TITLE:

Towards demand-side solutions for mitigating climate change

AUTHORS:

Felix Creutzig[1,2], Joyashree Roy[3], William F. Lamb[1], Inês M.L. Azevedo[4], Wändi Bruine de Bruin[5], Holger Dalkmann[6], Oreane Y. Edelenbosch[7], Frank W. Geels[8], Arnulf Grübler[9], Cameron Hepburn[10], Edgar Hertwich[11], Radhika Khosla[12], Linus Mattauch[10], Jan C. Minx[1,5], Anjali Ramakrishnan[1], Narasimha D. Rao[9], Julia Steinberger[5], Massimo Tavoni[7], Diana Ürge-Vorsatz[13], Elke U. Weber[14]

[1]Mercator Research Institute on Global Commons and Climate Change, Berlin

[2]Technische Universität Berlin

[3]Jadavpur University, Kolkata

[4]Carnegie Mellon University, Pittsburgh, PA

[5]University of Leeds

[6]Partnership on Sustainable, Low-Carbon Transport, Berlin

[7]Fondazione Eni Enrico Mattei, Milan

[8]University of Manchester

[9]International Institute for Advanced Systems Analysis, Laxenburg

[10] University of Oxford

[11]Yale University, New Haven, CT

[12]Centre for Policy Research, New Delhi

[13]Central European University, Budapest

[14]Princeton University, NJ

CORRESPONDING AUTHOR:

Correspondence to: Felix Creutzig (creutzig@mcc-berlin.net)

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.

The upcoming IPCC assessment report will feature a chapter on demand, services and social aspects of mitigation (Chapter 5, Working Group III, AR6). 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 on 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, due to a) competing frameworks and paradigms; b) lack of research synthesis (cf. with[6]); and c) predominant focus on techno-socio-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, behavior, lifestyles, coupled production-consumption infrastructures and systems, service provision, and associated socio-technical transitions. Disciplines vary in their approaches and research questions on demand side issues. For example, psychologists and behavioral economists focus on emotional factors and cognitive biases in decision making process; economists elaborate on how, under rational decision-making, carbon pricing, and other fiscal instruments can trigger change in demand; sociologists emphasize every-day 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 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 economy-energy system studies — 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; well-being implications; mitigation pathways; and the sustainable development context. These topics and their associated focal research questions are summarized in Figure 1.

Characterizing demand patterns

The starting point for a demand-side assessment seeks to characterize energy and food demand patterns and the associated GHG emissions. For example, energy demand to satisfy mobility needs varies with transport mode, distance, and frequency in its associated energy use and GHG emissions[8]. Choices between these 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 (Figure 1a)? Disciplines approach this question from disparate angles, as we will discuss next.

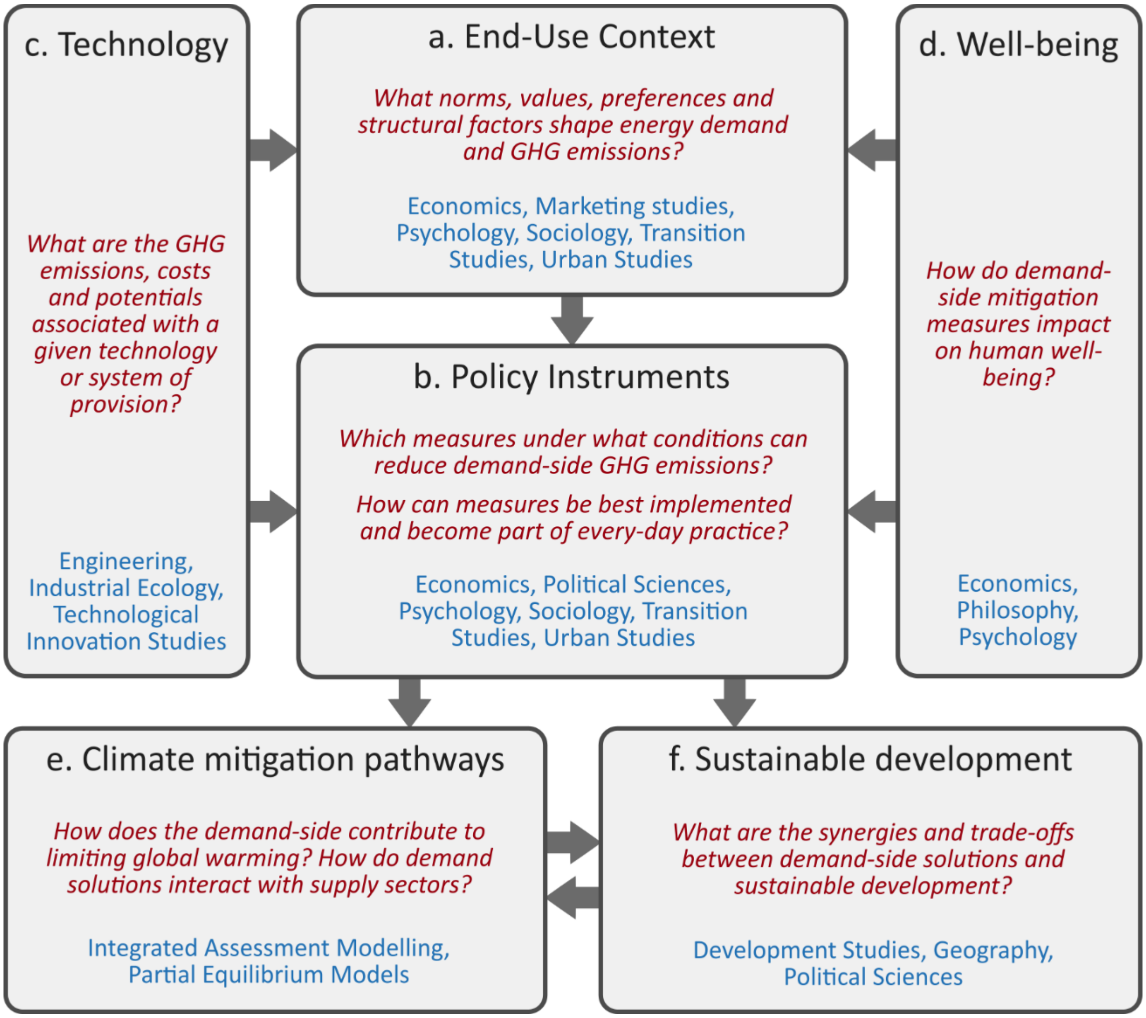

Figure 1. Key research questions and contributing disciplines for assessing demand-side solutions to mitigate climate change.

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 hence: 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 policy makers on the ground, leading to the third question: How can measures be best implemented and become part of every-day practice (Figure 1b)?

Different disciplines have provided important pieces to this big jigsaw, but still a lot remains to be done to put the assessment of policy instruments together in a truly inter-disciplinary effort and address the questions posed. Psychological theory predicts motivation for behaviors related to energy demand and behavioral studies demonstrate that people's responses to policy instruments and to energy choices may depart from the *homo economicus* 'perfect rationality' expectation[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 then mainstream them into society[12]. As human behavior 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 enables 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 every-day life, questions of agency loom large. For example, consider that policy measures can change preferences. We hence must understand the assumption of exogenous preference as a special and not very plausible case and instead should model humans as enculturated agents[14]. Understanding how to optimally adjust policy to the presence of endogenous preferences and how policies can change these preferences are crucial matters 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 below 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).

Box 1. The Avoid-Shift-Improve framework. The ASI approach originated in the early 1990s in Germany to structure policy measures that reduce the environmental impact of transport, was then taken up by international NGOs 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 the ASI approach, policies to limit GHG emissions in the transport sector need to consist of measures aimed at: (a) avoiding the need to travel, e.g. by improved urban planning, or teleworking, (b) shifting travel to the lowest carbon mode, e.g. cycling; and (c) improving vehicles to be more energy-efficient and fuels less carbon intensive.

Table 1. Illustrative Avoid-Shift-Improve options in different sectors and services. Many options, such as urban form and infrastructures are systemic, and influence several sectors simultaneously.

	Service	Avoid	Shift	Improve
Transport	➢ Accessibility ➢ Mobility	➢ Integrate transport & land use planning ➢ Smart logistics ➢ Tele-working ➢ Compact cities	➢ Mode shift from car to cycling, walking, or public transit	➢ Electric two, three, and four wheelers ➢ Eco-driving ➢ Electric vehicles ➢ Smaller, light-weight vehicles
Buildings	➢ Shelter	➢ Passive house or retrofit (avoiding demand for heating/ cooling)	➢ Heat pumps, district heating and cooling	➢ Condensing boilers ➢ Incremental insulation options ➢ Energy efficient appliances

		➢ Change temperature set-points	➢ Combined heat and power ➢ Invertor A/C	
Manufactured products and services	➢ Clothing ➢ Appliances	➢ Long lasting fabric, appliances, sharing economy ➢ eco-industrial parks, circular economy	➢ Shift to recycled materials, low-carbon materials for buildings and infrastructure	➢ Use of low carbon fabrics ➢ New manufacturing processes and equipment use
Food	➢ Nutrition	➢ Calories in line with daily needs ➢ Food waste reduction	➢ Shift from ruminant meat to other protein sources where appropriate	➢ Reuse food waste ➢ Smaller, efficient fridges ➢ Healthy fresh food to replace processed food

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 (Figure 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 only efficient technology design. For example, a specific service, such as mobility, can be systematically tested along a) purpose (need or want); b) physical requirement (is a physical trip required or can it be substituted, e.g. with telework); c) consumer preference (mode choice, e.g. car versus bike); d) use efficiency (e.g. the ratio of useful passenger weight to overall vehicle weight); e) service efficiency (e.g. car sharing versus private car); f) end-use efficiency (e.g. efficient fuel use of vehicle); and g) upstream efficiency (e.g. efficiency of fuel provision). Such a service-oriented perspective on emission reduction corresponds to the avoid-shift-improve approach: a)-b) are avoid; b)-d) are shift; and e)+f) are improve options.

Technological studies contribute to a dynamic system understanding, 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 on 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 impact well-being (Figure 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 also have the co-benefit of reducing emissions. Walking and cycling can increase personal fitness. It is thus a key challenge to systematically assess both benefits and costs of novel demand-side policies.

Moral philosophy and welfare economics distinguish three major 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]. Importantly, these different concepts may lead to sometimes similar but mostly diverging policy conclusions, as analyzed for the case of transportation[19].

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 (e.g., 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

Asking the sixth' question: How does the demand side contribute to limiting global warming? How do demand solutions interact with the supply system (Figure 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 like transition theory, insights on behavioral tipping points and social norms, and political economy insights on policy sequencing have all 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 integrated 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 modeling efforts an increased role of the demand-side mitigation opportunities might become available also in the quantitative assessments, potentially replacing part of the need for more controversial mitigation technologies. Modeling and other assessment studies can also clarify the time-scales over which actions and mitigations play out – an increasingly urgent requirement as time runs to reduce atmospheric CO_2 concentration below levels consistent with less than 2°C warming.

Sustainable Development

As a seventh and last assessment question: What are the synergies and tradeoffs between demand-side solutions and sustainable development (Figure 1f)? It is important to normatively evaluate the well-being implications of demand-side climate action. The SDGs have at their heart an integrated vision of the pre-requisites for human well-being and 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 collaborative and transdisciplinary efforts by relevant communities to achieve this fundamental goal.

REFERENCES:

1. Wilson, C., Grubler, A., Gallagher, K. S. & Nemet, G. F. Marginalization of end-use technologies in energy innovation for climate protection. *Nat. Clim. Change* **2,** 780–788 (2012).
2. Roy, J., Dowd, A.-M., Muller, A., Pal, S. & Prata, N. Lifestyles, well-being and energy. in *Global Energy Assessment (GEA)* 1527–1548 (Cambridge University Press, 2012).
3. Anderson, K., Quéré, C. L. & Mclachlan, C. *Radical emission reductions: the role of demand reductions in accelerating full decarbonization*. (Taylor & Francis, 2014).

4. Stern, P. C., Sovacool, B. K. & Dietz, T. Towards a science of climate and energy choices. *Nat. Clim. Change* **6,** 547–555 (2016).
5. Creutzig, F. *et al.* Beyond Technology: Demand-Side Solutions for Climate Change Mitigation. *Annu. Rev. Environ. Resour.* **41,** 173–198 (2016).
6. Minx, J., Callaghan, M. W., Lamb, W. F., Kowarsch, M. & Edenhofer, O. Learning about climate change solutions. *Environ. Sci. Policy* (submitted).
7. von Stechow, C. *et al.* 2° C and SDGs: united they stand, divided they fall? *Environ. Res. Lett.* **11,** 034022 (2016).
8. Mattioli, G. Transport needs in a climate-constrained world. A novel framework to reconcile social and environmental sustainability in transport. *Energy Res. Soc. Sci.* **18,** 118–128 (2016).
9. Kunreuther, H. *et al.* Integrated risk and uncertainty assessment of climate change response policies. (2014).
10. Ebeling, F. & Lotz, S. Domestic uptake of green energy promoted by opt-out tariffs. *Nat. Clim. Change* **5,** 868–871 (2015).
11. Shove, E. Beyond the ABC: climate change policy and theories of social change. *Environ. Plan. A* **42,** 1273–1285 (2010).
12. Geels, F. W. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Res. Policy* **39,** 495–510 (2010).
13. Nyborg, K. *et al.* Social norms as solutions. *Science* **354,** 42–43 (2016).
14. Lichtenstein, S. & Slovic, P. *The construction of preference*. (Cambridge University Press, 2006).
15. Wood, R. *et al.* Prioritizing Consumption-Based Carbon Policy Based on the Evaluation of Mitigation Potential Using Input-Output Methods. *J. Ind. Ecol.* n/a-n/a doi:10.1111/jiec.12702
16. Azevedo, I. M. Consumer end-use energy efficiency and rebound effects. *Annu. Rev. Environ. Resour.* **39,** 393–418 (2014).
17. Steinberger, J. K., Roberts, J. T., Peters, G. P. & Baiocchi, G. Pathways of human development and carbon emissions embodied in trade. *Nat. Clim. Change* **2,** 81–85 (2012).

18. Lamb, W. F. & Steinberger, J. K. Human well-being and climate change mitigation. *Wiley Interdiscip. Rev. Clim. Change* **8,** (2017).

19. Mattauch, L., Ridgway, M. & Creutzig, F. Happy or liberal? Making sense of behavior in transport policy design. *Transp. Res. Part Transp. Environ. Forthcom.* (2015).

20. Gough, I. & McGregor, J. A. *Wellbeing in developing countries: from theory to research*. (Cambridge University Press, 2007).

21. Mastrucci, A. & Rao, N. D. Decent housing in the developing world: Reducing life-cycle energy requirements. *Energy Build.* **152,** 629–642 (2017).

22. Sovacool, B. K. The political economy of energy poverty: A review of key challenges. *Energy Sustain. Dev.* **16,** 272–282 (2012).

23. Dalkmann, H. & Brannigan, C. Transport and climate change. A Sourcebook for Policy-Makers in Developing Cities: Module 5e. (2007).