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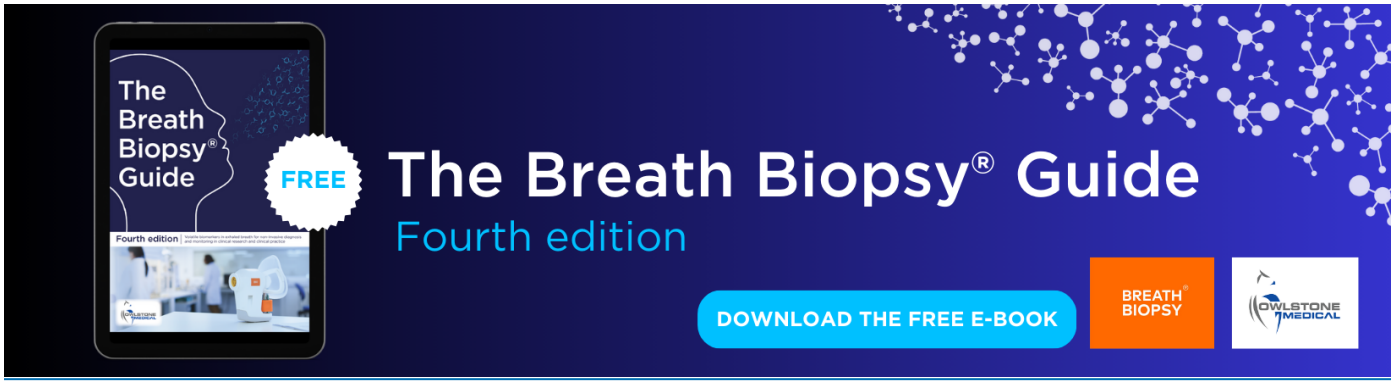

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EDITORIAL

Demand-side climate change mitigation: where do we stand and where do we go?

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Abstract

It is now well established that the demand side can contribute substantially to climate change mitigation thus increasing the solution space. The recent IPCC synthesis report for the first time explicitly reflected this class of solutions. Here, we provide an overview of an unique set of 22 review papers published in the focus issue of Environmental Research Letters. We also extract a key set of insights, ranging from the varied but rapidly evolving literature to demand-side mitigation potential, relevance for well-being, and consistent categorization of options across end-use sectors. We find that demand-side approaches to climate change mitigation supplement exclusively technology-focused supply side solutions and, in many cases, comprise system-wide effect contributing to well-being and planetary stability. Review studies cover macro-economics, well-being, and sustainable development goals on the metric side, and investigate consumption-based individual options, urban strategies, transport, building, and food sector potentials, but also the role of the circular economy, material efficiency, and digitalization. Demand-side measures can be categorized into avoid, shift, and improve approaches. Several additional reviews systematically investigate psychological and social approaches and initiatives to foster climate change mitigation. We finally outline important gaps and questions to be tackled in the coming years.

In this editorial, we synthesize a special issue and the findings from 22 systematic reviews on climate change mitigation that identify and scrutinize demand-side solutions for climate change mitigation. These reviews provide a comprehensive overview of the current state of research in this vital area, helping to shape and substantiate the most recent IPCC report (Skea *et al* 2022, Creutzig *et al* 2022b). Demand-side climate change mitigation is increasingly recognized as essential for achieving ambitious climate targets, supplementing supply side solutions firmly embedded in climate stabilization scenarios. This collection of reviews is particularly timely, given the pressing need to address these targets, but also considering the potential benefits of demand-side solutions for society. These solutions not only help in reducing greenhouse gas (GHG) emissions but also offer services that increase well-being and are consistent with broader planetary stability goals, such as reduced land use.

The demand-side of climate change has always been implicit in economic and social science research on climate change mitigation, but until recently has not been explicitly covered and quantified in assessment on climate solutions. A review synthesized how the 5th IPCC assessment report provided cases and examples on demand-side climate change mitigation in various chapters (Creutzig *et al* 2016). In a community wide effort, an outline of the scope of demand-side climate change mitigation was explored, highlighting the categorization of demand-side measures into avoid, shift, and improve (ASI) approaches (Creutzig *et al* 2018). We will see that this simple ASI categorization recurrently appears in this focus issue.

In this editorial, we discuss the review papers in 5 clusters. First, we start with an overview of

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the literature base. It begins with a discussion on 'History and Narratives', providing context and background on the evolution of demand-side mitigation. This is followed by an exploration of the 'Political Economy', assessing the influence of various stakeholders and economic factors. The next section, 'Economics of Transitioning', delves into the financial and economic implications of adopting demand-side strategies. Additionally, the 'Geography' section aims to address regional disparities and the unique challenges faced by different areas in implementing these strategies. Through these clusters, the editorial aims to provide a comprehensive understanding of demand-side climate change mitigation, setting the stage for the detailed reviews that follow.

1. The literature on demand-side solution evolves rapidly, and even more so than the climate change solution literature in general

A thorough analysis of the literature of demand side of climate change mitigation first requires a map of the literature and an accompanying definition of which part of the literature does so. The review titled 'Reviewing the scope and thematic focus of 100 000 publications on energy consumption, services and social aspects of climate change: a big data approach to demand-side mitigation' (Creutzig *et al* 2021) does so and presents a comprehensive review of literature on energy consumption, services, and social aspects of climate change. The review is based on a big literature data approach and focuses on demand-side mitigation.

The authors used a two-pronged approach to gather data. First, they used a top-down search query that yielded around 30 000 results. They then asked domain experts to identify five of the most important papers in their specific field relevant to demand, services, and social aspects of mitigation. Interestingly, over 50% of these papers were not discovered by the top-down query.

To address this, the authors developed 27 search queries that investigated aspects of the issue list in much more detail. These queries found 63 847 documents, of which 34% (21 913 documents) were also identified by the top–down search query. This means that expert queries identified two-thirds of documents not yet obtained by the top-down query, highlighting the important role of domain-experts in deriving search queries. The overall growth of the literature outperforms the overall literature on climate change solutions.

The authors then used topic modeling, an unsupervised machine learning technique, to explore the content of the studies in their queries, identifying four key clusters: policy, housing, mobility, and food/consumption. The mobility literature, specifically, sheds light on the significant role of transport in climate change mitigation, emphasizing the need for shifts in transport modalities and improved urban infrastructure to reduce dependency on personal vehicles. This insight is crucial in understanding how changes in mobility patterns can significantly contribute to reducing GHG emissions and enhancing urban sustainability. The housing literature emphasizes investments and refurbishment by homeowners, but also social and collective action, while the food/consumption literature points to the importance of behavioral change and its dynamic interaction with social norms. These clusters suggest that demand-side solutions can significantly improve public health. The centrality of the policy cluster within these findings underscores the critical role of political actions in integrating and enhancing the effectiveness of various demand-side approaches. This comprehensive analysis maps the underlying epistemic communities, demonstrating the interconnectedness of these areas of study in the broader context of demand-side climate change mitigation.

The study concludes that while the generic search of the 'chapter' queries is good at identifying the overall topics, expert domain queries find a high amount of additional literature (41 934 documents), making expert search queries and knowledge important for identifying in-depth literature.

A complementary, 'Systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part I: bibliometric and conceptual mapping' (Wiedenhofer *et al* 2020) investigates the literature on how macro-economic metrics relate to climate change mitigation. The systematic map and review scrutinizes the empirical literature on decoupling, focusing on the observed relationships between economic growth (approximated as GDP growth), resource use decoupling (materials, energy), and impact decoupling for GHG emissions on the national to global scale. The authors aim to understand the development of the relevant research streams, their conceptual and methodological approaches, and limitation, identifying three focal areas: energy flows and energy conversion chains in socio-economic systems, a more comprehensive perspective asserting that materials and energy are necessarily interlinked, and a stream based on data obtained from material and energy flow analysis. The authors find that decomposition and regression analyses (28%) and econometric time-series analyses (24%) are the most prevalent methods used in the studies. They also find that 46% of the analyses are single-country analyses, with China leading with 157 analyses, followed by the USA with 31 analyses.

The results implicate that future work should focus on comprehensive multi-indicator long-term analyses, conceptually grounded on the fundamental biophysical basis of socio-economic activities, incorporating the role of global supply chains as well as the wider societal role and preconditions of economic growth. The authors also suggest that understanding the interdependencies between economic growth and resource use and/or emissions is crucial, an area where demand-side measures play an important role.

2. Demand-side mitigation is an essential and relevant strategy to achieve climate goals especially in the mid-term until 2050

What is the overall scope and potential of demand-side solutions for climate change mitigations? In a review study in Nature Climate Change, aligning and quantitatively synthesizing the findings of this focus issue, Felix Creutzig *et al* comprehensively assess demand-side mitigation strategies for climate change and their impacts on well-being (2022a). The study categorizes these strategies into ASI options across various end-use sectors and identifies their aggregate mitigation potentials. The findings indicate that demand-side options can reduce sectoral emissions by 40%–70% until 2050, with largely beneficial effects on well-being: 79% of these impacts are positive, 18% neutral, and only 3% negative, emphasizing that such strategies not only aid in climate mitigation but also enhance various aspects of human well-being.

A systematic review of macro-economic factors, such as GDP, and their effect on GHG emissions substantiates the relevance of demand-side measures for achieving the goals of the Paris agreement. Specifically, 'A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights' provides a comprehensive review of the relationship between economic growth and various resource-use and emission indicators (Haberl *et al* 2020).

The authors conducted a qualitative synthesis of strategies and policy recommendations by drawing a random subsample of 15% from 835 articles, yielding 125 articles for further qualitative content synthesis. They used definitions of green growth and degrowth to interpretatively map the 125 papers. Articles were classified as 'green growth' if their framing aimed at absolute or relative decoupling without impeding economic growth. Articles were classified as 'degrowth' if their framing explicitly challenged the primacy of economic growth over the (absolute) reduction of resource use and emissions. Papers not meeting these criteria were classified as 'others'.

The review reveals that most observed decoupling is relative (less GHG emissions per unit of GDP) but not absolute (reduced GHG emissions). However, several countries display absolute decoupling, including a reduction in consumption based emissions (Quéré *et al* 2019, Lamb *et al* 2021). While there can be optimism on accelerating decarbonization in the energy sector due to low cost renewables (Creutzig *et al* 2023), Haberl *et al* rightly emphasize that demand-side measures, focused on improving well-being, while keeping energy use and GHG emissions low, are key to maintain the feasibility of keeping temperatures below 2 °C. Another review in this focus issue (see also below) proposes that the development of well-being approaches of mitigation pathways should be a new research direction (Saujot *et al* 2020). They suggest that the concept of lifestyle is a pivotal notion for such research, which will contribute to improving the assessment of pathways in terms of desirability, and thus feasibility.

In this light, Haberl *et al* also argue that GDP may be becoming an increasingly irrelevant measure of welfare, as it was only loosely coupled with well-being in OECD countries over the last 40 years. They suggest that GDP should be replaced or at least complemented by measures of wellbeing and planetary health. The question of how a good life for all on the planet can be organized within the planet's environmental limits may be more important than the extent to which GDP can be decoupled from resource use or emissions.

Demand-side measures are not only effective but also align well with sustainable development goals (SDGs) and the corresponding well-being dimensions, a key insights of the review 'Demand side climate change mitigation actions and SDGs: literature review with systematic evidence search' (Roy *et al* 2021) (see also (Creutzig *et al* 2022a) for a comprehensive well-being assessment). Similar to Ivanova *et al,* Roy *et al* categorize various demand side actions into the ASI categories. The 'Avoid' category includes actions aimed at avoiding the demand for high-emission intensive services; actions in the 'Shift' category help in substituting demand for high-emission intensive services with low/no intensive ones; and 'Improve' category actions are aimed at improving the energy/emission intensity of a service type.

The review finds that most of these demand side mitigation actions showed positive linkages with SDGs 7 (Affordable and Clean Energy), 9 (Industry, Innovation, and Infrastructure), and 11 (Sustainable Cities and Communities), highlighting the importance of looking at the longer term in a sustainability context, such as the performance of green buildings and the rebound effect of energy efficiency. Demand side actions to be effective enough need a systemwide embedding. For optimizing the mitigation actions, the interconnectedness across sectors is important. For example, demand side mitigation actions in the transport sector are highly dependent

on city planning and infrastructure, as also emphasized in novel technical estimates (Nachtigall *et al* 2023), and the construction sector is an integral part of the building sector.

For the relevance of demand-side measures, Roy *et al* suggest that a better understanding of the costs and benefits of these solutions could facilitate higher adoption. High upfront costs of low carbon options, inadequate infrastructure, incorrect understanding or low awareness regarding sustainable options, and socio-cultural factors currently limit uptake.

However, there are also trade-offs, for example at the interface between adaptation and energy demand. The study 'When adaptation increases energy demand: a systematic map of the literature' provides a comprehensive review of the literature on the impact of adaptation measures on energy demand (Viguié *et al* 2021), also investigating adaptation actions that moderate energy demand.

The number and type of actions studied are very heterogeneous across the studies. Among the many adaptation alternatives considered, 'better insulation' and 'use of shading devices/blinds' stand out as most frequently cited. Both appear and are quantified in about a third of the papers. Approximately 65% of the papers have a geographical resolution smaller than a country (e.g. states, provinces, or cities), and only a quarter (26%) rely on data at the country scale. Only four articles quantify alternatives at the regional or global scale.

The review finds that the choice of adaptation pathways studied in the papers strongly depends on the scale of the studies and the methodology used. For instance, quantified alternatives are rare among econometrics- or statistics-based papers. In contrast, they are studied in almost half of the papers using integrated or building energy models. It is more difficult to study the consequences of potential changes in technology adoption or behaviors with econometrics models, which are by nature designed to analyze the consequences of existing technologies and behaviors. In some papers, generic measures are studied (e.g. 'better insulation'), whereas in other papers specific actions are documented (e.g. 'mixed mode ventilation'). A direct comparison across the papers is therefore difficult.

3. Demand-side mitigation options vary across end-use sectors and are consistent with well-being

Key strategies include socio-behavioral change, low-carbon infrastructure and service provision, and rapid adoption of low-carbon technologies. These can be broadly mapped into ASI categories.

Demand side options are multifaceted and reach into every part of daily life. A wide array of different aspects are covered in the focus issue. Here, we start with considering an overview on consumption-based options from an individual perspective, then specify the urban contribution, followed by transport, building and food sector perspectives. This is the rounded up by circular economy (CE), material efficiency and digitalization specific reviews, exploring in each case demand-side mitigation options.

The systematic review 'Quantifying the potential for climate change mitigation of consumption options' investigates impacts of consumption options on climate change mitigation, based on a comprehensive screening of **consumption-based footprint studies** (Ivanova *et al* 2020). The study generated an initial sample of 11 626 references from Scopus and Web of Science. After removing duplicates and irrelevant studies, inter alia with the help of machine learning methods, the final sample consisted of 53 relevant studies. It identifies 60 consumption-based mitigation options, categorized in ASI categories, and estimates their potential, as based in the literature, with median and range values. The results can be seen as global benchmark, and are, for example, reflected in the Technical Summary of the IPCC report on climate solutions (Pathak *et al* 2022). A crucial next step is to harmonize consumption-based options as a function of income, culture, and spatial context.

Ivanova *et al* emphasize the importance of considering the full range of impacts of consumption options, including impacts on commuting travel, non-work travel, home energy use, and office energy use. While options appear at individual scale, there are multiple challenges, including technical, economic, and institutional barriers. Overcoming these barriers requires a combination of technological innovation, policy intervention, and behavioral change.

In the domain of transport, the options with the highest mitigation potential include:

1. Living car-free, which has the highest median mitigation potential across all of the reviewed options at 2.0 tCO_2eq/cap, with a range between 3.6 and 0.6 tCO_2eq/cap.
2. Reducing air travel. One less long return flight may reduce between 4.5 and 0.7 (mean of 1.9) tCO_2eq/cap, while taking one less medium return flight can reduce between 1.5 and 0.2 (0.6) tCO_2eq/cap. The two options have a median reduction potential of 1.7 and 0.6 tCO_2eq/cap, respectively.
3. Shifting to less carbon-intensive fuel sources, means, and modes of transportation.

In the context of food, the highest carbon savings come from dietary changes, particularly the adoption of a vegan diet with an average and median mitigation potential of 0.9 and 0.8 tCO_2eq/cap, respectively. In housing, main options include investments

into heat pumps, prosumer renewable energy systems (including balcony solar for renters), and insulation measures.

The mitigation potentials strongly depend on income, as high-income households fly much more and have different consumption patterns. Affluent households not only have more potential to decarbonize their lifestyles, but also more responsibility and more capacity (Nielsen *et al* 2021).

Demand-side solutions are particularly relevant in **cities**, an insight relevant also for the upcoming special report on cities and climate change in Seventh Assessment Cycle of IPCC. The review 'Climate change mitigation in cities: a systematic scoping of case studies' provides an in-depth analysis of urban mitigation solutions and their potential for GHG abatement (Sethi *et al* 2020).

The study identifies demand-side management solutions, including peak shaving or shifting, energy efficiency measures, and retrofitting buildings, as the most frequently investigated interventions. These solutions are crucial for local climate mitigation. Sethi *et al* emphasize the active role of local governments in leading urban climate solutions, either through regulations or partnerships with private or non-governmental actors. Findings suggest that a mix of market mechanisms, user incentives, subsidies, and voluntary measures in cooperation with non-governmental actors is crucial for local climate mitigation.

The study finds that technology-based interventions are more prevalent, with 80% of urban climate solutions being technologically driven. However, it also highlights the importance of combining technological and social experiments to expand and upscale mitigation efforts in urban systems. The highest mitigation values are observed in buildings with net-zero emission buildings (105%), transportation with E-mobility (94%), and waste with waste to energy (87%). However, the performance of certain climate policies, such as the deployment of cool roofs, can vary significantly depending on location. Many of the case studies originated in Europe and China. Crucially, Sethi and colleagues also find that the scale of intervention controls mitigation potential at two levels. Interventions with smaller absolute scope demonstrate greater marginal mitigation potential than more system-wide interventions. The review concludes that urban climate research requires a fusion of disciplinary knowledge to better utilize quantitative and qualitative data on how cities could respond to global warming.

The review titled 'Determinants of low-carbon transport mode adoption: systematic review of reviews' focuses on the factors that influence the adoption of **low-carbon transport modes** (Javaid *et al* 2020). The authors conducted a systematic review of literature reviews, categorizing them into meta-analysis or traditional reviews. They extracted information across these different review types, differentiating between quantitative and qualitative studies. The data extraction process involved two steps: extracting information and judging the quality of information.

The study identified around 75 reviews that fulfilled all the necessary conditions. Thematically, most review studies are linked to infrastructure factors (59 reviews), whereas social factors are lacking in most cases (only 11 review studies). Individual-level factors are also relatively well represented with 32 reviews dealing with these factors. Most of the reviews cover studies from North America, Europe, and Australia. Only 20% of the reviews contain at least one study from Asia or Africa.

From an individual, social, and infrastructure perspective, the study finds that all three dimensions unambiguously interfere with mode choice. Individuals are most motivated to shift modes if they are well-informed, if personal norms match low-carbon mode use, and, most importantly, if they perceive to have personal control over decisions. Perceptions about common travel behavior (descriptive social norms), especially if supported by perceived normative beliefs of others (injunctive norms), are highly influential to support mode shift.

However, the overall margin of shift as induced by individual and social settings remains limited. Instead, the infrastructure factors explain large differences in mode choice. New shared mobility modes, and teleworking and shopping, add a long tail to modes chosen, but are no game changer. The study concludes that a transition to low-carbon mobility requires low-carbon infrastructure, which leverages enthusiastic individuals' concerns and empowers them for mode change, and that address safety concerns prevalent especially in cities of the Global South. The mode shift to low-carbon option can then be sustained and enhanced by social influence in the form of collective social norms.

A more detailed issue is mobility patterns, and in particular the case of avoiding commuting altogether by **teleworking**, an issue that gained increased traction with COVID-19. Accordingly, 'A systematic review of the energy and climate impacts of teleworking' provides a comprehensive investigation of the impacts of teleworking on energy consumption and climate change (Hook *et al* 2020). The study generated an initial sample of 11 626 references from Scopus and Web of Science. After removing duplicates and irrelevant studies, the final sample consisted of 39 relevant studies. The majority of the studies (26 out of 39) suggest that teleworking leads to a net reduction in energy use and/or emissions, with only five studies finding a net increase. These benefits largely result from the elimination of the commute, reductions in congestion, and reductions in office-based energy

consumption. A related review, not in this focus issue, suggests that travel related rebound effects can consume up to one fifth of the emission savings, which still clarifies that telecommuting is largely beneficial to the environment and climate change (Hostettler Macias *et al* 2022).

Hook and coauthors emphasize the importance of considering the full range of impacts of teleworking, including impacts on commuting travel, non-work travel, home energy use, and office energy use, pointing out that the potential for energy and emission reductions through teleworking is often overlooked in climate policy. They conclude that overcoming barriers to telecommuting requires a combination of technological innovation, policy intervention, and behavioral change.

The study 'A map of roadmaps for zero and low energy and carbon buildings worldwide' provides a comprehensive overview of global efforts towards achieving **zero and low energy and carbon buildings** (ZLECB) (Érika Mata *et al* 2020). It maps and classifies 117 roadmaps, policies, and plans from 37 countries. The majority of the documents focus on more developed regions (76% or 325 documents), including Europe subregions, USA & Canada, and Australia & New Zealand. Only 4% of the documents have global coverage.

The most frequent types of documents are recommendations made by researchers and academics to inform policymakers and performance assessment case studies done to establish design practices or prove the efficiency of demonstration projects. The policy objectives include increasing the energy efficiency of new and existing buildings and appliances, encouraging energy distribution companies to support emission reduction from the building sector, targeting attitudes and behavior change, and substituting fossil fuels (FF) with renewable energy sources (RES).

As key demand-side measures, the review specifies the need for effective building design, efficient technical systems, on-site production from RES, and low impact material choices to achieve low energy and carbon during a building's lifecycle. Mata and colleagues identify evidence gaps and clusters, suggesting areas for future research and potential for synthesis via full systematic reviews and emphasize the need for a comprehensive understanding of current efforts, including which measures work and which do not, to avoid wasting funding and resources.

As an accompanying review, 'Systematic map of determinants of buildings' energy demand and CO_2 emissions shows need for decoupling' provides a systematic mapping of the literature on determinants of **energy demand** and CO_2 emissions from **buildings** (Mata *et al* 2021). The authors identify 376 relevant studies and highlight gaps in terms of the studied variables, geographical scope, and methodological approach. The study confirms that worldwide, income, energy price, and outdoor temperature are unequivocal drivers of buildings' energy demand and CO_2 emissions, followed by other indicators of scale such as population or heated floor area. The authors emphasize that decoupling from rising wealth levels has not been observed, which will continue to challenge reductions in energy use and CO_2 emissions from buildings in line with climate targets.

In terms of demand-side climate change mitigation, the study suggests that macroeconomic policies focusing on the impacts of income, energy price, population, and growing floor area are needed in combination with technical policy to reduce the impact of outdoor climate. The authors argue that a comprehensive understanding of the key factors behind buildings' energy use can serve as a basis to define the policy actions most suited to drive the decarbonization of the building sector.

Food stands out as where the largest demand-side potential for GHG emission reduction is located, particulary in diet shift from meat to plant-based diets (Creutzig *et al* 2022a). Correspondingly, the review 'Climate change mitigation through dietary change: a systematic review of empirical and modeling studies on the environmental footprints and health effects of 'sustainable diets' is another important contribution to this focus issue (Jarmul *et al* 2020).

The review systematically investigates the role of dietary changes in climate change mitigation. The authors highlight that the global food system contributes 21%–37% of global GHG emissions, and its impact on the environment is expected to increase substantially by 2050, largely due to population growth and dietary change, particularly in rapidly transitioning economies.

The study identifies the adoption of diets with low environmental impact, often referred to as 'sustainable diets', as an important climate change mitigation strategy. These diets are typically high in plant-sourced foods and low in animal-sourced and processed foods. The review found that switching to 'sustainable diets' results in an average 25.8% reduction in GHG emissions, with vegan diets leading to the largest reduction (approximately 70.3%). However, it also noted an increase in water use associated with these diets. The research is based on 18 studies, encompassing 412 measurements, and highlights the substantial potential for dietary changes to contribute to climate change mitigation and improve health outcomes. The relationship between food systems and climate change is bi-directional, and climate change is currently affecting yields of crops and livestock products and is projected to continue to do so in the future. Hence, demand-side options, such as dietary shifts, can also help to better allocate scarce land resources to human nutrition. Overall, changes in consumer behavior, specifically dietary choices, but

also food waste reduction, can contribute to mitigating climate change at a highly relevant scale.

What can the CE contribute to climate change mitigation? 'Saving resources and the climate? A systematic review of the CE and its mitigation potential' provides a systematic review of the literature on the CE and its potential for climate change mitigation (Cantzler *et al* 2020). The authors conducted a comprehensive literature review, identifying 3244 studies initially, of which 341 (10%) were deemed relevant based on specific mitigation references. The studies were then synthesized and categorized based on sector, geography, resolution, and CE principles.

The document discusses the challenges of synthesizing the mitigation potential of the studies due to the use of different baselines, metrics, and indicators. There is a lack of standardization in the understanding and application of the CE concept, leading to a wide array of measures under the CE umbrella. While the CE concept may serve as a communication tool to accelerate policy action, there is a need for transparency and clarity in its use to avoid confusion and ensure effective climate change mitigation efforts.

Material efficiency is a key CE strategy, relating to demand-side change also within industry. 'Material efficiency strategies to reducing GHG emissions associated with buildings, vehicles, and electronics—a review' presents an extensive review of strategies to enhance material efficiency and reduce GHG emissions (Hertwich *et al* 2019). The authors find that material efficiency could reduce GHG emissions by 12%–21% in the construction sector, 26%–31% in the vehicle sector, and 14%–53% in the electronics sector.

The potential for GHG reduction in the construction sector is mainly due to the reduction in the use of concrete and steel, which are the most emission-intensive materials. In the vehicle sector, lightweight design, car sharing, and longer vehicle lifetimes could significantly reduce emissions. In the electronics sector, the extension of product lifetimes, and the reuse and recycling of components, could lead to significant emission reductions.

Hertwich and colleagues emphasizes the importance of policy interventions to promote material efficiency. The potential for emission reductions through material efficiency remains often overlooked in climate policy. Hence, material efficiency strategies should be integrated into the broader framework of climate policy to achieve significant emission reductions.

On consumer side, it has been long speculated that **digitalization** provides efficiency gains in end use. The review titled 'Digitalization of goods: a systematic review of the determinants and magnitude of the impacts on energy consumption' provides a comprehensive review of the impacts of digitalization on energy consumption (Court and Sorrell 2020), focusing on five categories of goods or services that have been digitalized: e-publications (books, magazines, and journals), e-news, e-business, e-music, and e-videos and games. The study employs a systematic review methodology, including a comprehensive search of literature, screening of titles and abstracts, full-text screening, and data extraction. The search phase generated an initial sample of 12 849 references, which after removing duplicates and irrelevant studies, resulted in a final sample of 31 relevant studies.

The review identifies several examples of potential energy savings due to digitalization in specific technologies. For instance, in the case of e-publications, there's a notable reduction in energy consumption compared to physical books, depending on user behavior and device efficiency. Similarly, digitalization in music and news industries shows a trend towards energy savings when compared to traditional media formats. These savings are context-dependent and vary based on factors like device usage, energy sources, and the displacement of non-digital activities.

4. Behavioral and social interventions and initiatives to reduce GHG emissions

Another set of reviews in the focus section complements demand-side mitigation options with a view on behavioral and social interventions and approaches—society perspectives—on climate change mitigation, revealing the relevance of understanding motivations and rationalities of people both as consumers and as social actors and citizens.

The review titled 'Effectiveness of behavioral interventions to reduce household energy demand: a scoping review' provides a comprehensive review of **behavioral interventions** aimed at reducing household GHG emissions (Composto and Weber 2022).

The authors have conducted a scoping review of 584 empirical papers. The most studied behavioral interventions are providing timely feedback and reminders (258 papers) and making information intuitive and easy to access (246), followed by communicating a norm (158). Electricity use is the most studied target behavior (439 papers), followed by investments in energy efficiency (94), choice in mode of transportation (41), choice of energy source (17), and buying carbon offsets (4).

Similar to other reviews in these focus issue, the authors categorize behavioral changes into three types: ASI. Avoid responses are examined in the most papers (415 papers), followed by shift (112) and improve (77) responses. 72 of the 584 papers included an economic incentive; the choice architecture interventions of reframing consequences (26%) and setting proper defaults (24%) are most frequently combined with an economic incentive. The authors

also discuss the methodological aspects of the studies reviewed, noting the presence of publication bias and the need for larger sample sizes, random assignment, control groups, and field applications. They also highlight the need for future research to routinely measure longer-term impacts of interventions.

Another review and meta-analysis, titled 'Meta-analytic evidence for a robust and positive association between individuals' pro-environmental behaviors and their subjective wellbeing' (Zawadzki *et al* 2020), explores the relationship between individuals' **pro-environmental behaviors** and their subjective well-being. Such behaviors, which are crucial for reducing carbon emissions, can have a significant impact on people's daily lives. The review investigates whether and how individuals' pro-environmental behavior is related to subjective wellbeing, and whether pro-environmental behaviors can be promoted in a way that protects and promotes individuals' subjective wellbeing.

The review finds that fostering pro-environmental behaviors among individuals can be a key strategy for reducing GHG emissions. The relationship between pro-environmental behaviors and subjective wellbeing is positive and robust. This implies that individuals who engage in pro-environmental behaviors tend to experience higher levels of subjective wellbeing. The authors suggest that this relationship may be due to the meaningfulness of pro-environmental behaviors. Specifically, behaviors that are consciously decided and clearly meaningful at the time of performance, such as sustainable purchase decisions, are associated with higher levels of subjective wellbeing. Similarly, indicators of subjective wellbeing that reflect personal meaning, such as a sense of 'warm glow' or eudaimonic happiness, are also strongly related to pro-environmental behavior.

The authors point outs that policymakers can leverage this relationship to design 'win-win' sustainability programs that not only positively impact the environment but also enhance people's subjective wellbeing. It may be beneficial to emphasize how pro-environmental behaviors can enhance, rather than detract from, people's subjective wellbeing to maintain public engagement with pro-environmental programs or policies. Future studies could test which strategies are most effective in emphasizing the meaning of pro-environmental behavior, and to make people aware of the beneficial effects of pro-environmental actions on subjective wellbeing.

In a shift of gear, the review titled 'Is working less really good for the environment? A systematic review of the empirical evidence for resource use, GHG emissions and the ecological footprint' provides a comprehensive review of the relationship between **working time** reduction (WTR) and environmental impacts (Antal *et al* 2021). The authors conducted a systematic review of the literature, including full-text screening, citation snowballing, and coding based on pre-developed criteria. The review identified 15 fully relevant research articles, which were then critically appraised and synthesized.

The document discusses the empirical literature on working time, resource use, and emissions, with a focus on country-level studies that use econometric approaches to investigate the relationship between aggregate working time and environmental indicators. The review found that while WTR can lead to reduced GHG emissions and resource use, the outcomes are highly context-dependent. The environmental benefits of WTR are primarily through decreased incomes and consumption expenditures. However, the study also notes significant variations in results due to different methodologies and indicators used across studies, making it challenging to draw definitive conclusions.

The desire for **status** can drive unsustainable consumption, but also motivate acquiring energy saving goods and services. The review titled 'Status consciousness in energy consumption: a systematic review' explores the relationship between status and energy consumption, and how this relationship can be leveraged for climate change mitigation (Ramakrishnan and Creutzig 2021). The authors conducted a comprehensive review of existing published work that links status to household consumption decisions and behavior across all end-use sectors. They screened 2662 papers and fully reviewed 53 papers that complied with their criteria.

The review identified 23 distinct theories, with the literature most frequently referring to Veblen's theory of conspicuous consumption. The authors also detailed estimations of status-related energy consumption and identified studies that quantitatively relate status to energy-saving behavior or decisions, and studies that relate status to increased emissions. Status can explain up to 20% change in consumption levels or the willingness-to-pay for carbon reducing consumption.

Interestingly, the authors found that major status-related consumption decisions, such as for housing and big cars, are hardly captured by the literature that relates status consumption to energy use and GHG emissions. This is a considerable gap in the literature, omitting major sources of status-related decisions with high carbon footprint.

The paper concludes that framing energy-saving behavior as high status is a promising strategy for emission reduction. Progressive taxation of status items, such as floor space and vehicle size, can effectively internalize the positional externalities and signal social undesirability, but also reduce emissions.

The review titled '**Lifestyle changes** in mitigation pathways: policy and scientific insights' systematically

investigates the relevance of demand-side measures from individual, social, and infrastructure perspectives regarding GHG emission reduction (Saujot *et al* 2020).

The authors argue that changes in lifestyle, driven by individual and societal choices, can create the necessary space for a feasible supply-side decarbonisation within a 1.5 °C emission budget without the need for negative emissions. This implies that demand-side measures, such as changes in consumption patterns and behaviors, can significantly contribute to GHG emission reduction. The review also highlights the importance of policies that influence future lifestyles, their cost-effectiveness, their consequences on well-being, and their legitimacy. Most of the pathways reviewed do not satisfactorily investigate these aspects. Human and social sciences have a lot to say about understanding changes in lifestyles, including their drivers (e.g. household life-cycle, values), constraints (e.g. infrastructure lock-in, social norms), and the dynamics at play.

The study also acknowledges the political nature of mitigation pathways and argues that this should not preclude lifestyle changes from consideration in pathway development. Saujot and colleagues believe that most changes related to technologies and to the socio-technical system are not value-neutral and that acknowledging this can help in developing more effective and acceptable mitigation strategies.

The study 'Movements shaping climate futures: a systematic mapping of protests against FF and low-carbon energy (LCE) projects' provides a comprehensive analysis of protests against both FF and LCE projects (Temper *et al* 2020). It finds that place-based movements are successful in curbing both FF and LCE projects, with over a quarter of projects encountering social resistance being shelved, suspended, or delayed. The research highlights that LCE projects are almost as conflictive as FF projects, with 30% of FF conflicts and 26% of LCE projects being high intensity. Both project types particularly impact vulnerable groups such as rural communities and Indigenous peoples, with Indigenous peoples involved in 58% of the cases analyzed.

Among LCE projects, hydropower was found to be particularly socially and environmentally damaging, leading to mass displacement and large-scale ecosystem transformation. Incidents of repression or violence against protesters and land defenders occurred in one third of cases, with violent responses most common in hydropower, biomass, pipelines, and coal extraction conflicts. Ten percent of all cases involved the assassination of activists.

The study also highlights 'sacrifice zones' in both the FF and the emerging LCE economies. These zones are areas disproportionately affected by environmental hazards and polluting activities due to industrial, extractive, or infrastructural projects. Specific examples include regions affected by coal mining, oil and gas extraction, and hydraulic fracturing. These areas often face significant environmental degradation, health risks, and social and economic impacts. The study highlights that these sacrifice zones are frequently located in marginalized communities, underscoring issues of environmental justice and inequality. The review also identifies the claims and demands coming from project-impacted communities for a socio-environmental justice approach in building low-carbon futures. The data suggests that the energy transition and decarbonization risk producing similarly unequal social burdens unless there is a deeper transformation of the energy system, informed by engagement and co-design with communities on the energy futures they want. Without community engagement and co-design in shaping energy futures, the transition to LCE may reproduce the social inequalities seen in the FF economy.

Last but not least, a review on 'Limiting food waste via grassroots initiatives as a potential for climate change mitigation: a systematic review' focuses on the role of **grassroots** initiatives in reducing food waste and thereby mitigating climate change (Mariam *et al* 2020). From a quantitative perspective, the study found that grassroots initiatives have the potential to reduce GHG emissions by 4.3%–8.2% of the food sector's emissions. This reduction is equivalent to 0.3%–0.6% of total global emissions. The study also found that these initiatives could potentially reduce food waste by 30%–46%.

From a qualitative perspective, the study highlights the importance of grassroots initiatives in fostering a culture of sustainability and reducing food waste. These initiatives often involve local communities and individuals, and they can have a significant impact on social norms and behaviors related to food consumption and waste. By engaging individuals and communities in efforts to reduce food waste, these initiatives can help shift consumption patterns and social norms in a more sustainable direction. Moreover, they can also contribute to the development of infrastructure and systems for reducing food waste, such as food sharing platforms and community gardens. Thus, grassroots initiatives can have significant impacts not only at the individual and community levels but also in terms of broader social and infrastructural changes.

5. Outlook

We here present a comprehensive overview of 22 review papers on demand-side climate change mitigation, highlighting the significant potential of demand-side approaches to complement technology-focused solutions, and emphasizing their contribution to well-being and planetary stability. This systematic and extensive reviews underscore the

essential role of demand-side strategies in achieving climate goals, particularly in the context of the Paris Agreement's objectives. By choosing to aggregate a complete focus issue with systematic reviews and meta-analysis, we here synthesize crucial evidence relevant to understanding of demand-side mitigation's role in climate change efforts.

Forward looking, we suggest that research on demand-side climate solutions should fill gaps in the when, who, how, and where.

When: studying history and narratives can reveal how various societies and cultures have historically implemented practices akin to demand-side climate mitigation and when they shifted away. By examining historical lifestyles, consumption patterns, and social norms, researchers can identify instances where communities naturally engaged in low-impact living, resource conservation, or sustainable practices. Historical examples can provide insights into successful implementation strategies, the role of cultural values in shaping consumption, and the potential for societal adaptation. For example, traditional lifestyles in the Amazonian rainforest strived for harmony with ecosystems and biodiversity and, while impossible to transfer to modern lifestyles, can provide guidance on strategies and mindsets. Historical narratives can also show at what junctures human societies moved away from sustainable to non-sustainable practices.

Who: studies on the political economy of demand-side measures are crucial for understanding how economic and political structures, power relations create role models, influence lifestyle choices and consumption patterns. They shed light on the vested interests that may create a social hierarchy and interdependence that resist changes promoting sustainable living, offering insights into the dynamics that impede the adoption of climate-friendly lifestyles. Key examples include the FF industry, but also intermediate industries, such as suppliers for car manufacturers. Studies may help to identify barriers and develop strategies to overcome resistance from entities benefiting from the status quo.

How: the design of the 'how of the transition' in demand-side solutions for climate change requires an interdisciplinary, full-system perspective. This involves coordinating various elements such as economic incentives, regulatory frameworks, sociocultural changes (including the influence of religions and identities), and the role of physical infrastructures and the built environment. Such an approach needs to be sequenced and coordinated, transcending the scope of individual disciplines or sometimes collaborative disciplinary approaches. Investigating these complex interactions in a controlled setting is challenging if not impossible, but research from a systems' view is nonetheless needed. Technosphere concepts, such as automobility, digitalization, and energy systems, may be in the center of these investigations. This necessitates more collaborative research across disciplines to understand and implement effective demand-side solutions.

Where: the systematic reviews in this focus issues, similarly to other reviews and systematic maps on, for example, cities (Lamb *et al* 2019), is unambiguous in that studies on the Global South are missing. Also, in global south rural density and interdependence of cities and rural geographies and interdependence of formal and informal economies deserve a special attention to avoid uncontrolled penetration of unsustainable practices among new consumer groups. However, as developing countries are still urbanizing and growing in terms of economic activities, studies are urgently needed that explore and substantiate how demand for better services can be provisioned and satisfied, bringing low emissions together with high quality of life.

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References

Andrew H, Court V, Sovacool B K and Sorrell S 2020 A systematic review of the energy and climate impacts of teleworking *Environ. Res. Lett.* **15** 093003

Antal M, Plank B, Mokos J and Wiedenhofer D 2021 Is working less really good for the environment? A systematic review of the empirical evidence for resource use, greenhouse gas emissions and the ecological footprint *Environ. Res. Lett.* **16** 013002

Cantzler J, Creutzig F, Ayargarnchanakul E, Javaid A, Wong L and Haas W 2020 Saving resources and the climate? A systematic review of the circular economy and its mitigation potential *Environ. Res. Lett.* **15** 123001

Composto J W and Weber E U 2022 Effectiveness of behavioural interventions to reduce household energy demand: a scoping review *Environ. Res. Lett.* **17** 063005

Court V and Sorrell S 2020 Digitalisation of goods: a systematic review of the determinants and magnitude of the impacts on energy consumption *Environ. Res. Lett.* **15** 043001

Creutzig F *et al* 2018 Towards demand-side solutions for mitigating climate change *Nat. Clim. Change* **8** 260–3

Creutzig F *et al* 2021 A typology of 100,000 publications on demand, services and social aspects of climate change mitigation *Environ. Res. Lett.* **16** 033001

Creutzig F *et al* 2022a Demand-side solutions to climate change mitigation consistent with high levels of well-being *Nat. Clim. Change* **12** 36–46

Creutzig F *et al* 2022b Chapter 5—Demand, services and social aspects of mitigation *Climate Change 2022: Mitigation of Climate Change* (Cambridge University Press)

Creutzig F, Fernandez B, Haberl H, Khosla R, Mulugetta Y and Seto K C 2016 Beyond technology: demand-side solutions for climate change mitigation *Annu. Rev. Environ. Resour.* **41** 173–98

Creutzig F, Hilaire J, Nemet G, Müller-Hansen F and Minx J C 2023 Technological innovation enables low cost climate change mitigation *Energy Res. Soc. Sci.* **105** 103276

Haberl H *et al* 2020 A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, Part II: synthesizing the insights *Environ. Res. Lett.* **15** 065003

Hertwich E G, Ali S, Ciacci L, Fishman T, Heeren N, Masanet E, Asghari F N, Olivetti E, Pauliuk S and Qingshi T 2019 Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review *Environ. Res. Lett.* **14** 043004

Hostettler Macias L, Ravalet E and Rérat P 2022 Potential rebound effects of teleworking on residential and daily mobility *Geogr. Compass* **16** e12657

Ivanova D, Barrett J, Wiedenhofer D, Macura B, Callaghan M and Creutzig F 2020 Quantifying the potential for climate change mitigation of consumption options *Environ. Res. Lett.* **15** 093001

Jarmul S, Dangour A D, Green R, Liew Z, Haines A and Scheelbeek P F D 2020 Climate change mitigation through dietary change: a systematic review of empirical and modelling studies on the environmental footprints and health effects of 'sustainable diets *Environ. Res. Lett.* **15** 123014

Javaid A, Creutzig F and Bamberg S 2020 Determinants of low-carbon transport mode adoption: systematic review of reviews *Environ. Res. Lett.* **15** 103002

Lamb W F *et al* 2021 A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018 *Environ. Res. Lett.* **16** 073005

Lamb W F, Creutzig F, Callaghan M W and Minx J C 2019 Learning about urban climate solutions from case studies *Nat. Clim. Change* **9** 279–87

Mariam N, Valerie K, Karin D, Angelika W-R and Nina L 2020 Limiting food waste via grassroots initiatives as a potential for climate change mitigation: a systematic review *Environ. Res. Lett.* **15** 123008

Mata É, Korpal A K, Cheng S H, Jiménez Navarro J P, Filippidou F, Reyna J and Wang R 2020 A map of roadmaps for zero and low energy and carbon buildings worldwide *Environ. Res. Lett.* **15** 113003

Mata É, Wanemark J, Cheng S H, Ó Broin E, Hennlock M and Sandvall A 2021 Systematic map of determinants of Buildings' energy demand and CO_2 emissions shows need for decoupling *Environ. Res. Lett.* **16** 055011

Nachtigall F, Wagner F, Berrill P and Creutzig F 2023 The built environment and induced transport CO_2 emissions: a double machine learning approach to account for residential self-selection (arXiv:2312.06616v1)

Nielsen K S, Nicholas K A, Creutzig F, Dietz T and Stern P C 2021 The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions *Nat. Energy* **6** 1011–6

Pathak M, Slade R, Pichs-Madruga R, Ürge-Vorsatz D, Shukla P R, Skea J, Abdulla A, Al Khourdajie A, Babiker M and Bai Q 2022 Working group III contribution to the IPCC sixth assessment report (AR6)(Technical summary)

Quéré C L, Ivar Korsbakken J, Wilson C, Tosun J, Andrew R, Andres R J, Canadell J G, Jordan A, Peters G P and van Vuuren D P 2019 Drivers of declining CO_2 emissions in 18 developed economies *Nat. Clim. Change* **9** 213–7

Ramakrishnan A and Creutzig F 2021 Status consciousness in energy consumption decisions: a systematic review *Environ. Res. Lett.* **16** 053010

Roy J, Some S, Das N and Pathak M 2021 Demand side climate change mitigation actions and sdgs: literature review with systematic evidence search *Environ. Res. Lett.* **16** 043003

Saujot M, Le Gallic T and Waisman H 2020 Lifestyle changes in mitigation pathways: policy and scientific insights *Environ. Res. Lett.* **16** 015005

Sethi M, Lamb W, Minx J and Creutzig F 2020 Climate change mitigation in cities: a systematic scoping of case studies *Environ. Res. Lett.* **15** 093008

Skea J, Shukla P, Reisinger A, Slade R and Pathak M 2022 *Climate Change 2022. Mitigation of Climate Change. Summary for Policymaker* (IPCC)

Temper L *et al* 2020 Movements shaping climate futures: a systematic mapping of protests against fossil fuel and low-carbon energy projects *Environ. Res. Lett.* **15** 123004

Viguié V, Juhel S, Ben-Ari T, Colombert M, Ford J D, Giraudet L G and Reckien D 2021 When adaptation increases energy demand: a systematic map of the literature *Environ. Res. Lett.* **16** 033004

Wiedenhofer D *et al* 2020 A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part I: bibliometric and conceptual mapping *Environ. Res. Lett.* **15** 063002

Zawadzki S J, Steg L and Bouman T 2020 Meta-analytic evidence for a robust and positive association between individuals' pro-environmental behaviors and their subjective wellbeing *Environ. Res. Lett.* **15** 123007