiency advisers, technology installers and car dealers, 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). Middle actors can bring about change in several different directions be it, upstream, or downstream or sideways. They can redefine professional ethics around sustainability issues, and 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.

5.4.4 Institutional Drivers

The allocation of political power to incumbent actors and coalitions has contributed to lock-in of particular institutions, stabilising the interests of incumbents through networks that include policymakers, bureaucracies, advocacy groups and knowledge institutions (*high agreement, high evidence*). There is high evidence and high agreement in that institutions are central in addressing climate change mitigation. Indeed, social provisioning contexts including equity, democracy, public services and high quality infrastructure are found to facilitate high levels of need satisfaction at lower energy use, whereas economic growth beyond moderate incomes and dependence on extractive industries inhibit it (Vogel et al. 2021). They shape and interact with technological systems (Unruh 2000; Foxon et al. 2004; Seto et al. 2014) and represent rules, norms and conventions that organise and structure actions (Vatn 2015) and help create new path dependency or strengthen existing path dependency (Mattioli et al. 2020) (also see case studies in Box 5.5-5.8 and Supplementary Material Chapter 5). These drive behaviour of actors through formal (e.g., laws, regulations, and standards) or informal (e.g., norms, habits, and customs) processes, and can create constraints on policy options (Breukers and Wolsink 2007). For example, 'the car dependent transport system' is maintained by interlocking elements and institutions, consisting of i) the automotive industry; ii) the provision of car infrastructure; iii) the political economy of urban sprawl; iv) the provision of public transport; v) cultures of car consumption (Mattioli et al. 2020). The behaviour of actors, their processes and implications on policy options and decisions is discussed further in Section 5.6.

START BOX 5.8 HERE

Box 5.8 Shifts from private to public transport in Indian megacities

In densely populated, fast-growing megacities, policy makers face the difficult challenge of preventing widespread adoption of petrol or diesel fuelled private cars as a mode of transport. The megacity of Kolkata in India provides a useful case study. As many as twelve different modes of public transportation, each with its own system structure, actors and meanings co-exist and offers means of mobility to its 14 million citizens. Most of the public transport modes are shared mobility options ranging from sharing between two people in a rickshaw or between a few hundred in metro or sub-urban trains. Sharing also happens informally as daily commuters avail shared taxis and neighbours borrow each other's car or bicycle for urgent or day trips.

A key role is played by the state government, in collaboration with other stakeholders, to improve the system as whole and formalise certain semi-formal modes of transport. An important policy consideration has been to make Kolkata's mobility system more efficient (in terms of speed, reliability and avoidance of congestion) and sustainable through strengthening coordination between different mode-based regimes (Ghosh 2019) and comfortable with airconditioned space in a hot and humid climate (Roy et al. 2018b). Policy makers have introduced multiple technological, behavioural and socio-cultural measures to tackle this challenge. New buses have been purchased by public authorities (Ghosh and Schot 2019). These have been promoted to middle-class workers in terms of modernity, efficiency and comfort, and implemented using premium-fares. Digitalisation and the sharing economy has encouraged take-up of shared taxi rides ('app cabs'), being low cost and fast, but also influenced by levels of social trust involved in rides with strangers (Acheampong and Siiba 2019; Ghosh and Schot 2019). Rickshaws have been improved through use of LNG and cycling has been banned from busy roads. These measures contributed positively in bringing down the trend of greenhouse gas emissions per unit of GDP to half in one decade within the Kolkata metropolitan area, with potential for further reduction (Colenbrander et al. 2016). However, social movements have opposed some changes due to concerns about social equity, since many of the new policies cater to middle class aspirations and preferences, at the cost of low income and less privileged communities.

To conclude, urban mobility transitions in Kolkata shows interconnected policy, institutional and socio-cultural drivers for socio-technical change. Change has unfolded in complex interactions between multiple actors, sustainability values and megatrends, where direct causalities are hard to identify. However, the prominence of policy actors as change-agents is clear as they are changing multiple regimes from within. The state government initiated infrastructural change in public bus systems, coordinated with private and non-governmental actors such as auto-rickshaw operators, app-cab owners who hold crucial agency in offering public transport services in the city. The latter can directly be attributed to the global momentum of mobility-as-a-service platforms, at the intersection of digitalisation and sharing economy trends. More thoughtful action at a policy level is required to sustain and coordinate the diversity of public transport modes through infrastructure design and reflecting on the overall directionality of change (Schot and Steinmueller 2018; Roy et al. 2018b). See more in Supplementary Material Chapter 5, SM5.6.3.

END BOX 5.8 HERE

5.4.5 Technological/Infrastructural Drivers

Technologies and infrastructures shape social practices and their design matters for effective mitigation measures (*high evidence, high agreement*). There are systemic interconnections between infrastructures and practices (Cass et al. 2018; Haberl et al. 2021), and their intersection explains their relevance (Thacker et al. 2019). The design of a new electricity system to meet new emerging demand based on intermittent renewable, can lead to a change in consumption habits and the adaption of lifestyles compliant with more power supply interruption (Maïzi et al. 2017; Maïzi and Mazauric 2019). The quality of the service delivery impacts directly the potential user uptake of low-carbon technologies. In the state of Himachal Pradesh of India, shift from LPG to electricity, with induction stove, has been successful due to the availability of stable and continuous electricity which has been difficult to achieve in any other Indian state (Banerjee et al. 2016). In contrast, in South Africa, where people who were using electricity earlier are now adopting LPG to diversify the energy source for cooking due to high electricity tariff and frequent blackouts (Kimemia and Annegarn 2016) (see Box 5.5 and Supplementary Material Chapter 5).

From a welfare point of view, infrastructure investments are not constrained by revealed or stated preferences (*high evidence*, *high agreement*). Preferences change with social and physical environment, and infrastructure interventions can be justified by objective measures, such as public health and climate change mitigation, not only given preferences *(high agreement, high evidence)*. Specifically, there is a case for more investment in low-carbon transport infrastructure than assumed in environmental economics as it induces low-carbon preferences (Creutzig et al. 2016a; Mattauch et al. 2018, 2016). 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. 2020; Abraham et al. 2021). 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 (also see mobility case study in Box 5.7).

The dynamic interaction of habits and infrastructures also predict CO_2-intensive choices. 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). 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 (Bamberg et al. 2003). Similarly, an exogenous change to route choice in public transport makes commuters change their habitual routes (Larcom et al. 2017).

Table 5.4 Main features, insights, and policy implications of five drivers of decision and action. Entries in each column are independent lists, not intended to line up with each other.

Driver	How does driver contribute to status quo bias?	What needs to change?	Driver's policy implications	Examples
Behavioural	Habits and routines formed under different circumstances do not get updated. Present-bias penalises upfront costs and discourages energy efficiency investments. Loss aversion magnifies the costs of change.	New goals (sustainable lifestyle) New capabilities (online real-time communication) New resources (increased education) Use of full range of incentives and mechanisms to change demand-side behaviour	Policies need to be context specific and coordinate economic, legal, social, and infrastructural tools and nudges Relate climate action to salient local risks and issues.	India's new LPG scale up policy uses insights about multiple behavioural drivers of adoption and use. Rooftop solar adoption expanded in Germany, when FITs removed risk from upfront-cost recovery Nuclear power policies in

	When climate change is seen as distant, it is not feared. Nuclear power and accident potential score high on psychological dread			Germany post Fukushima affected by emotional factors
Socio-Cultural	Cultural norms (e.g. status, comfort, convenience) support existing behaviour. Lack of social trust reduces willingness to shift behaviour (e.g. adopt car-sharing). Fear of social disapproval decreases willingness to adopt new behaviours. Lack of opportunities to participate in policy create reactance against 'top down' imposition. Unclear or dystopian narratives of climate response reduce willingness to change and to accept new policies and technologies.	Create positive meanings and norms around low-emission service delivery (e.g. mass transit). Community initiatives to build social trust and engagement, capacity building, and social capital formation. Climate movements that call out the insufficient, highly problematic state of delayed climate action. Public participation in policy making and technology implementation that increases trust, builds capacity and increases social acceptance. Positive narratives about possible futures that avoid emissions (e.g. emphasis upon health and slow/active travel).	Embed policies in supportive social norms. Support collective action on climate mitigation to create social trust and inclusion. Involve arts and humanities to create narratives for policy process	Communicate descriptive norms to electricity end users. Community energy initiative RESCOOP. Friday For Future.
Business and Corporate	Lock-in mechanisms that make incumbent firms reluctant to change: core capabilities, sunk investments in staff and factories, stranded assets.	New companies (like car sharing companies, renewable energy start-ups) that pioneer new business models or energy service provisions.	Influence consumer behaviour via product innovation Provide capital for clean energy innovation.	Electrification of transport opens up new markets for more than a hundred million new vehicles.
Institutional	Lock-in mechanisms related to power struggles, lobbying, political economy.	New policy instruments, policy discussions, policy platforms, implementation agencies, including capacity.	Feed-in Tariffs and other regulations that turn energy consumers into prosumers.	Mobility case study, India's LPG policy sequence.
Infrastructural	various lock-in mechanisms such as	many emerging technologies, which are	systemic governance to	Urban walking and bike paths.

	sunk investments, capabilities, embedding in routines/lifestyles.	initially often more expensive, but may benefit from learning curves and scale economies that drive costs down.	avoid rebound effects.	Stable and continuous electricity supply fostering induction stoves.

5.5 An integrative view on transitioning

5.5.1 Demand-side transitions as multi-dimensional processes

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. 2017) conceptualise demand-side transitions as multi-dimensional and interacting processes (*high evidence*, *high agreement*). Social practice theory emphasises interactions between artefacts, competences, and cultural meanings (Røpke 2009; Shove and Walker 2014)(Shove and Walker 2014; Røpke 2009). The energy cultures framework highlights feedbacks between materials, norms, and behavioural practices (Stephenson et al. 2015; Jürisoo et al. 2019). Socio-technical transitions theory addresses interactions between technologies, user practices, cultural meanings, business, infrastructures, and public policies (McMeekin and Southerton 2012; Geels et al. 2017) and can thus accommodate the five drivers of change and stability discussed in Section 5.4.

Section 5.4 shows with *high evidence and high agreement* that the relative influence of different drivers varies between demand-side solutions. The deployment of 'improve' options like LEDs and clean cookstoves mostly involves technological change, adoption by consumers who integrate new technologies in their daily life practices (Smith et al. 1993; Sanderson and Simons 2014; Franceschini and Alkemade 2016), and some policy change. Changes in meanings are less pertinent for those 'improve'-options that are primarily about technological substitution. Other improve-options, like clean cookstoves, involve both technological substitution and changes in cultural meanings and traditions.

Deployment of 'shift' options like enhanced public transport involves substantial behavioural change and transitions to new or expanded provisioning systems, which may include new technologies (buses, trams), infrastructures (light rail, dedicated bus lanes), institutions (operational licenses, performance contracts), financial arrangements, and new organisations (with particular responsibilities and oversight) (*high evidence*, *high agreement*) (Deng and Nelson 2011; Turnheim and Geels 2019). Changes in cultural meanings can facilitate 'shift' options. Shifts towards low-meat diets, for instance, are motivated by costs and by beliefs about the undesirability of meat that relate more to issues like health, nutrition and animal welfare than climate change (De Boer et al. 2014; Mylan 2018).

'Avoid' options that reduce service levels (e.g. sufficiency or downshifting) imply very substantial behavioural and cultural changes that may not resonate with mainstream consumers (Dubois et al. 2019). Other 'avoid' options like tele-working also require changes in cultural meanings and beliefs (about the importance of supervision, coaching, social contacts, or office politics), as well as changes in behaviour, institutions, business, and technology (including good internet connections and office space at home). Because these interconnected changes were not widespread, tele-working remained stuck in small niches and did not diffuse widely before the COVID-19 crisis (Hynes 2014, 2016; Belzunegui-Eraso and Erro-Garcés 2020; Stiles 2020). As preferences change, new infrastructures and social settings can also elicit new desirabilities associated with emerging low-energy demand service provisioning systems (see 5.4.5).

Demand-side transitions involve interactions between radical social or technical innovations (such as the avoid, shift, improve options discussed in Section 5.3) and existing socio-technical systems, energy cultures, and social practices (*high evidence, high agreement*) (Stephenson et al. 2015; Geels et al. 2017). Radical innovations such as tele-working, plant-based burgers, car sharing, vegetarianism, or electric vehicles initially emerge in small, peripheral niches (Kemp et al. 1998; Schot and Geels 2008), constituted by R&D projects, technological demonstration projects (Borghei and Magnusson 2016; Rosenbloom et al. 2018b), local community initiatives or grassroots projects by environmental activists (Hargreaves et al. 2013a; Hossain 2016). Such niches offer protection from mainstream selection pressures and nurture the development of radical innovations (Smith and Raven 2012). Many low-carbon niche-innovations, such as those described in Section 5.3, face uphill struggles against existing socio-technical systems, energy cultures, and social practices that are stabilised by multiple lock-in mechanisms (*high evidence, high agreement*) (Klitkou et al. 2015; Seto et al. 2016; Clausen et al. 2017; Ivanova et al. 2018). Demand-side transitions therefore do not happen easily and involve interacting processes and struggles on the behavioural, socio-cultural, institutional, business and technological dimensions (Nikas et al. 2020) (see also Section 5.4).

5.5.2 Phases in transitions

Transitions often take several decades, unfolding through several phases. Although there is variability across innovations, sectors, and countries, the transitions literature distinguishes four phases, characterised by generic core processes and challenges: 1) emergence, 2) early adaptation, 3) diffusion, 4) stabilisation (*high confidence*) (Rotmans et al. 2001; Markard et al. 2012; Geels et al. 2017) (Cross-Chapter Box 12 in Chapter 16). 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). There is also no guarantee that technological, social, or business model innovations progress beyond the first phase.

In the first phase, radical innovations emerge in peripheral niches, where researchers, inventors, social movement organisations or community activists dedicate time and effort to their development (*high confidence*) (Kemp et al. 1998; Schot and Geels 2008). Radical social, technical and business model innovations are initially characterised by many uncertainties about technical performance, consumer interest, institutions and cultural meanings. Learning processes are therefore essential and can be stimulated through R&D, demonstration projects, local community initiatives or grassroots projects (Borghei and Magnusson 2016; Hossain 2016; Rosenbloom et al. 2018b; van Mierlo and Beers 2020). Typical challenges are fragmentation and high rates of project failure (den Hartog et al. 2018; Dana et al. 2021), limited funding (Auerswald and Branscomb 2003), limited consumer interest, and socio-cultural acceptance problems due to being perceived as strange or unfamiliar (Lounsbury and Glynn 2001) .

In the second phase, social or technical innovations are appropriated or purchased by early adopters, which increases visibility and may provide a small but steady flow of financial resources (*high evidence, high agreement*) (Zimmerman and Zeitz 2002; Dewald and Truffer 2011). Learning processes, knowledge sharing and codification activities help stabilise the innovation, leading to best practice guidelines, standards, and formalised knowledge (*high evidence, high agreement*) (Raven et al. 2008; Borghei and Magnusson 2018). User innovation may lead to the articulation of new routines and social practices, often in tandem with the integration of new technologies into people's daily lives (Nielsen et al. 2016; Schot et al. 2016). Radical innovations remain confined to niches in the second phase because adoption is limited to small, dedicated groups (Schot et al. 2016), innovations are expensive or do not appeal to wider groups, or because complementary infrastructure are missing (Markard and Hoffmann 2016).

In the third phase, radical innovations diffuse into wider communities and mainstream markets. Typical drivers are performance improvements, cost reductions, widespread consumer interest, investments in infrastructure and complementary technologies, institutional support and strong cultural appeal (*high evidence, high agreement)* (Wilson 2012; Markard and Hoffmann 2016; Raven et al. 2017; Malone et al. 2017; Kanger et al. 2019). The latter may be related to wider cultural shifts such as increased public attention to climate change and new framings like 'climate emergency' which gained traction before the Covid-19 pandemic (Bouman et al. 2020b). These concerns may not last, however, since public attention typically follows cycles (Downs 1972; Djerf-Pierre 2012).

This phase often involves multiple struggles: economic competition between low-carbon innovations and existing technologies and practices, business struggles between incumbents and new entrants (Hockerts and Wüstenhagen 2010), cultural and framing struggles in public opinion arenas (Kammermann and Dermont 2018; Rosenbloom 2018; Hess 2019a), and political struggles over adjustments in policies and institutions, which shape markets and innovations (Meadowcroft 2011; Roberts and Geels 2019). The lock-in mechanisms of existing practices and systems tend to weaken in the third phase, either because competing innovations erode their economic viability, cultural legitimacy or institutional support (Turnheim and Geels 2012; Roberts 2017; Kuokkanen et al. 2018; Leipprand and Flachsland 2018) or because exogenous shocks and pressures disrupt the status quo (Kungl and Geels 2018; Simpson 2019).

In the fourth phase, the diffusing innovations replace or substantially reconfigure existing practices and systems, which may lead to the downfall or reorientation of incumbent firms (Bergek et al. 2013; McMeekin et al. 2019). The new system becomes institutionalised 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; Shove and Southerton 2000; Barnes et al. 2018)

Avoid, shift and improve options vary with regard to the four transition phases. Incremental 'improve' options, such as energy-efficient appliances or stand-alone insulation measures, are not transitions but upgrades of existing technologies. They have progressed furthest since they build on existing knowledge and do not require wider changes (Geels et al. 2018). Some radical 'improve' options, which have a different technological knowledge base, are beginning to diffuse, moving from phase two to three in multiple countries. Examples are electric vehicles, light-emitting diodes, or passive house designs (Franceschini and Alkemade 2016; Berkeley et al. 2017). 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 mostly 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, Copenhagen, and more recently Paris, 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 evidence, high agreement*).

5.5.3 Feasible rate of change

Transitional change is usually slow in the first and second transition phase, because experimentation, social and technological learning, and stabilisation processes take a long time, often decades, and remain restricted to small niches (*high confidence*) (Wilson 2012; Bento 2013; Bento et al. 2018b).

Transitional change accelerates in the third phase, as radical innovations diffuse from initial niches into mainstream markets, propelled by the self-reinforcing mechanisms, discussed above. The rate of adoption (diffusion) of new practices, processes, artefacts, and behaviours is determined by a wide range of factors at the macro- and micro-scales, which have been identified by several decades of diffusion research in multiple disciplines (for comprehensive reviews see, e.g. (Mansfield 1968; Martino et al. 1978; Davis 1979; Mahajan et al. 1990; Ausubel 1991; Grubler 1991; Feder and Umali 1993; Bayus 1994; Comin and Hobijn 2003; Rogers 2003; Van den Bulte and Stremersch 2004; Meade and Islam 2006; Peres et al. 2010)).

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).
Despite differences, the literature offers three robust conclusions on acceleration (*high evidence, high agreement*): 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, Wilson 2012). 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; Leibowicz 2018). Also, the creation of entirely new systems (diffusion) takes longer time than replacements of existing technologies/practices (substitution) (Grübler et al. 1999); and late adopters tend to adopt faster than early pioneers (Wilson 2012; Grubler 1996).

Arguments about scale in the energy system date back at least to the 1970s when Schumacher, Lovins and others argued the case for smaller-scale, distributed technologies (Schumacher 1974; Lovins 1976, 1979). In 'Small is Profitable' Lovins and colleagues evidenced over 200 reasons why decentralised energy resources, from distributed generation to end-use efficiency, made good business sense in addition to their social, human-centred benefits (Lovins et al. 2003). More recent advances in digital, solar and energy storage technologies have renewed technical and economic arguments in favour of adopting decentralised approaches to decarbonisation (Cook et al. 2016; Jain et al. 2017; Lovins et al. 2018). Smaller-scale technologies from microprocessors to solar panels show dramatically faster cost and performance improvement trajectories than large-scale energy supply facilities (Trancik 2014; Sweerts et al. 2020, Creutzig et al, 2021, Fig. 5.15). Analysing the performance of over 80 energy technologies historically, Wilson et al. (2020) found that smaller scale, more 'granular' technologies are empirically associated with faster diffusion, lower investment risk, faster learning, more opportunities to escape lock-in, more equitable access, more job creation, and higher social returns on innovation investment. These advantages of more granular technologies are consistent with accelerated low-carbon transformation (Wilson et al. 2020a).

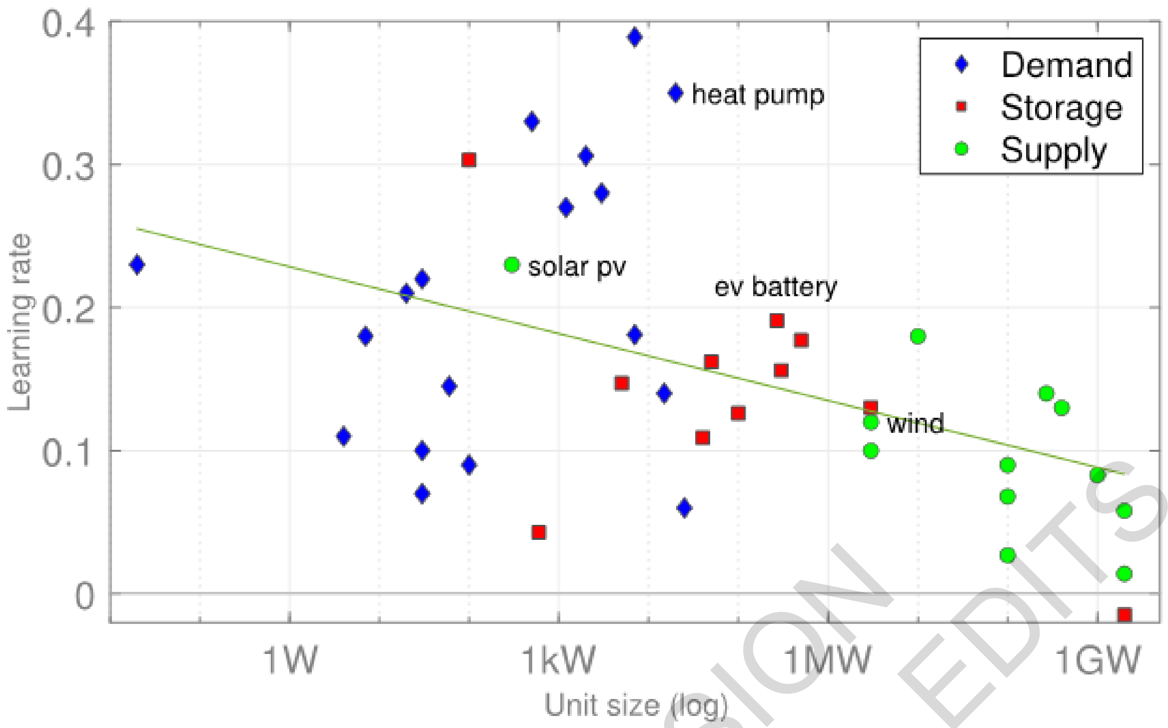


Figure 5.15 Demand technologies show high learning rates. Learning from small-scale granular technologies outperforms learning in larger supply side technologies. Line is linear fit of log unit size to learning rate for all 41 technologies plotted.

Source: Creutzig et al, 2021; based on Sweerts et al 2020.

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., carbon capture, transport and storage, or a hydrogen 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 mobilisation 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 5.9).

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Box 5.9 Is leapfrogging possible?

The concept of leapfrogging emerged in development economics (Soete 1985), energy policy (Goldemberg 1991) and environmental regulation (Perkins 2003), which provides a first critical review of the concept), 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 industrialisation, 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 but also highlights limitations (for a review see Watson and Sauter (Watson and Sauter 2011); with example case studies for China e.g. Gallagher (Gallagher 2006) or Chen and Li-Hua (Chen and Li-Hua 2011); Mexico (Gallagher and Zarsky 2007); or Japan and Korea, e.g. Cho et al. (Cho et al. 1998). Increasingly the concept is being integrated into the literature of low-carbon development, including innovation and technology transfer policies (for a review see Pigato (Pigato et al. 2020)), highlighting in particular the importance of contextual factors of successful technology transfer and leapfrogging including: domestic absorptive capacity and technological capabilities (Cirera and Maloney 2017); human capital, skills, and relevant technical know-how (Nelson and Phelps 1966); the size of the market (Keller 2004); greater openness to trade (Sachs and Warner 1995; Keller 2004); geographical proximity to investors and financing (Comin et al. 2012); environmental regulatory proximity (Dechezleprêtre et al. 2015); and stronger protection of intellectual property rights (Dechezleprêtre et al. 2013; Dussaux et al. 2017). The existence of a technological potential for leapfrogging therefore needs to be considered within a wider context of social, institutional, and economic factors that influence if leapfrogging potentials can be realised (*high evidence, high agreement*).

END BOX 5.9 HERE

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. 2018b) and potentially lead to a pre-mature lock-in of solutions that later turn out to have negative impacts (Cowan 1990, 1991) (*high evidence, medium agreement*).

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. 2019a) suggesting an important area for future research.
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 (cf. the reviews in (Sovacool et al. 2014; Wilson et al. 2020a) and the comprehensive discussion in (Smith et al. 2016) *(high evidence, medium agreement*). 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 decentralised, 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), digitalisation, 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 contextualisation and granularity in policy approaches is therefore important to address the challenges of rapid transitions towards zero-carbon systems *(high evidence, high agreement*).

5.6 Governance and policy

5.6.1 Governing mitigation: participation and social trust

In demand side mitigation, governance is key to drive the multidimensional changes needed to meet service needs within a society that provide people with a decent living while increasingly reducing resource and energy input levels (Rojas-Rueda et al. 2012; Batchelor et al. 2018; OECD 2019a). Impartial governance, understood as equal treatment of everyone by the rule of law, creates social trust and is thus a key enabler of inclusive and participatory demand-side climate policies (Rothstein 2011). Inclusive and broad-based participation itself also leads to greater social trust and thus is also a key enabler of demand-side climate mitigation (see Section 5.2 for details). Higher social trust and inclusive participatory processes also reduce inequality, restrain opportunistic behaviour and enhance cooperation (Drews and van den Bergh 2016; Gür 2020) (see also Section 5.2). Altogether, broad-based participatory processes are central to the successful implementation of climate policies (Rothstein and Teorell 2008; Klenert et al. 2018) (*high evidence , medium agreement)*. A culture of cooperation feeds back to increase social trust and enables action that reduce GHG emissions (Carattini et al. 2015; Jo and Carattini 2021), and requires including explicit consideration of the informal sector (Box 5.10). More equitable societies also have the institutional flexibility to allow for mitigation to advance faster, given their readiness to adopt locally appropriate mitigation policies; they also suffer less from policy lock-in (Tanner et al. 2009; Lorenz 2013; Chu 2015; Cloutier et al. 2015; Martin 2016; Vandeweerdt et al. 2016; Turnheim et al. 2018; Seto et al. 2016).

START BOX 5.10 HERE

Box 5.10 The informal sector and climate mitigation

The informal economy represents a large and growing portion of socio-economic activities (Charmes 2016; Muchie et al. 2016; Mbaye and Gueye 2018), including much of the work done by women worldwide. It 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), representing roughly 30% of GDP across a range of countries (Durán Heras 2012; Narayan 2017). Due to its importance, policies which support informal-sector climate mitigation activities may be extremely efficient (Garland and Allison M. 2015). For example, environmental and energy taxes may have negative gross costs when the informal sector dominates economic activity since these taxes indirectly tax the informal sector; informal production may substitute for energy-intensive goods, with strong welfare-enhancing effects (Bento et al. 2018a). The informal sector can assemble social and financial capital, create jobs, and build low-carbon local economies (Ruzek 2015). Constraints on small and informal-sector firms' ability to build climate resilience include financial and data barriers, limited access to information technology, and policy exclusion (Kraemer-Mbula and Wunsch-Vincent 2016; Crick et al. 2018a,b).

Informal-sector innovation is often underrated. It gives marginalised people access to welfare-enhancing innovations, building on alternative knowledge and socially-embedded reciprocal exchange (Jaffe and Koster 2019; Sheikh 2019; Sheikh and Bhaduri 2020). Large improvements in low-emission, locally-appropriate service provision are possible by facilitating informal-sector service providers' access to low-energy technologies (while taking care not to additionally burden the unpaid and marginalised), 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. The importance of the informal economy, especially in low-income countries, opens many possibilities for new approaches to DLS service provision along with climate resilience (Rynikiewicz and Chetaille 2006; 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; Schröder et al. 2019; Javaid et al. 2020).

Public information and understanding of the CO_2-eq emissions implied by consumption patterns can unleash great creativity for meeting 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; Williams et al. 2019). Community-based mapping, social learning, green infrastructure development, and participatory governance facilitate such information-sharing (Tauhid and Zawani 2018; Mazeka et al. 2019; Sharifi 2020), strengthening mitigation policies (Loiter et al. 1999; Stokes and Warshaw 2017; Zhou et al. 2019).

Since informal settlements are usually dense, upgrading them supports low-carbon development pathways which leapfrog less-efficient housing, transport and other service provision, using locally-appropriate innovations (Satterthwaite et al. 2018). Examples of informal-sector mitigation include digital banking in Africa; mobility in India using recycled motors and collective transport; food production, meal 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, and illumination (Hordijk 2000; Baldez 2003; Maumbe 2006; Gutberlet 2008; Chaturvedi and Gidwani 2011; Nandy et al. 2015; Rouse and Verhoef 2016; Ackah 2017).

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5.6.2 Policies to strengthen Avoid-Shift-Improve

There is high untapped potential of demand-side mitigation options if considered holistically within the domains of avoid-shift-improve (Sections 5.3 and 5.4; Tables 5.1, 5.2, 5.3a, and 5.3b). Within the demand-side mitigation options opportunity space, policies currently focus more on efficiency and 'improve' options and relatively less on 'shift' and 'avoid' options (Dubois et al. 2019; Moberg et al. 2019). Current demand side policies are fragmented, piecemeal and too weak to drive demand-side transitions commensurate with 1.5ºC or 2ºC climate goals (Wilson et al. 2012; Fawcett et al. 2019; Mundaca et al. 2019; Moberg et al. 2019) (*high evidence, high agreement)*. However, increasingly policy mix in a number of countries has seen a rise in prohibitions on fossil fuel use as a way to weaken lock-ins, for example, in fossil fuel heating in favour of low carbon alternatives (Rosenbloom et al. 2020). Policies that are aimed at behaviour and lifestyle changes carry a perception of political risks for policy makers, which may explain why policy instruments focus more on information provision and adoption of incentives than on regulation and investment (Rosenow et al. 2017; Moberg et al. 2019). Acceleration of demand-side transitions would thus require both a broadening of demand-side options and the creation of comprehensive and targeted policy mixes (Kern et al. 2017; Rosenow et al. 2017; IPCC 2018) that strengthens five drivers of decision and action identified in Section 5.4, Table 5. and in the tables below *(high evidence, high agreement)*. 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).

Systematic categorisation of demand-side policy options in different sectors and services through the avoid-shift-improve (ASI) framework enables identification of major entry points and possible associated social struggles to overcome for the policy instruments/interventions as discussed below.

5.6.2.1 Avoid policies

There is high evidence and agreement that "Avoid' policies that affect lifestyle changes offer opportunities for cost-effective reductions in energy use and emissions, but would need to overcome political sensitivities around government efforts to shape and modify individual-level behaviour (see Table 5.5) (Grubb et al. 2020; Rosenow et al. 2017). These policies include ways to help avoid travel growth through integrated city planning or building retrofits to help avoid demand for transport, heating or cooling (Bakker et al. 2014; Lucon et al. 2014; de Feijter et al. 2019), which interact with existing infrastructure. Dense pedestrianised cities and towns and medium-density transit corridors are better placed to implement policies for car reductions than 'sprawled' cities characterised by low-density, auto-dependent and separated land uses (Seto et al. 2014; Newman and Kenworthy 2015; Newman et al. 2017; Bakker et al. 2014).

Cities face pressing priorities like poverty reduction, meeting basic services and building human and institutional capacity. These are met with highly accessible walkable and cyclable cities, connected with public transit corridors, enabling equal accessibility for all citizens, and enabling a high level of service provisioning (UN-Habitat 2013; Creutzig et al. 2016b). Infrastructure development costs less than for car dependent cities. However, it requires a mindset shift for urban and transport planners (*medium evidence, high agreement*).

Policies that support the avoidance of higher emission lifestyles and improve wellbeing are facilitated by the introduction of smart technologies, infrastructures and practices (Amini et al. 2019). They include regulations and measures for investment in high-quality ICT infrastructure, regulations to restrict number plates as well as company policy around flexible working conditions (Lachapelle et al. 2018; Shabanpour et al. 2018). Working-from-home arrangements may advantage certain segments of society such as male, older, higher educated and highly paid employees, potentially exacerbating existing inequalities in the labour market (Lambert et al. 2020; Bonacini et al. 2021). In the absence of distributive or other equity-based measures, the potential gains in terms of emissions reduction may therefore be counteracted by the cost of increasing inequality. This potential growth in inequality is likely to be more severe in poorer countries that will additionally suffer from a lack of international funding for achieving the SDGs (Barbier and Burgess 2020; UN 2020) (*high evidence, medium agreement*).

Table 5.5 Examples of policies to enable "avoid" options

Mitigation Option	Perceived struggles to overcome	Policy to overcome struggles (Incentives)
Reduce passenger km	Overcoming existing paradigms and planning practices and car dependency (Rosenow et al. 2017; Grubb et al. 2020).	Integrated city planning to avoid travel growth, car reduction, building retrofits to avoid heating or cooling demand (Bakker et al. 2014; Lucon et al. 2014; de Feijter et al. 2019).
	Financial and capacity barrier in many developing countries.	Public-private partnership to overcome financial barrier. (see Box 5.7) (Roy et al. 2018b).
	Status dimension of private cars	Taxation of status consumption; reframing of low-carbon transport as high status (Hoor 2020; Ramakrishnan and Creutzig 2021).

Reduce/avoid food waste	Little visible political and social momentum to prevent food waste in the Global North.	Strengthen national nutrition guidelines for health safety, Improve education/awareness on food waste; policies to eliminate ambiguous food labelling include well-defined and clear date labelling systems for food (Wilson et al. 2017); policies to support R&D to improve packaging to extend shelf life (Thyberg and Tonjes 2016). Charging according to how much food households throw away.
Reduce size of dwellings	Size of residents/dwelling getting smaller in many countries.	Compact city design, taxing residential properties with high per capita area, progressive taxation of high status consumption (Ramakrishnan and Creutzig 2021).
Reduce/avoid heating, cooling and lighting in dwellings	Change in individual behaviour in dress codes and working times	Temperature set point as norm; building energy codes that set building standards; bioclimatic or/and zero emissions; cities and buildings that incorporate features like daylighting and increased building depth, height, and compactness (Steemers 2003; Creutzig et al. 2016a).
Sharing economy for more service per product	Inclusivity and involvement of users in design. Digital divide, unequal access and unequal digital literacy (Pouri and Hilty 2018). Political or power relations among actors involved in the sharing economy (Curtis and Lehner 2019).	Lower prices for public parking, and subsidies towards the purchase of electric vehicles providers of electric vehicle (EV) sharing services were given subsidies towards the purchase of electric vehicles (Jung and Koo 2018).

5.6.2.2 Shift policies

As indicated in Table 5.6, 'Shift' policies have various forms such as the demand for low carbon materials for buildings and infrastructure in manufacturing and services and shift from meat-based protein, mainly beef, to plant-based diets of other protein sources (Willett et al. 2019; Ritchie et al. 2018; Springmann et al. 2016a) (*high evidence, high agreement*). Governments also play a direct role beyond nudging citizens with information about health and wellbeing. While the effectiveness of these policies on behaviour change overall may be limited (Pearson-Stuttard et al. 2017; Shangguan et al. 2019), there is some room for policy to influence actors upstream, i.e. industry and supermarkets which may give rise to longer-term, structural change.

Table 5.6 Examples of policies to enable "shift" options

Mitigation Option	Perceived struggles to overcome	Policy to overcome struggles (Incentives)
More walking, less car use, train rather air travel	Adequate infrastructure may be absent, speed a part of modern life.	Congestion charges (Pearson-Stuttard et al. 2017; Shangguan et al. 2019); deliberate urban design including cycling lanes, shared micromobility, and extensive cycling infrastructure; synchronised/integrated transport system & timetable . Fair street space allocation (Creutzig et al. 2020).

Multifamily housing,	Zonings that favour single family homes have been dominant in planning (Hagen 2016).	Taxation, relaxation of single-family zoning policies and land use regulation (Geffner 2017).
Shifting from meat to other protein	Minimal meat required for protein intake, especially in developing countries for population suffering from malnutrition and when plant-based protein is lacking(Garnett 2011; Sunguya et al. 2014; Behrens et al. 2017; Godfray et al. 2018); Dominance of market-based instruments limits governments' role to nudging citizens with information about health and wellbeing, and point-of-purchase labelling (Pearson-Stuttard et al. 2017; Shangguan et al. 2019).	Tax on meat/beef in wealthier countries and/or households (Edjabou and Smed 2013; Säll and Gren 2015). Nationally recommended diets (NRDs) (Behrens et al. 2017; Garnett 2011; Sunguya et al. 2014; Godfray et al. 2018).
Material-efficient product design, packaging	Resistance by architects and builders who might perceive risks with lean designs. Cultural/ social norms. Policy measures not keeping up with changes on the ground such as increased consumption of packaging.	Embodied carbon standards for buildings (IEA 2019c).
Architectural design with shading and ventilation	Lack of education, awareness and capacity for new thinking, local air pollution.	Incentives for increased urban density and incentives to encourage architectural forms with lower surface-to-volume ratios and increased shading support (Creutzig et al. 2016a).

Mobility services is one of the key areas where a combination of market-based and command-and-control measures have been implemented to persuade large numbers of people to get out of their automobiles and take up public transport and cycling alternatives (Gehl et al. 2011). Congestion charges are often complemented by other measures such as company subsidies for bicycles to incentivise the shift to public mobility services. Attracting people to public transport requires sufficient spatial coverage of transport with adequate level of provision, and good quality service at affordable fares (Sims et al. 2014; Moberg et al. 2019) (*high evidence, high agreement*). Cities such as Bogota, Buenos Aires and Santiago have seen rapid growth of cycling, resulting in an 6-fold of cyclists (Pucher and Buehler 2017). Broadly, the history and type of city determines how quickly the transition to public modes of transport can be achieved. For example, cities in developed countries enjoy an advantage in that network of high-quality public transport predating the advent of automobiles, whereas cities in less developed countries are latecomers in large-scale network infrastructure (Gota et al. 2019; UN-Habitat 2013).

5.6.2.3 Improve policies

'Improve' policies focus on the efficiency and enhancement of technological performance of services (Table). In mobility services, *'improve'* policies aim at improving vehicles, comfort, fuels, transport operations and management technologies; and in building, they include policies for improving efficiency of heating systems and retrofitting existing buildings. Efficiency *improvements* in electric cooking appliances, together with the ongoing decrease in prices of renewable energy technologies, is opening policy opportunities to support households to adopt electrical cooking at mass scale (IEA 2017c; Puzzolo et al. 2019) (*medium evidence*, *medium agreement*). 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 and technology and fuel pathways (Martínez et al. 2017; Mondal et al. 2018; Rosenthal et al. 2018; Serrano-Medrano et al. 2018; Hof et al. 2019) (*high evidence, high agreement*) (see Box 5.6).

Table 5.7 Examples of policies to enable "improve" options

Mitigation Option	Perceived struggles to overcome	Policy to overcome struggles (Incentives)
Lightweight vehicle, hydrogen car, electric vehicles, ecodriving	Adequate infrastructure may be absent, speed a part of modern life.	Monetary incentives and traffic regulations favouring EVs; investment in public charging infrastructure; car purchase tax calculated by a combination of weight, CO_2 and NOx emissions (Haugneland and Kvisle 2015; Globisch et al. 2018; Gnann et al. 2018; Lieven and Rietmann 2018; Rietmann and Lieven 2019).
Use low carbon materials in dwelling design	Manufacturing and R&D costs, recycling processes and aesthetic performance (Orsini and Marrone 2019). Access to secondary materials in the building sector (Nußholz et al. 2019).	Increasing recycling of construction and demolition waste; Incentives must be available to companies in the waste collection and recovery markets to offer recovered material at higher value (Nußholz et al. 2019).
Better insulation and retrofitting	Policies to advance retrofitting and GHG emission reductions in buildings are laden with high expectations since they are core components of politically ambitious city climate targets (Haug et al. 2010). Bringing building owners to implement measures identified in auditing results Lack of incentive for building owners to invest in higher efficiency than required norms (Trencher et al. 2016).	Grants and loans through Development Banks, building and heating system labels, and technical renovation requirements to continuously raise standards (Ortiz et al. 2019; Sebi et al. 2019); disclosure of energy use, financing and technical assistance (Sebi et al. 2019).
Widen low carbon energy access	Access to finance, capacity, robust policies, affordability for poor households for off-grid solutions until recently (Rolffs et al. 2015; Fuso Nerini et al. 2018; Mulugetta et al. 2019).	Feed-in-tariffs and auctions to stimulate investment. Pay-as-you-go (PAYG) end-user financing scheme where 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).
Improve illumination related emission	Supply side solution for low carbon electricity provision.	Building energy codes that set building standards; grants and other incentives for R&D.
Improve efficiency of cooking appliances	Reliability of power in many countries is not guaranteed; electricity tariff is high in many countries; cooking appliances are mostly imported using scarce foreign currency.	Driven by a combination of government support for appliance purchases, shifting subsidies 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, coal 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; Dendup and Arimura 2019; Pattanayak et al. 2019; Martínez et al. 2017).
Shift to LED lamp	People spend increasing amounts of time indoors, with heavy dependence on and demand for artificial lighting environment (Ding et al. 2020).	Government Incentive, utility incentive (Bertoldi et al. 2021). EU bans on directional and non-directional halogen bulbs (Franceschini et al. 2018).
Solar water heating	Dominance of incumbent energy source i.e. electricity; cheap conventional energy; high initial investment costs and long payback (Joubert et al. 2016).	Subsidy for solar heaters (Li et al. 2013; Bessa and Prado 2015; Sgouridis et al. 2016).

Table 5.7 highlights the significant progress made in the uptake of the Electrical Vehicle (EV) in Europe, driven by a suite of incentives and policies. Increased activity in widening Electric Vehicle (EV) use is also occurring in developing countries. The Indian Government's proposal to reach the target of a 100% electric vehicle fleet by 2030 has stimulated investment in charging infrastructure that can facilitate diffusion of larger EVs (Dhar et al. 2017). Although the proposal was not converted into a policy, India's large and growing two-wheeler market has benefitted from the policy attention on EVs , showing a significant potential for increasing the share of electric two-and three-wheelers in the short-term (Ahmad and Creutzig 2019). Similar opportunities exist for China where e-bikes have replaced car trips and are reported to act as intermediate links in multimodal mobility (Cherry et al. 2016).

In recent years, policy interest has arisen to address the energy access challenge in Africa using low-carbon energy technologies 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 appliance efficiency such as 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) (*high evidence, high agreement*).

5.6.3 Policies in transition phases

Demand-side policies tend to vary for different transition phases (*high evidence, high agreement*) (Sandin et al. 2019; Roberts and Geels 2019). In the first phase, which is characterised 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, standardisation, cost reduction, and the creation of early market niches (Ruggiero et al. 2018; Borghei and Magnusson 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; Strauch 2020; Geels et al. 2018). In the fourth phases, transitions can also be stimulated through policies that weaken or phase-out existing regimes such as removing inefficient subsidies (for cheap petrol or fuel oil) that encourage wasteful consumption, increasing taxes on carbon-intensive products and practices (Box 5.11), or substantially tightening regulations and standards (Kivimaa and Kern 2016; David 2017; Rogge and Johnstone 2017).

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Box 5.11: 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) and national position in international climate negotiations with major implications for policy design. For example, policy proposals need to circumvent "solution aversion": that is, individuals are more doubtful about the urgency of climate change mitigation if the proposed policy contradicts their political worldviews (Campbell and Kay 2014). While there are reasons to believe that 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 efficiency feature alone is not what makes citizens like or dislike carbon pricing schemes (Kallbekken et al. 2011; Carattini et al. 2017; Klenert et al. 2018).

Citizens tend to ignore or doubt the idea that pricing carbon emissions reduces GHG emissions (Kallbekken et al. 2011; Douenne and Fabre 2019; Maestre-Andrés et al. 2019). Further, citizens have fairness concerns about carbon pricing (Büchs and Schnepf 2013; Douenne and Fabre 2019; Maestre-Andrés et al. 2019), even if higher carbon prices can be made progressive by suitable use of revenues (Rausch et al. 2011; Williams et al. 2015; Klenert and Mattauch 2016). 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 (Kallbekken et al. 2011; Carattini et al. 2017). It may be that the word "tax" evokes a feeling of distrust in government and may have high costs, low benefits and distributional effects (Strand 2020). Trust in politicians is negatively 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. 2019). Few developing countries have adopted carbon taxes, probably due to high costs, relatively low benefits, and distributional effects (Strand 2020).

To address these realities regarding support for carbon pricing, some studies have examined whether specific uses of the revenue can increase public support for higher carbon prices (Carattini et al. 2017; Beiser-McGrath and Bernauer 2019). 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. 2017) 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, returning the revenues to individuals in a salient manner may increase public support and alleviate fairness proposals, given sufficient information (Carattini et al. 2017; Klenert et al. 2018). Perceived fairness is one of the strongest predictors of policy support (Jagers et al. 2010; Whittle et al. 2019).

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5.6.4 Policy sequencing and packaging to strengthen enabling conditions

Policy coordination is critical to manage infrastructure interdependence across sectors, and to avoid trade-off effects (Raven and Verbong 2007; Hiteva and Watson 2019), specifically requiring the consideration of interactions among supply-side and demand-side measures (Kivimaa and Virkamäki 2014; Rogge and Reichardt 2016; de Coninck et al. 2018; Edmondson et al. 2019) (*high evidence, high*

agreement). For example, the amount of electricity required for cooking can overwhelm the grid which can lead to failure, causing end-users to shift back to traditional biomass or fossil fuels (Ateba et al. 2018; Israel-Akinbo et al. 2018); thus grid stability policies need to be undertaken in conjunction.
Policy makers operate in a politically dynamic national and international environment, and their policies often reflect their contextual situations and constraints with regards to climate-related reforms (Levin et al. 2012; Copland 2019), including differentiation between developed and developing countries (Beer and Beer 2014; Roy et al. 2018c) *(high evidence, high agreement).* Variables such as internal political stability, equity, informality (Box 5.10), macro-economic conditions, public debt, governance of policies, global oil prices, quality of public services, and the maturity of green technologies play important roles in determining policy directions.

Sequencing policies appropriately is a success factor for climate policy regimes (*high evidence, high agreement*). In most situations policy measures require a preparatory phase that prepares the ground by lowering the costs of policies, communicating the costs and benefits to citizens, and building coalitions for policies, thus reducing political resistance (Meckling et al. 2017). This policy sequencing aims to incrementally relax or remove barriers over time to enable significant cumulative increases in policy stringency and create coalitions that support future policy development (Pahle et al. 2018). German policies into renewables began with funding for RD&D, then subsidies for demonstration projects during the 1970s and 1980s, and continued to larger-scale projects such as 'Solar Roofs' programmes in the 1990s, including the scaled-up FITs for solar power (Jacobsson and Lauber 2006). These policies led to industrial expansion in wind and solar energy systems, giving rise to powerful renewables interest coalitions that defend existing measures and lend political support for further action. Policy sequencing has also been deployed to introduce technology bans and strict performance standards with a view to eliminate emissions as the end goal, and may the involve simultaneous support low carbon options while deliberately phasing out established technological regime (Rogge and Johnstone 2017).

As a key contending policy instrument, carbon pricing also requires embedding into policy packages *(high evidence, medium agreement).* Pricing may be regressive and perceived as additional costs by households and industry, making investments into green infrastructure politically unfeasible, as examples from France and Australia show (Copland 2019; Douenne and Fabre 2020). Reforms that would push up household energy expenses are often left aside for fear of how citizens, especially the poor, would react or cope with higher bills (Martinez and Viegas 2017; Tesfamichael et al. 2021) (*high evidence, medium agreement*). This makes it important to precede carbon pricing with investments into renewable energy and low carbon transport modes (Biber et al. 2017; Tvinnereim and Mehling 2018), and especially support developing countries by building up low-carbon energy and mobility infrastructures and technologies, thus reducing resistance to carbon pricing (Creutzig 2019). Additionally, carbon pricing receives higher acceptance if fairness and distributive consideration are made explicit in revenue distribution (see Box 5.11).

The effectiveness of a policy package is determined by design decisions as well as the wider governance context that include the political environment, institutions for coordination across scales, bureaucratic traditions, and judicial functioning (Howlett and Rayner 2013; Rogge and Reichardt 2013; Rosenow et al. 2016) (*high evidence, high agreement*). Policy packages often emerge through interactions between different policy instruments as they operate in either complementary or contradictory ways, resulting from conflicting policy goals (Cunningham et al. 2013; Givoni et al. 2013). An example includes the acceleration in shift from traditional biomass to the adoption of modern cooking fuel for 80 million households in rural India over a very short period of 4 years (2016-2020), which employed a comprehensive 'policy package' including financial incentives, infrastructural support and strengthening of the supply chain to induce households to shift towards a clean cooking fuel from the use of biomass (Kumar 2019). This was operationalised by creating a LPG supply chain by linking oil and gas companies with distributors to assure availability, create infrastructure for local storage along with an improvement of the rural road network, especially in the rural context (Sankhyayan and Dasgupta 2019). State governments initiated separate policies to increase the distributorship of LPG in their states (Kumar et al. 2016). Similarly, policy actions for scaling up electric vehicles need to be well designed and coordinated where EV policy, transport policy and climate policy are used together, working on different decision points and different aspects of human behaviour (Barton and Schütte 2017). The coordination of the multiple policy actions enables co-evolution of multiple outcomes that involve shifting towards renewable energy production, improving access to charging infrastructure, carbon pricing and other GHG measures (Wolbertus et al. 2018).

Design of policy packages should consider not only policies that support low carbon transitions but also those that challenge existing carbon-intensive regimes, generating not just policy "winners" but also "losers" (Carley and Konisky 2020) (*high evidence, high agreement*). The winners include low carbon innovators and entrepreneurs, while the potential losers include incumbents with vested interests in sustaining the status quo (Mundaca et al. 2018; Monasterolo and Raberto 2019). Low carbon policy packages would benefit from looking beyond climate benefits to include non-climate benefits such as health benefits, fuel poverty reductions and environmental co-benefits (Ürge-Vorsatz et al. 2014; Sovacool et al. 2020b). The uptake of decentralised energy services using solar PV in rural areas in developing countries is one such example where successful initiatives are linked to the convergence of multiple policies that include import tariffs, research incentives for R&D, job creation programmes, policies to widen health and education services, and strategies for increased safety for women and children (Kattumuri and Kruse 2019; Gebreslassie 2020).

The energy efficient lighting transition in Europe represents a good case of the formation of policy coalitions that led to the development of policy packages. As attention for energy efficiency in Europe increased in the 1990s, policymakers attempted to stimulate energy-saving lamp diffusion through voluntary measures. But policies stimulated only limited adoption. Consumers perceived CFLs as giving 'cold' light, being unattractively shaped, taking too long to achieve full brightness, unsuitable for many fixtures, and unreliable (Wall and Crosbie 2009). Still, innovations by major CFL and LED multinationals continued. Increasing political attention to climate change and criticisms from environmental NGOs (e.g. WWF, Greenpeace) strengthened awareness about the inefficiency of incandescent light bulbs (ILBs), which led to negative socio-cultural framings that associated ILBs with energy waste (Franceschini and Alkemade 2016). The combined pressures from the lighting industry, NGOs and member states led the European Commission to introduce the 2009 ban of ILBs of more than 80W, progressing to lower-wattage bans in successive years. While the ILB ban initially mainly boosted CFL diffusion, it also stimulated LED uptake. LED prices decreased quickly by more than 85% between 2008 and 2012 (Sanderson and Simons 2014), because of scale economies, standardisation and commoditisation of LED chip technology, and improved manufacturing techniques. Because of further rapid developments to meet consumer tastes, LEDs came to be seen as the future of domestic lighting (Franceschini et al. 2018). Acknowledging these changing views, the 2016 and 2018 European bans on directional and non-directional halogen bulbs explicitly intended to further accelerate the LED transition and reduce energy consumption for residential lighting.

In summary, more equitable societies are associated with high levels of social trust and enables action that reduce GHG emissions. To this end, people play an important role in the delivery of demand-side mitigation options within which efficiency and 'improve' options dominate. Policies that are aimed at behaviour and lifestyle changes come with political risks for policy makers. However, the potential exists for broadening demand-side interventions to include 'avoid' and 'shift' policies. Longer term thinking and implementation that involves careful sequencing of policies as well as designing policy packages that address multiple co-benefits would be critical to manage interactions among supply-side and demand-side options to accelerate mitigation.

5.7 Knowledge gaps

Knowledge gap 1: Better metric to measure actual human well-being

Knowledge on climate action that starts with the social practices and how people live in various environments, cultures, contexts and attempts to improve their well-being, is still in its infancy. In models, climate solutions remain supply-side oriented, and evaluated against GDP, without acknowledging the reduction in well-being due to climate impacts. GDP is a poor metric of human well-being, and climate policy evaluation requires better grounding in relation to decent living standards and or similar benchmarks. Actual solutions will invariably include demand, service provisioning and end use. Literature on how gender, informal economies mostly in developing countries, and solidarity and care frameworks translate into climate action, but also how climate action can improve the life of marginalised groups remains scarce. The working of economic systems under a well-being driven rather than GDP driven paradigm requires better understanding.

Knowledge gap 2: Evaluation of climate implication of the digital economy

The digital economy, as well as shared and circular economy, is emerging as template for great narratives, hopes and fears. Yet, there is few systematic evaluations of what is already happening and what can govern it towards a better narrative. Research needs to better gauge energy trends for rapidly evolving systems like data centres, increased use of social media and influence of consumption and choices, AI, blockchain, implication of digital divide among social groups and countries on well-being. Governance decisions on AI, indirectly fostering either climate harming or climate mitigating activities remain unexplored. Better integration of mitigation models and consequential life cycle analysis is needed for assessing how digitalisation, shared economy and circular economy change material and energy demand.

Knowledge gap 3: Scenario modelling of services

Scenarios start within parameter-rich models carrying more than 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 diversity in concepts and patterns of lifestyles rarely considered. A new class of flexible and modular models with focus on services and activities, based on variety of data sources including big data collected and compiled is needed. There is scope for more sensitivity analysis on two aspects to better guide further detailed studies on societal response to policy. These aspects need to explore which socio-behavioural aspects/ organisation changes has biggest impact on energy/emissions reductions, and on the scale for take-back effects, due to interdependence on inclusion or exclusion of groups of people. Models mostly consider behavioural change free, and don’t account for how savings due to “avoid” measures may be re-spent. Most quantitatively measurable service indicators e.g. pkm or tkm are also inadequate to measure services in the sense of well-being contributions. More research is needed on how to measure e.g. accessibility, social inclusion etc. Otherwise services will also be poorly represented in scenarios.

Knowledge gap 4: Dynamic interaction between individual, social, and structural drivers of change

Better understanding is required on: (1) More detailed causal mechanisms in the mutual interactions between individual, social, and structural drivers of change and how these vary over time, i.e. what is their relative importance in different transition phases; (2) how narratives associated with specific technologies, group identities, and climate change 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. (7) how shocks like prolonged pandemic impacts willingness and capacity to change and their permanency for various social actors and country contexts. The debate on the most powerful leverage point/s and policies for speeding up change in social and technological systems need to be resolved with more evidence. Discussion on the policy interdependence and implications of end-user and efficiency focused strategies have only just started suggesting an important area for future research.

Frequently Asked Questions (FAQs)

FAQ 5.1 What can every person do to limit warming to 1.5°C?

People can be educated through knowledge transfer so they can act in different roles, and in each role everyone can contribute to limit global warming to 1.5°C. As citizens, with enough knowledge can organise and put political pressure on the system. Role models can set examples to others. Professionals (e.g., engineers, urban planners, teachers, researchers) can change professional standards in consistency with decarbonisation; e.g., urban planners and architects can design physical infrastructures to facilitate low-carbon mobility and energy use by making walking and cycling safe for children. Rich investors can make strategic plan to divest from fossils and invest in carbon-neutral technologies. As consumers, especially if one belongs to the top 10% of the world population in terms of income, can limit consumption, especially in mobility, and explore the good life consistent with sustainable consumption. Policy makers support individual actions in certain contexts not only by economic incentives, such as carbon pricing, but also by interventions that understand complex decision making processes, habits, and routines. Examples of such interventions include but are not limited to choice architectures and nudges that set green options as default, shift away from cheap petrol or gasoline, increasing taxes on carbon-intensive products, or substantially tightening regulations and standards support shifts in social norms, and thus can be effective beyond the direct economic incentive.

FAQ 5.2 How does society perceive transformative change?

Human induced global warming, together with other global trends and events, such as digitalisation and automation, and the COVID-19 pandemic, induces changes in labour markets, and bring large uncertainty and ambiguity. History and psychology reveal that societies can thrive in these circumstances if they openly embrace uncertainty on the future and try out ways to improve life. Tolerating ambiguity can be learned, e.g., by interacting with history, poetry and the arts. Sometimes religion and philosophy also help.

As a key enabler, novel narratives created in a variety of ways e.g., by advertising, images, entertainment industry, help to break away from the established meanings, values and discourses and the status quo. For example, discourses that frame comfortable public transport service to avoid stress from driving cars on busy, congested roads help avoid car driving as a status symbol and create a new social norm to shift to public transport. Discourses that portray plant based protein and as healthy and natural promote and stabilise particular diets. Novel narratives and inclusive processes help strategies to overcome multiple barriers. Case studies demonstrate that citizens support transformative changes if participatory processes enable a design that meets local interests and culture. Promising narratives specify that even as speed and capabilities differ humanity embarks on a joint journey towards well-being for all and a healthy planet.

FAQ 5.3 Is demand reduction compatible with growth of human well-being?

There is a growing realisation that mere monetary value of income growth is insufficient to measure national welfare and individual well-being. Hence, any action towards climate change mitigation is best evaluated against a set of indicators that represent a broader variety of needs to define individual well-being, macroeconomic stability, and planetary health. Many solutions that reduce primary material and fossil energy demand, and thus reduce GHG emissions, provide better services to help achieve well-being for all.

Economic growth measured by total or individual income growth is a main driver of GHG emissions. Only a few countries with low economic growth rates have reduced both territorial and consumption-based GHG emissions from, typically by switching from fossil fuels to renewable energy and by reduction in energy low/zero carbon fuels, but until now at insufficient rates and levels for stabilising global warming at 1.5°C. High deployment of low/zero carbon fuels and associated rapid reduction in demand and use of coal, gas, and oil can further reduce the interdependence between economic growth and GHG emissions.

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