Towards demand-side solutions for mitigating climate change

Research on climate change mitigation tends to focus on supply-side technology solutions. A better understanding of demand-side solutions is missing. We propose a transdisciplinary approach to identify demand-side climate solutions, investigate their mitigation potential, detail policy measures and assess their implications for well-being.

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The upcoming sixth assessment report, AR6, of the Intergovernmental Panel on Climate Change (IPCC) will feature a chapter on demand, services and social aspects of mitigation (Chapter 5, Working Group III). This focus on demand promises to integrate scientific knowledge from diverse and underrepresented disciplines. Previous IPCC reports emphasized improved end-use efficiency but provided little insight into the nature, scale, implementation and implications of demand-side solutions, and ignored associated changes in lifestyles, social norms and well-being. There are promising disciplinary frameworks to estimate demand-side, consumption-based or lifestyle-based approaches for climate change mitigation[1–5], but a comprehensive assessment of the underlying science and methods needed to provide realistic assessments of their potential is still missing, because of competing frameworks and paradigms, lack of research synthesis (compare with ref. [6]) and predominant focus on techno-economic scenarios within the IPCC framing. This gap is unfortunate, as demand-side solutions entail fewer environmental risks than many supply-side technologies[7].

Demand-side solutions for mitigating climate change include strategies targeting technology choices, consumption, behaviour, lifestyles, coupled production–consumption infrastructures and systems, service provision and associated socio-technical transitions. Disciplines vary in their approaches and in the research questions that they ask on demand-side issues. For example, psychologists and behavioural economists focus on emotional factors and cognitive biases in the decision-making process; economists elaborate on how, under rational decision-making, carbon pricing and other fiscal instruments can trigger change in demand; sociologists emphasize everyday practices, structural issues and socio-economic inequality; anthropologists address the role of culture in energy consumption; and studies in technological innovation consider socio-technical transitions and the norms, rules and pace of adoption that support dominant technologies.

Synthesizing the existing approaches and findings from different fields can help to define a tractable research agenda to inform demand-side solutions. We call for a synthesis of social science and engineering research — including (but not limited to) contributions from psychology, economics, sociology, political science, industrial ecology, technological innovation studies and energy system modelling — to understand the demand-side potential for climate change mitigation. We sketch out a demand-side assessment framework and discuss key topics that need to be addressed: the characterization of demand; policy instruments and how they would affect demand; techno-economic evaluation; implications for well-being; mitigation pathways; and the sustainable development context. These topics and their associated focal research questions are summarized in Fig. 1.

Characterizing demand patterns

The starting point for a demand-side assessment seeks to characterize patterns of demand for energy, mobility, food and shelter, and the associated greenhouse gas (GHG) emissions. For example, energy demand to satisfy mobility needs will vary with transport mode, distance and frequency in its associated energy use and GHG emissions[8]. Choices between alternative strategies to provide the same energy service are highly contextual. Hence the first question to ask is: what norms, values, preferences and structural factors shape energy demand and GHG emissions (Fig. 1a)? Disciplines approach this question from disparate angles, as we will discuss next.

Identifying policy instruments

Policy instruments can spur demand-side solutions, in ways that depend on the specific energy service and socio-economic context. The second assessment question is therefore: which measures can reduce demand-side GHG emissions, and under what conditions? One needs to understand whether the proposed policy mechanism is realistically implementable, meeting the real constraints of policymakers on the ground, leading to the third question: how can measures best be implemented and become part of everyday practice (Fig. 1b)?

Different disciplines have provided important pieces of this big jigsaw, but much remains to be done to put the assessment of policy instruments together in a truly interdisciplinary effort and address the questions posed. Psychological theory predicts motivation for behaviours related to energy demand, and behavioural studies demonstrate that people's responses to policy instruments and to energy choices depart from the 'perfect rationality' expected of *homo economicus*[9]. As a result, 'nudges' — subtle changes in choice architectures — have been proposed and implemented as suitable policy instruments[10], supplementing other policies. Social practice theory emphasizes that demand is affected by socio-demographics, inequality, habits and structural aspects of consumption[11], pointing also to the social contexts for policy action. Economics evaluates the effectiveness of policy instruments by a social welfare function. Transition theory emphasizes the importance of group dynamics to develop niche solutions and

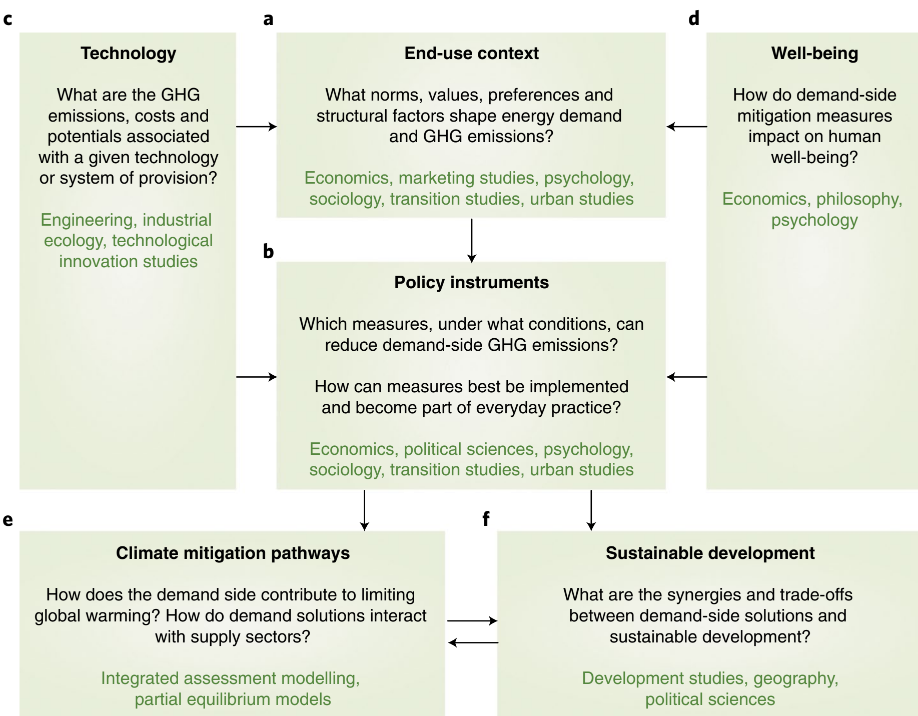

Fig. 1 | Key research questions and contributing disciplines for assessing demand-side solutions to mitigate climate change.

then mainstream them into society[12]. As human behaviour is affected by what others believe and do, policies that address social norms may lead to large-scale tipping points[13]. Furthermore, physical infrastructure also affects demand[5]. For example, transport-oriented development can lead to low-carbon mobility and accessibility, enabling habit formation congruent with climate mitigation. Such measures are particularly appealing in addressing multiple objectives[5].

As demand-side solutions deeply intersect with everyday life, questions of agency loom large. For example, consider that policy measures can change preferences. We hence must understand the assumption of exogenous preference (in which people's behaviour is determined by external factors outside the remit of a model) as a special and not very plausible case and instead should model humans as enculturated agents, affected by the norms and values of their culture[14]. Understanding how to optimally adjust policy to the presence of endogenous preferences and how policies can change these preferences is crucial for the accurate design of demand-side climate policy[5].

To enable transdisciplinary collaboration, common frameworks can serve as inclusive focal points for discussions and research. As an example, Box 1 describes the 'avoid–shift–improve' approach, a well-established framework in the sustainable transport community. The avoid–shift–improve approach enables a categorization of policy options and, by comparison, can enable cross-sectoral learning (see Table 1 for examples).

Accounting for GHG emissions, cost and potentials

The fourth question is: what are the GHG emissions, costs and potentials associated with a given technology or system of provision (Fig. 1c)? Industrial ecology has quantified the carbon footprint of different consumption categories, developed methods to identify the impact of changes in the choice of product or producer, and identified emission reduction potentials from a life-cycle perspective. Tools that provide quick, macro-level estimates of the efficacy of consumer-oriented policy measures can account for system-wide effects, such as rebounds, and can help to prioritize relevant policies[15,16].

Beyond specific technologies, research should take a wider scope and ask for the efficient and reliable provision of end-use services, rather than efficient technology design alone. For example, a specific service, such as mobility, can be systematically tested along (i) purpose (need or want); (ii) physical requirement (is a physical trip required or can it be substituted, for example, by telework?); (iii) consumer preference (mode choice, such as car versus bike); (iv) use efficiency (such as the ratio of useful passenger weight to overall vehicle weight); (v) service efficiency (for example, car sharing versus private car); (vi) end-use efficiency (for example, efficient fuel use of vehicle); and (vii) upstream efficiency (such as efficiency of fuel provision). Such a service-oriented perspective on emission reduction corresponds to the avoid–shift–improve approach: (i) and (ii) are 'avoid'; (iii) and (iv) are 'shift'; and (v)–(vii) are 'improve' options.

Technological studies contribute to an understanding of dynamic systems, describing cost reductions and strategies to overcome barriers on the path from research and development of a technology to market-scale deployment and uptake. Such insights are crucial not only for evaluating the emission reduction potential of options, but also to clarify the timescales involved until new technologies make a difference for climate mitigation. Insights into environmental or social risks associated with specific mitigation options are equally important to set the social boundaries for mitigation pathways.

Well-being implications

The fifth assessment question is: how do demand-side mitigation measures affect well-being (Fig. 1d)? Reducing energy use or GHG emissions needs to be balanced with the goal of enhancing human well-being[17]. On the one hand, there is a need for improved energy services among poor populations, who may not have access to clean cooking fuels or affordable and reliable electricity. On the other hand, there are numerous opportunities to enhance well-being and reduce GHG emissions at the same time. For example, policies aiming at reducing red meat consumption to reduce cardiovascular disease risks will have the co-benefit of reducing emissions. Walking and cycling can increase personal fitness and improve health. It is thus a key challenge to systematically assess both benefits and costs of new demand-side policies.

Moral philosophy and welfare economics distinguish three main concepts for the evaluation of well-being: (1) preferences, a utility-based concept that has been the workhorse of micro-economics; (2) hedonic concepts, such as those focusing on happiness and subjective well-being; and (3) eudaimonic approaches that encompass human needs and capability assessments[18]. These different concepts may lead to sometimes similar but mostly diverging policy conclusions, as analysed for the case of transportation[19].

Box 1 | The avoid–shift–improve framework

The avoid–shift–improve approach originated in the early 1990s in Germany to structure policy measures that reduce the environmental impact of transport; it was then taken up by international non-governmental organizations to address rapid motorization in developing countries in the 2000s, and was endorsed by Asian and Latin American countries in the 2013 Bogota Declaration on Sustainable Transport[23]. According to this approach, policies to limit GHG emissions in the transport sector need to consist of measures aimed at avoiding the need to travel, for example by improved urban planning, or teleworking; shifting travel to the lowest-carbon mode, such as cycling; and improving vehicles to be more energy-efficient and fuels to be less carbon-intensive.

We argue that a focus on human needs is particularly suited for developing countries, where demand is increasing quickly but where poverty eradication remains a central issue[20] and is closely associated with providing decent housing and services (for instance, electricity for light and cooking)[21]. It remains relevant in the context of deepening inequality and energy poverty in developed economies[22]. In developed countries, or places with higher income structure, a human-needs approach gains different connotations, possibly supporting the transition to more equitable consumption and higher well-being. Together, a focus on services rather than products enables the identification of wider mitigation options, but also the direct evaluation of well-being impacts and outcomes.

Climate mitigation pathways

This brings us to the sixth question: how does the demand side contribute to limiting global warming? How do demand solutions interact with the supply system (Fig. 1e)? Even the best of individual policies and measures will be relevant to climate change mitigation only within a coordinated framework of action. Sketched approaches such as transition theory, study of behavioural tipping points and social norms, and political economy insights into policy sequencing have the potential for laying out short-term and action-oriented mitigation pathways. Such approaches, together with bottom-up assessments from technological studies, can be soft-coupled and combined with integrated assessment models (IAMs) and similar economic models that assess system-wide potentials, reflecting the interaction between sectors, and mitigation options. With more consistent and systematic modelling efforts, an increased role for demand-side mitigation opportunities might also become available in the quantitative assessments, potentially replacing part of the need for more controversial mitigation technologies. Modelling and other assessment studies can also clarify the timescales over which actions and mitigations play out — an increasingly urgent requirement as time runs short to reduce atmospheric CO_2 concentration below levels consistent with less than 2 °C warming.

Sustainable development

Our seventh and last assessment question is: what are the synergies and trade-offs between demand-side solutions and sustainable development (Fig. 1f)? It is important to evaluate normatively the well-being implications of demand-side climate action. The United Nations' Sustainable Development Goals (SDGs) have at their heart an integrated vision of the prerequisites for human well-being, and they go beyond climate action (SDG 13) alone. For example, providing low-or-zero-carbon and resource efficient services equates with responsible consumption and production (SDG 12). But other SDGs are also directly implicated. Providing safe and sufficient nutrition tackles the zero-hunger goal (SDG 2) and good health and well-being (SDG 3); electricity services for light, cooking and others are key for the affordable and clean energy goal (SDG 7); and providing mobility and accessibility services is closely related to achieving sustainable cities and communities (SDG 11). The linkage between sustainable development and climate change is also articulated in the 'nationally determined' language of the Paris Agreement, which promotes climate mitigation that coincides with nationally determined development outcomes. A demand-side assessment should also be able to inform sustainable development pathways.

The ambition of AR6 to fill crucial evidence gaps on the demand side is critical, as the IPCC assessments of available solutions have suffered from this lacuna in literature. We have outlined some key avenues for research that scientists need to tackle over the coming years. We call for

Table 1 | Illustrative 'avoid–shift–improve' options in different sectors and services

	Service	Avoid	Shift	Improve
Transport	AccessibilityMobility	Integrate transport and land-use planningSmart logisticsTeleworkingCompact cities	Mode shift from car to cycling, walking, or public transit	Electric two-, three- and four-wheelersEco-drivingElectric vehiclesSmaller, light weight vehicles
Buildings	Shelter	Passive house or retrofit (avoiding demand for heating/cooling)Change temperature set-points	Heat pumps, district heating and coolingCombined heat and powerInvertor air conditioning	Condensing boilersIncremental insulation optionsEnergy-efficient appliances
Manufactured products and services	ClothingAppliances	Long-lasting fabric, appliances, sharing economyEco-industrial parks, circular economy	Shift to recycled materials, low-carbon materials for buildings and infrastructure	Use of low-carbon fabricsNew manufacturing processes and equipment use
Food	Nutrition	Calories in line with daily needsFood waste reduction	Shift from ruminant meat to other protein sources where appropriate	Reuse food wasteSmaller, efficient fridgesHealthy fresh food to replace processed food

Many options, such as urban form and infrastructures, are systemic and influence several sectors simultaneously.

collaborative and transdisciplinary efforts by relevant communities to achieve this fundamental goal. ❐

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Competing interests

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