Energy Research & Social Science 127 (2025) 104225

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Conceptualizing supply- and demand-side climate change mitigation: A typology and new research directions

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ARTICLE INFO

Keywords:
Demand-side climate change mitigation
Fossil fuel phase-out
Production and consumption corridors
Provisioning systems
Social-ecological practices
Social-ecological transformation
Supply-side climate policy

Despite broad scientific consensus on the urgent need to rapidly reduce greenhouse gas emissions, the question of *how* to achieve this remains contested. Existing proposals emphasize either supply-side or demand-side strategies, yet conceptual integration between the two is rare. This article develops a typology for climate change mitigation research by distinguishing two key dimensions: the primary entry point of intervention (supply-side vs. demand-side) and the dominant scope of intervention (individual vs. systemic). Within this typology, we identify four research perspectives – techno-innovation, individual decision-making, industrial transformation, and embedded lifestyles – and compare them in terms of their problem framings, disciplinary origins, forms of intervention, policy proposals, and target actors. Our typology shows that while mitigation strategies have become more diverse, they still tend to prioritize either supply-side *or* demand-side interventions, rather than integrating them as complementary pathways for social-ecological transformation. To address this gap, we propose three promising research directions: provisioning systems, sufficiency corridors, and social-ecological practices. These directions (1) analyze production and consumption as coupled systems, challenging the traditional supply-demand dichotomy; (2) frame climate change mitigation not only as a technological challenge but also as a call for absolute reductions in production and consumption; and (3) pursue transformative change on a systemic level, moving beyond the cumulative effects of individual decisions by emphasizing collective, rules-based interventions.

1. Introduction

There is overwhelming consensus in interdisciplinary climate research on the need for immediate and sustained reductions in GHG emissions, but strategies for achieving this remain contested [1,2]. Mainstream strategies for climate change mitigation mainly focus on "greening" the economy, for example, through more efficient technologies and the expansion of low-carbon energy supply. However, a substantial "emissions gap" persists between implemented policies and the reductions needed to meet the 1.5 or 2 °C targets [3]. Strategies to reduce emissions by changing energy demand, alongside technological carbon dioxide removal and geo-engineering, are gaining increasing attention [1]. At the same time, the phase-out of fossil fuels and other emissions-intensive sectors remains highly contested at both the international level [4] and in national and regional climate politics [5–7].

In interdisciplinary climate research, an important dichotomy revolves around supply-side and demand-side climate change mitigation (hereafter: supply-side and demand-side mitigation) strategies [8–12]. In this dichotomy, *supply-side* strategies target the supply of energy and emissions-intensive goods and services (e.g., fossil fuels, meat products) primarily through technological innovation and shifts toward low-carbon technologies, while *demand-side* strategies focus on energy

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https://doi.org/10.1016/j.erss.2025.104225
Received 7 January 2025; Received in revised form 3 July 2025; Accepted 16 July 2025
Available online 24 July 2025

demand, mainly through behavioral change [13]. With the escalating climate crisis, and the growing recognition that rapidly and sufficiently reducing GHG emissions through technological solutions alone is infeasible [14–16], more radical and systemic strategies have been proposed from both demand-side and supply-side perspectives.

A new wave of demand-side research challenges the dominant focus on technological solutions by framing demand-side mitigation – focused on energy *service* demand (e.g., reducing travel need, minimizing heating and cooling needs through building design, or lowering material consumption through sharing and repairing) rather than just energy demand (e.g., liters of gasoline, kilowatt-hours of electricity) [17] – as a strategy to *directly reduce* the total amount of energy and materials needed [16–20]. At the same time, research on systemic supply-side mitigation strategies has diversified [22–25] but has received comparatively less attention in interdisciplinary climate research [1]. These new "supply-side climate policies" [26] differ substantially from efficiency-centered and technology-driven strategies and emphasize the mandatory restriction of emissions-intensive sectors. In so doing, they fundamentally challenge incumbent power relations and entrenched carbon lock-ins [6,10,27,28].

In sum, while research on both supply- and demand-side mitigation strategies has become increasingly diverse, the respective research communities have – to the best of our knowledge, given the absence of systematic studies on their interaction – largely developed separately and rarely engage with or learn from one another. At the same time, the dichotomous use of the concepts and strategies – although understandable given diverse academic origins and/or strategic considerations – obstructs a more holistic understanding of transformative change and the development of effective interventions [29]. This article therefore broadens the scope of demand- and supply-side mitigation research and outlines research directions that move beyond this dichotomy. The aim of the article is twofold. First, there is an *analytical* aim to differentiate and structure diverse mitigation strategies – within a heterogeneous and rapidly evolving body of literature – to better understand their distinct framings of the climate crisis and forms of intervention. By doing so, the article provides guidance for researchers in positioning relevant contributions and identifying which framings are best suited to address specific research questions or problems. Second, there is a *strategic* aim to integrate different mitigation strategies in order to develop more systemic and transformative interventions. Rather than opting for supply- *or* demand-side strategies, we argue for integrating both in their systemic forms to reduce energy and resource use in absolute terms, while simultaneously addressing well-being and transition concerns among affected communities and vulnerable groups.

The article is structured as follows: In Section 2, we provide details on our methodology. Section 3 then serves as a brief discussion and clarification of important terms (e.g., supply and demand, production and consumption, efficiency and sufficiency) that are often conflated or used interchangeably in interdisciplinary climate research. In Section 4, we typologize mitigation strategies along the entry point (supply-side or demand-side) and scope of intervention (individual or systemic). We outline one research perspective for each quadrant and compare them in terms of their specific forms of intervention, key policies, and target actors. Based on this comparative discussion, Section 5 introduces three research directions that move beyond the supply-demand dichotomy. Section 6 concludes.

2. Methodology

Our contribution aims to analytically distinguish and structure diverse mitigation strategies, while strategically integrating more systemic ones that have received less attention in climate policy. To this end, we combine a typology approach [30,31] with a narrative review [32]. This allows us to map existing research perspectives and outline research directions with the potential to bridge the supply-demand divide. We followed a three-step process (see [33] for a similar methodological approach). In a first step, based on extensive exchange among the co-authors and discussions with colleagues, we developed a simple conceptual framework of mitigation strategies based on two axes: the primary *entry point of intervention* (supply-side or demand-side) and the dominant *scope of intervention* (individual or systemic). With regard to the latter, the categories 'individual' and 'systemic' seek to capture differences in the underlying understanding of how transformation occurs: either through the cumulative effect of individual decisions (individual) or through structural changes across society (systemic) [34]. In addition, they also reflect differences in the binding nature of mitigation strategies: low-binding, incentive-based interventions (individual) or high-binding, collective-rules-based interventions (systemic) [35,36]. This resulted in a 2 × 2 matrix (Table 1), designed to facilitate the identification of research perspectives and investigate concrete differences and fault lines.

In a second step, this conceptual matrix guided our narrative literature review, aimed at developing a typology of research perspectives and exploring the problem framing, academic origins, forms of intervention, policy proposals, and target actors within these perspectives. A narrative review approach is "particularly useful for exploratory reviews that seek to synthesize insights from a variety of perspectives and disciplines" [32]. Since the research perspectives, often rooted in different disciplines, do not necessarily use the same terms and concepts – or may use them differently – systematic and predefined search strings were considered less useful. Our aim was therefore not to conduct a systematic review, but rather to *typologize* the literature on supply- and demand-side mitigation strategies, synthesizing key publications, terms, and authors. According to Jaakkola [30], a typology "classifies conceptual variants as distinct types" to provide "a more precise and nuanced understanding of a phenomenon or concept, pinpointing and justifying key dimensions that distinguish the variants" [23]. The typology thus fills the conceptual 2 × 2 matrix with four distinct research perspectives (see Section 4). These are ideal types characterized by distinct features but encompassing varying degrees of homogeneity within the associated bodies of research.

Finally, in a third step, we outlined three non-exhaustive research directions that move beyond the supply-demand dichotomy – provisioning systems, sufficiency corridors, and social-ecological practices – and discuss how these perspectives advance our understanding of mitigation strategies. We select these three directions because they (1) challenge the conventional supply-demand dichotomy; (2) frame climate change mitigation not only as a technological challenge but also call for direct, absolute reductions in production and consumption volumes; and (3) target the systemic level, moving beyond both the cumulative effects (aggregation) of individual decisions and the limitations of low-binding, incentive-based interventions.

3. On supply and demand, production and consumption, efficiency and sufficiency

Different research communities and authors in interdisciplinary climate research frequently refer to supply-side and demand-side strategies, but their meanings are often unclear or ambiguous. This ambiguity increases due to the entanglement with other important terms in the mitigation literature, which are sometimes used interchangeably. In this section, we provide a brief introduction into two of these entanglements.

A *first* entanglement refers to the terms *production* and *consumption* which are often used interchangeably with *supply* and *demand*. In conventional economics, *supply* and *demand* describe *behaviors* under varying conditions: demand is understood as the willingness and ability to procure a good or service, while supply is associated with the willingness and ability to provide that good. In basic theories and models, these behaviors are influenced by factors such as prices, production costs, available resources, and income levels [37], while more complex models and theories also consider the effect of norms, habits,

Table 1
Conceptual 2 × 2 matrix of climate change mitigation strategies.

		Entry point of intervention	
		Supply-side	Demand-side
Scope of intervention	Individual	Aggregation of individual supply-side decisions; low-binding, incentive-based interventions	Aggregation of individual demand-side decisions; low-binding, incentive-based interventions
	Systemic	Structural changes across the supply-side; high-binding, collective-rules-based interventions	Structural changes across the demand-side; high-binding, collective-rules-based interventions

institutions, power relations, and legacies [38,39]. In contrast, *production* and *consumption* can be understood as activities involving the *quantities* and *qualities* of goods and services that are actually produced and consumed [34]. Importantly, in specific economic interactions, many actors function as both producers *and* consumers, depending on the particular section of the economy under consideration. For example, individuals act as private consumers while also supplying labor, and firms not only supply goods and services but also demand them for their operations. While we neither claim that these economic definitions of demand-supply and production-consumption are the only valid ones, nor endorse the oversimplified assumptions about behavior and society often associated with these concepts (e.g., rationality, perfect competition, linearity), we find it useful to distinguish between demand-supply as *behavioral tendencies* (or entry points for intervention) and production-consumption as *actual quantities and qualities* (or outcomes). This distinction also clarifies that the quantitative reduction and qualitative transformation of production and consumption are outcomes of the interaction between supply and demand.

A *second* entanglement comprises *efficiency* and *sufficiency*. Sufficiency measures aim to avoid, limit, or reduce the excessive production and consumption of goods and services, particularly those associated with harmful or emissions-intensive activities, while delivering well-being [33,40]. Efficiency measures, in contrast, focus on reducing resource and energy use as well as environmental impacts for the same (or even increased) production and consumption levels [41–43]. Efficiency measures may reduce energy use and emissions in relative terms (per unit of output), but not necessarily in absolute terms. In the current academic debate, sufficiency measures are often associated with demand-side or consumption-based strategies [18,44]. Because of this conflation, the entry point is frequently directed toward final consumers [45]. Contrary to this trend, some argue that sufficiency measures are equally applicable – and indeed necessary – for supply-side behavior, for example, through incentives and regulations for producers and sectors [6,27,46]. At the same time, efficiency measures are often discussed as supply-side interventions [47], but they are also influenced by demand, for example, through consumer preferences for more sustainable alternatives of the same product [48,49] or through consumer acceptance of circular economy offerings [50]. Limiting sufficiency to demand-side and efficiency to supply-side strategies is therefore unwarranted.

4. Mapping research perspectives along the entry point and scope of intervention: toward a typology of current mitigation strategies

In this section, we classify mitigation strategies along the entry point (supply-side or demand-side) and scope of intervention (individual or systemic) (Fig. 1). We outline one research perspective for each quadrant and then discuss the research question or problem it addresses, its disciplinary origin, specific forms of intervention, associated policies, and target actors. This separation along the supply-demand and individual-systemic axes reflects general tendencies and does not imply clear-cut boundaries as overlaps exist both in theory and practice.

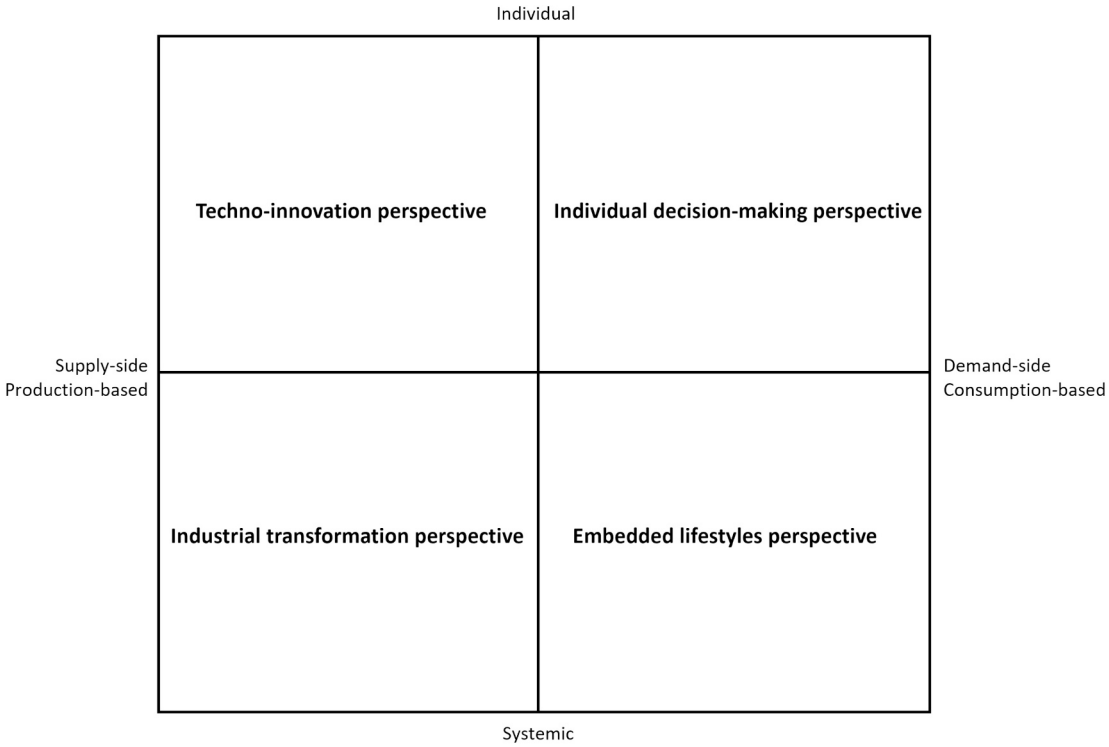

Fig. 1. Research perspectives along the entry point of intervention (x-axis: supply-side or demand-side) and the scope of intervention (y-axis: individual or systemic).

Nonetheless, we consider this typology a useful tool for navigating the heterogenous and rapidly evolving mitigation literature.

4.1. Techno-innovation perspective

Techno-innovation is the most influential supply-side research perspective [1]. It is associated with improving energy efficiency and shifting toward low-carbon or renewable-based technologies and inputs – primarily wind and solar but also nuclear energy and hydropower – to mitigate climate change. Techno-innovation strategies are typically based on cost-effectiveness and target the behavior of businesses, aiming to improve existing technologies and promote low-carbon innovations without questioning growth in production and consumption [51]. Additionally, they often rely on the extensive deployment of negative-emissions technologies [52,53].

Many strategies within the techno-innovation perspective are rooted in environmental economics, favoring market-based instruments to *incentivize* the cost-effective uptake of low-carbon technologies [54,55]. These instruments (e.g., carbon pricing) are designed to "internalize" the environmental and social costs of carbon emissions or other environmentally harmful substances. By doing so, they aim to create economic signals to incentivize corporate behavior toward low-carbon innovation and resource efficiency. The techno-innovation perspective frequently relies on derisking strategies [56] and favors economic instruments – and sometimes voluntary agreements – over command-and-control regulation [54,57].

4.2. Individual decision-making perspective

The individual decision-making perspective focuses on the potential of individuals to drive demand-side change through their consumption choices, assuming that the cumulative (aggregated) effects of these individual choices can shift economic systems toward more climate-friendly outcomes [58–60]. Rooted in neoclassical (behavioral) economics, this perspective traditionally investigates the effects of price incentives, such as taxes on petroleum or meat, but increasingly incorporates interventions beyond purely economic costs and benefits to encourage climate-friendly behavior [58]. These interventions, often referred to as "nudging", aim to subtly influence the context in which decisions are made, for example, by implementing climate-friendly default settings (e.g., for electricity tariffs), communicating social norms, using subconscious cues (priming), or enhancing the salience of climate-related information on products [58,61,62]. Similar to the techno-innovation perspective – though now applied to the demand side – these incentives aim to alter individual choices without directly eliminating options or *significantly* changing economic incentives [63,64].

Research also highlights individual interventions beyond mere consumer choice. Mostly rooted in psychology, these approaches address individual behavioral change across various settings, such as workplaces, local communities, social movements, and political engagement as citizens and voters [65,66]. As such, the individual decision-making perspective examines individual perceptions and values, and how these relate to varied responses to financial incentives or policies – a phenomenon referred to as behavioral plasticity [67–69]. More recently, behavioral approaches have also emphasized the importance of targeting the actual environmental impact of individual behaviors (e.g., avoiding flying and car use, reducing meat and dairy consumption) and addressing personal carbon footprint inequality when designing economic and regulatory interventions [66,70].

4.3. Industrial transformation perspective

The industrial transformation perspective represents research and strategies calling for systemic changes in production systems that go beyond technological innovations and business incentives. These emerging "supply-side climate policies" [10] are primarily proposed by political scientists, political economists, and sustainability transition scholars [22,26,71,72]. They challenge the effectiveness of carbon pricing [73] and the dominant focus on innovation [74], advocating instead for system-wide reductions in production and the phase-out of fossil fuels. Similar suggestions have been introduced as exnovation, decline, post-growth, sunset or destabilization policies [71,74–76]. Beyond phasing out of fossil fuels, research also emphasizes the degrowth of other emissions-intensive sectors, such as the livestock [24,77,78] and automotive industries [6,79]. Policy instruments for such industrial transformations include laws and standards [80], technology bans (e.g., on internal combustion engine cars or gas boilers [81,82]), credit guidance [56,83,84], and moratoria on fossil fuel extraction [85–87]. Other approaches involve establishing local fossil free zones [88] and promoting an international fossil fuel non-proliferation treaty [89,90].

While this perspective highlights the need for the active phase-out of fossil fuel technologies, sectors, and practices, recent literature also emphasizes major political-economic barriers to this transformation, largely rooted in capitalist structures and associated "questions of social power and distribution" [91]. These barriers stem primarily from the entrenched power of incumbent fossil fuel companies [92–94] and the social impacts of energy transitions on workers in impacted industries [95–98]. This has given rise to calls for just transition frameworks, for example, in coal phase-out plans [99,100], the restructuring of the automotive industry [96,101,102], and the protein transition [103]. Amid growing conflicts and backlash against mitigation efforts, the industrial transformation perspective links the phase-out of fossil fuels and related industries to active industrial, social and labor market policies to enhance legitimacy and acceptance for structural transformations [96,104]. The transformation of the welfare state to address these challenges is of particular importance here [105–107], alongside industrial policy and green economic planning to actively steer transformative change toward low-carbon industries [6,84,108–110]. Furthermore, many political economy analyses challenge private ownership of energy- and emission-intensive companies, identifying it as a major obstacle to structural transformation, and propose alternatives such as commons-public partnerships [111]. Similarly, feminist approaches highlight that just transitions require a redistribution of capacities from productive to reproductive sectors, placing greater emphasis to unpaid care work for both people and ecosystems [112].

4.4. Embedded lifestyles perspective

Unlike individual strategies for demand-side mitigation, the embedded lifestyles perspective bridges "socio-behavioural, infrastructural and technological domains" [18] to emphasize the systemic embeddedness of individual activities and lifestyles. The avoid-shift-improve (ASI) framework, initially developed in transport studies [113] and now widely adopted in interdisciplinary climate research, has become particularly influential for analyzing demand-side strategies from such a systemic angle. It structures interventions along a hierarchy of *avoiding* emissions-intensive activities (e.g., reduced travel demand), *shifting* activities to low-carbon technologies, services or practices (e.g., transitioning from individual motorized to active and public mobility, or from animal-based to plant-based proteins), and *improving* existing technologies and activities (e.g., replacing internal combustion engines with electric vehicles) [18]. The core argument is that by changing demand, it is possible to maintain service delivery and well-being while simultaneously reducing overall resource use and emissions [18]. As such, the embedded lifestyles perspective explicitly targets absolute *reductions* in energy and material use through demand-side, yet systemic, interventions [9,114,115].

Related research on sufficiency – developed partly independently from the ASI framework – deepens and substantiates the focus on *avoiding* emissions-intensive lifestyles and *reducing* consumption levels

of high consuming classes, while securing well-being [116]. The embedded lifestyles perspective embeds individual behavioral changes (e.g., dietary shifts, adopting active mobility, avoiding air travel) within deeper transformations of infrastructures, urban settlements, and economic and regulatory systems [9]. Consequently, research from this perspective emphasizes the need for policy mixes [117] and identifies institutional actors, such as spatial planners and policymakers, as important transformative change agents [118].

4.5. Comparative discussion

This section compares the research perspectives with respect to their specific forms of intervention, associated policies, and target actors (Table 2).

In terms of *forms of intervention*, mitigation strategies range from individual to systemic. While especially the latter have become increasingly differentiated in recent years, this differentiation has resulted in a more distinct emphasis on *either* supply-side *or* demand-side mitigation strategies. These emphases have often emerged as critical responses to dominant research perspectives that traditionally focus on individual-level interventions aiming for the cost-effective, incentive-driven change of technology and behavior (i.e., techno-innovation and individual decision-making perspectives). For example, the growing focus on systemic demand-side solutions [9,21] reflects a reaction to the techno-innovation dominance in the IPCC literature [114]. As restrictions on and avoidance of energy *supply* were often deemed politically infeasible, energy *demand* has been left as the only viable entry point for *avoiding* or *reducing* energy and resource use [119]. Within this debate, interventions to *improve* and *shift* can be associated with both supply-side and demand-side measures, whereas interventions to *avoid* are largely limited to demand-side change (embedded lifestyles perspective). The dominance of the techno-innovation perspective has therefore also hindered the exploration of more systemic supply-side mitigation strategies. These strategies target both production volumes (and the relentless growth in production) and the composition of production [77]. Accordingly, the entry points for an industrial transformation perspective lie within the political-economic systems themselves – including working conditions, accumulation strategies, and capitalist ownership structures – as well as within sectoral supply chains that currently obstruct the restriction and avoidance of energy *supply* and emissions-intensive *production* [26,78,120].

With regard to mitigation *policies* [121], economic instruments (e.g., carbon pricing, subsidies, tax cuts) and voluntary agreements have predominated within the techno-innovation perspective. This is notable given that early successful environmental policies – including at the international level – were mainly associated with command-and-control instruments, such as regulatory standards and bans (e.g., the phase-out of ozone-depleting substances under the Montreal Protocol or environmental improvements in frontrunner countries like Sweden [72,122]). However, with the Kyoto Protocol, and alongside neoliberal restructuring, market-based incentives became the primary policy recommendation [123]. While these incentives have reduced energy use and emissions per unit of output, they have been less successful in the absolute and system-wide reduction of energy use and emissions at the necessary speed and scale [14,73]. Cap-and-trade systems, offering a fixed and declining number of emission certificates, are said to provide greater certainty regarding actual emission reductions [121]. They link regulatory interventions (cap) with market-based incentives (trade), positioning them at the interface of individual and systemic supply-side policies – provided that certificate caps are steadily reduced and prices consistently rise as planned [117,124].

As concerns about the effectiveness of economic instruments have grown [73,117,125], recent supply-side climate policies increasingly call for command-and-control instruments (e.g., bans and moratoria) to curb fossil-fuel extraction, supply, and related production [126]. As such, the industrial transformation perspective complements support for

Table 2
Comparative analysis of the research perspectives along selected categories.

	Techno-innovation	Individual decision-making	Industrial transformation	Embedded lifestyles
Problem framing	How can economic incentives support companies in transitioning toward low-carbon energy in a cost-effective way?	How can various incentives support individuals in adopting more climate-friendly consumption behaviors?	How can regulatory interventions enforce the phase-out of fossil fuels and emissions-intensive sectors in a just way, overcoming political-economic barriers?	How can systemic interventions transform energy service demand to maintain well-being while aligning with absolute reductions in emissions?
Academic origins	environmental economics; business management	behavioral economics; psychology	political science; sustainability transition studies; political economy; social-ecological economics; labor studies; sociology	ecological economics; mobility studies; environmental science; strong sustainable consumption governance
Form of intervention	supply-side; individual, based on low-binding, incentive-based intervention	demand-side; individual, based on low-binding, incentive-based intervention	supply-side; systemic, based on high(er)-binding, collective-rules-based interventions	demand-side; systemic, based on both high(er)-binding, collective-rules-based interventions and individual incentives
Key policies	economic instruments (e.g., carbon pricing, subsidies for innovations, tax reductions); voluntary company commitments	economic instruments (e.g., price incentives for consumers); informational instruments (e.g., labels, nudging)	command-and-control instruments; industrial and labor market policies; green economic planning; public provisioning; sustainable welfare policies	spatial planning; policy mixes of command-and-control, economic and informational instruments (e.g., choice editing)
Target actors	(producer) companies	individuals as consumers, citizens, voters, etc.	institutional actors at different scales (e.g., states, international treaties, municipalities); fossil-fuel and emissions-intensive companies; workers and affected communities; social movements and unions	individuals and households embedded in socio-economic and material structures operating at different scales; institutional actors (e.g., spatial planners, policymakers)

innovation and low-carbon technology with a stronger focus on green economic planning, exnovation, and phase-out policies [127]. It also emphasizes the integration of such phase-out policies with industrial, labor and (eco-)social policies to achieve more transformative and equitable outcomes as well as greater acceptance among affected communities and workers [128–130]. The embedded lifestyles perspective similarly advocates for the combination of policy options, including policy mixes [131] and policy sequencing [132]. These include economic instruments, regulatory standards (e.g., building codes, performance standards), behavioral policies (e.g., green defaults), but also spatial planning interventions (e.g., infrastructure development, street space reallocation), which are less emphasized in other perspectives [18,117].

Finally, in terms of *target actors*, the perspectives range from addressing individuals – mainly as (producer) companies or consumers, but also as voters, citizens and individuals embedded in socio-economic and material structures – to institutional actors, including policymakers, spatial planners, workers, unions, and affected communities. The techno-innovation perspective primarily targets companies and businesses, aiming to subtly steer investment toward (green) technological innovation and away from fossil fuels, especially through derisking [133]. Similar individual in focus, the individual decision-making perspective addresses actors mainly as consumers making informed decisions, based largely on their economic preferences [134]. Consequently, much of this literature focuses on how consumers can be encouraged to accept higher carbon prices [135–137].

The state appears as an important actor in both individual-centered perspectives, but is mainly construed as a neutral, non-partial entity enabling informed choices, 'competitiveness', and level playing fields for companies and consumers, for example, through facilitating carbon markets. In contrast, systemic perspectives, particularly the industrial transformation perspective, attribute a more active and direct role to the state. Phase-out polices and other command-and-control interventions require strong state capacities to plan and coordinate such interventions [6,33,110]. However, this literature also emphasizes the political-economic barriers to more progressive state involvement due to its entanglement with fossil capital [10] and other entrenched power complexes [92]. Therefore, the state itself is not seen as a homogenous actor but a contested terrain, where incumbent structures and the very functions of the modern capitalist state (e.g., through its reliance on economic growth) impede systemic change [10,138,139]. Networks and coalitions of actors are therefore recognized as vital for coordinating action and transforming institutional barriers [10,138]. Within this framework, the industrial transformation perspective places specific emphasis on workers and affected communities as transformation actors [6,95,140]. The embedded lifestyles perspective shares the focus on networks, coordinated action, and actor coalitions for implementing policy mixes and transforming infrastructures but places less direct emphasis on identifying specific actors. Instead, it highlights the complex system configurations that shape lifestyles [117].

While both systemic perspectives broaden the range of actors – such as municipalities, social movements, international alliances [90,96,141–143] – they still largely overlook intermediary actors (e.g., traders, processors, retailers), or assign them exclusively to either the demand or the supply side [47,126,144]. This dichotomy obscures the crucial role of supply-chain intermediaries in linking production and consumption systems – a key factor in understanding barriers to transformation, for example in the agri-food sector [28,145].

5. New research directions beyond the supply-demand dichotomy

The comparison above highlights the richness, diversity, and complementarity of existing approaches for investigating supply-side and demand-side mitigation options. However, in focusing on either the supply-side *or* the demand-side as the primary entry point, all perspectives have critical blind spots when exploring pathways for transformative change. In this section, we therefore introduce research directions that hold the potential to advance or inform transformative mitigation strategies. We introduce three such directions – provisioning systems, sufficiency corridors, and social-ecological practices – and describe how they move beyond supply-demand dichotomies. Subsequently, we discuss common reference points shared by these research directions.

5.1. Provisioning systems perspective

Provisioning systems are social-ecological systems, processes, and relations through which societies consume, produce, and distribute the goods and services to meet their needs and wants. As such, they mediate biophysical resource use (e.g., energy use) and social outcomes (i.e., human (un)well-being) [146]. Provisioning systems encompass material aspects (e.g., infrastructure, technology, manufacturing) and societal aspects (e.g., institutions, policies, labor/care relations) [147,148]. As a concept, provisioning systems are broader than traditional economic production systems, as they include both market-based, commodified, and monetized as well as non-market-based, un−/de-commodified, and non-monetized activities necessary to organize livelihoods [34,147].

The dominant problem framing highlights that "consumption outcomes depend on the system by which a good or service is provided [which] in turn is shaped by the nature of the good itself and the context in which both production and consumption, and the connections between them, are situated" [149]. This framing highlights the need to understand the "unique political economy" of each commodity or service [148] and to unpack the systemic factors that determine who gets what, how, and why [149]. The provisioning systems perspective acknowledges that energy supply and demand (as well as associated behaviors and practices) are embedded in wider societal contexts, including material infrastructures, economic and regulatory systems as well as labor relations [150–153]. For example, applying a provisioning systems perspective, Staritz et al. [154] challenge the conventional view that price-making is an objective, market-driven process. They show how critical raw material extraction and consumption are closely intertwined within a broader socio-ecological context, where price-making is shaped by the dominance of financial actors, power struggles, social relationships, institutions, and the physical realities of mineral commodities. Focusing on food provisioning, Bayliss and Fine [149] examine how profit-driven food production requires practices like land grabbing and commodity speculation as well as advertising and widespread retail outlets to push consumption. At the same time, consumers experience pressures both to eat and to diet, developing specific cultural patterns around food consumption. Investigating the political economy of car dependence through a provisioning systems perspective, Mattioli et al. [79] show how car-dominated, high-carbon transport systems are co-determined by the interests of the automotive industry, the provision of car infrastructure, the political economy of urban sprawl, and cultures of car consumption (see also, [96]).

Rather than establishing a dichotomy between supply-side technological change and the reduction of energy demand, the provisioning systems perspective frames production and consumption as coupled systems across various sectors [20,155]. It highlights how, under certain political-economic conditions, industries are driven to continuously expand production, thereby creating demand (and wants) that often exceed actual needs [156,157]. At the same time, consumers interact with these underlying material, economic, and social structures through their behavioral tendencies (demand), which are shaped by routines and cultures that have developed around specific commodities and services [149,158].

The provisioning systems perspective offers a variety of systemic entry points for transformative change, both on the demand-side and supply-side as well as along various phases of establishing and sustaining provisioning systems. For example, Schaffartzik et al. [152]

differentiate five such phases of provisioning systems development (groundwork, investment and construction, operation, maintenance, and dissolution), each with unique implications and opportunities for intervention. In the groundwork phase, land appropriation and legal changes lay the socio-political foundation, often displacing local populations, offering early intervention opportunities to prevent long-term damage. The investment and construction phase locks in material commitments, with protests, labor actions, and legal challenges potentially stopping irreversible changes. The operation and use phase comes with the highest resource consumption and pollution, where various activities can target halting harmful activities. Maintenance prolongs system life, allowing divestment or policy shifts as critical intervention points. Finally, obsolescence and dismantling leave lasting environmental and social legacies, where reclamation and corrective justice campaigns seek to mitigate – and potentially correct – long-term impacts. Each phase provides specific moments for intervention and resistance to transform rather than reproduce current provisioning systems.

5.2. Sufficiency corridors perspective

The concept of *corridors*, which has gained recognition in the latest IPCC report [159], offers another framework for addressing excessive energy and resource use while ensuring human well-being – potentially spanning both production and consumption spheres [160]. Corridors define minimum standards for a good life and maximum limits on the use of natural and social resources [161]. Corridors can be understood as the space between these two boundaries, with the goal of gradually narrowing this space over time. This is achieved by raising the floor to universally ensure the satisfaction of human needs, while simultaneously lowering the ceiling to limit wasteful or harmful overproduction and overconsumption. This idea recognizes that sustainability is not just about making things more efficient but about deciding what kinds of production and consumption should be prioritized (e.g., luxury versus essential production and consumption).

A corridor perspective frames the research problem as one of distribution and inequalities, emphasizing that social-ecological crises "are, *at their core*, distributional crises, where excess and deprivation, overshoot and shortfall are interconnected" [160]. This approach criticizes the prevailing focus on technology, highlighting that such strategies overlook the deeper issue of inequality. It seeks to shift the focus from decoupling growth from resource use to addressing the unequal contribution to and distribution of environmental impacts, the unequal access to resources needed for protection against these impacts, and ensuring fair resource access for all. Closely related to the question of who gets what, how, and why (see Section 5.1), a corridors perspective highlights the need to think about the *distribution* of, for example, "space, available time, and financial capital" [162]. Among others, the application of corridors has been explored in areas such as residential space [163], the development of green public spaces [164], information and communication technologies [165], fashion and textiles [166], as well as urban mobility [167].

Initially, the concept has been developed as *consumption corridors* that "describe a space between minimum consumption standards that provide every individual with the ability to live a good life, and maximum consumption standards that keep individuals from consuming in quantities or ways that hurt others' chances to do the same" ([168], see also, [162,169]). However, research on consumption corridors is rooted in a tradition of "strong sustainable consumption governance" which considers the distinction between production and consumption "partly artificial" [170] and focuses on consumption-production systems (e.g., [171,172,173]). Nevertheless, the literature on consumption corridors tends to foreground the consumption side, aligning with a broader trend in the sufficiency literature, where sufficiency is rarely applied to production [119]. From a systemic perspective, however, integrating consumption and production corridors is crucial to challenge growth-oriented political economic systems. Bärnthaler and Gough [27] have therefore introduced the concept of *production corridors* to complement the focus on consumption in reaching sufficiency (see also [174]). They differentiate between essential production, excess production, and in-between production to conceptualize production corridors as dynamic spaces between social-ecological floors and ceilings. As a research agenda, *sufficiency corridors* then aim to integrate the production and consumption sphere as a "space between a floor of meeting needs and a ceiling of ungeneralizable excess" [160].

A sufficiency corridors perspective aims to integrate key insights from the embedded lifestyles perspective (from which the concept of consumption corridors emerged) and from the industrial transformation perspective (which underpins the idea of production corridors). For example, while the former is particularly concerned with structurally embedded lifestyles, high-energy consumers, co-benefits, and the political and socio-cultural renegotiation and reconfiguration of need satisfiers, the latter places greater emphasis on questions of ownership, macro-financial regimes, critical and unnecessary labor, and industrial policy, and is more strongly anchored in green economic or eco-socialist planning debates — although both share a strong focus on equity and eco-social policies [105,175,176]. As a — yet largely unrealised — research agenda, sufficiency corridors would seek to bridge these debates and entry points through the shared objective of raising social floors and lowering ceilings, exploring implications for alliance building, new transformation narratives, and strategic interventions.

5.3. Social-ecological practices perspective

Finally, a third, influential research perspective, rooted in sociology, focuses on *practices* as the main intervention unit, for example, sharing practices, shifting to plant-based diets, reducing the size of living space, car use or air travel [116]. Social practices are active integrations of *materials* (e.g., infrastructure, built environment), *meanings* (e.g., cultural norms and conventions, rules), and *competences* (e.g., skills, knowledge) [177–179]. They are not individual actions but socially shared patterns of routinized behavior that involve both human activity and the material world, connecting individual and societal levels of activity [180]. Hence, like provisioning systems, they are material, socio-cultural, and political-economic phenomena — although most practice theories would benefit significantly from a deeper engagement with political economy — shaping how we live, produce, and consume.

A social-ecological practices perspective has emerged as a critique of the influential ABC (Attitude-Behavior-Choice) model, which is central to the individual decision-making perspective [181]. This model assumes that social change depends on attitudes (A), which drive behavior (B) that leads to choices (C). By placing too much emphasis on individual choice, this model neglects the broader social, political, cultural, and material contexts that shape everyday practices. A social-ecological practices perspective shifts the problem framing from individual choices (as emphasized in the individual decision-making perspective) and efficiency improvements (central to the techno-innovation perspective) toward understanding how energy is used as part of everyday social practices, rather than as an isolated technical issue ([182], see also, [183]). It challenges the view that efficiency is purely about delivering more services with less energy, arguing instead that such approaches obscure how societal norms and rules, material arrangements, and infrastructures drive energy demand and supply. Climate change mitigation strategies thus require a deeper understanding of how social-ecological practices evolve and shape energy use.

Social practice theory focuses on how both supply and demand are interwoven in everyday practices. Rather than viewing production and consumption as separate processes, it sees them as mutually constitutive within social-ecological practices. For example, Shove and Trentmann ([179], see also, [184]) discuss how infrastructure-practice (re)configurations can support alternative resource supply systems and significantly reduce consumption. They emphasize the need for specific

infrastructures (e.g., to support prosuming practices), new institutional models that move away from volume-based business models, and network-dependent appliances to facilitate resource reuse in low-carbon practices. Additionally, they highlight the importance of changing the relationships between social practices and networks (e.g., around comfort and convenience) and between consumers and producers (e.g., consumer involvement in the provisioning process, which may require more time and new skills as well as localized production).

A social-ecological practices perspective offers a variety of entry points for transformative change that span production (supply) and consumption (demand) spheres [178]. In terms of materials, changes in technology and infrastructure – such as expanding public transport networks or transiting to solar energy systems – can reshape both production (how energy services are generated and distributed) and consumption (how energy services are used at home or in transport). In terms of meanings, socio-cultural shifts in the perception of needs – such as redefining "luxury" as sustainable living or experiencing high-impact behaviors like flying or meat consumption as increasingly out of step with social norms – can reduce demand for resource-intensive products and services and alter how goods are produced and marketed. Finally, in terms of competences, the development of new skills and knowledge – like navigating shared, multi-modal transport systems or adopting energy-saving habits at home – is crucial for consumers and producers to enable and reproduce low carbon and material practices. Importantly, since practices are ongoing integrations of materials, meanings, and competences, transformative interventions must go beyond isolated changes in these elements. They must also focus on breaking and (re-) making the connections between them, as well as changing how different practices – such as leisure, care, and mobility – interlock [178,185].

5.4. Common reference points

The discussion above highlights that the presented research directions share common reference points, which could serve as a foundation for future research on climate change mitigation and help identify interconnected entry points for transformative change.

First, the three perspectives analyze *production and consumption as coupled systems,* where consumption is rooted in production and vice versa. They acknowledge that consumption is also an induced outcome of growth- and productivity-driven production sectors that, among others, channel long working hours and labor-productivity gains into increasing consumption [186], drive consumption through practices like advertising and planned obsolescence [187,188], and are controlled by those who own and manage the means of production under certain political-economic conditions [189,190].

Second, the three perspectives share a common understanding that focusing mitigation strategies primarily on more efficient and low-carbon technologies and practices is insufficient. Achieving the necessary absolute reductions in production and consumption levels also requires changes in political-economic framework conditions. Hence, in coupled systems, transformative interventions have to complement efficient and renewable technologies with strategies aimed at *avoiding* the use of energy and other resources. These 'avoid strategies' need to target both the consumption and production of fossil fuels and emissions-intensive sectors, rather than being limited to either demand-side *or* supply-side mitigation. Relatedly, the three perspectives are concerned with how specific (energy) *services* (e.g., mobility, nutrition, housing) – framed as social outcomes (provisioning systems), specific kinds of consumption and production (sufficiency corridors), or social-ecological practices – can be achieved with less material and energy input, while ensuring high levels of well-being [8,191].

Third, the three perspectives share a *systemic* understanding of transformative change – that is, they address change beyond the cumulative effects of individual decisions, whether by consumers or companies, and recognize the need for collective-rules-based interventions. Accordingly, these research directions emphasize the critical role of material infrastructure [192,193], political economy and labor relations [91,96], political institutions and regulations [139], and shared social-ecological practices [184,194] in comprehensively understanding the interplay between supply-side and demand-side mitigation strategies. This systemic focus does not imply that individual decisions should be neglected, especially when they have significant emissions implications (e.g., flying, cruise vacation, meat consumption). Rather, it highlights that the barriers to transformative change are not primarily rooted in a lack of information, consumer acceptance, or incentives, but in the unequal distribution of power and resources, the resistance of incumbent actors, and entrenched society-nature relations [28,92,195].

6. Conclusion

In recent years, the body of climate change mitigation literature has become increasingly diverse, with a growing emphasis on either supply-side or demand-side strategies. In this article, we have developed a typology of these strategies, clustering four research perspectives based on the entry point of intervention (supply-side or demand-side) and the scope of intervention (individual or systemic). These perspectives are: techno-innovation, individual decision-making, industrial transformation, and embedded lifestyles. We discussed each perspective in terms of its problem framing, academic origin, forms of intervention, key policies, and target actors. While dominant problem framings – and the corresponding forms of intervention and policies – mainly target individual consumers and companies (as reflected in the techno-innovation and individual decision-making perspectives), we also observe a dynamic research landscape emphasizing systemic mitigation strategies. These systemic perspectives address both supply-side (industrial transformation perspective) and demand-side interventions (embedded lifestyles perspective). The embedded lifestyles perspective has effectively highlighted the importance of reducing and avoiding energy and resource use in absolute terms, rather than merely improving efficiency. However, equating the need for reduction and avoidance solely with demand-side mitigation is unwarranted. The emerging industrial transformation perspective emphasizes systemic supply-side strategies that target production volumes (and profits) and therefore require stronger forms of collective-rules-based intervention to address the underlying capitalist political-economic systems – including working conditions and ownership structures – that drive continuous growth in both production and consumption.

Despite the richness and complementarity of these research perspectives, they generally fail to actively overcome the supply-demand dichotomy, resulting in persistent blind spots. In the final section of the article, we therefore introduced three research directions that explicitly aim to transcend this dichotomy. These perspectives – provisioning systems, sufficiency corridors, and social-ecological practices – share three key features: first, they analyze production and consumption as coupled systems; second, they agree that climate change mitigation requires not only more efficient and low-carbon technologies and practices but also an absolute reduction in production and consumption levels, alongside a focus on (energy) services; and third, they emphasize a systemic understanding of change, moving beyond the cumulative effects of individual decisions to collectively reshape infrastructures, political and economic relations, and shared practices. As such, these perspectives provide a foundation for future research on climate change mitigation and open new entry points for alliance building and transformative change.

CRediT authorship contribution statement

Melanie Pichler: Methodology, Conceptualization, Writing – review & editing, Writing – original draft. **Richard Bärnthaler:** Methodology, Conceptualization, Writing – review & editing, Writing – original draft.

Dominik Wiedenhofer: Methodology, Conceptualization, Writing – review & editing. **Nicolas Roux:** Methodology, Conceptualization, Writing – review & editing. **Simone Gingrich:** Methodology, Funding acquisition, Conceptualization, Writing – review & editing, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Melanie Pichler, Dominik Wiedenhofer and Richard Bärnthaler acknowledge funding from the Austrian Climate Research Programme (ACRP) through the project HABITATION-CORRIDORS (grant agreement FO99913168). Dominik Wiedenhofer acknowledges funding from the Horizon Europe programme through the project CircEUlar (101056810), the EDITS project, funded by Ministry of Economy, Trade, and Industry (METI), Japan, as well as from the Austrian Science Fund (FWF) through the project REMASS (10.55776/EFP5). Nicolas Roux acknowledges funding from the FWF through the project LandCube (P35420) and the ACRP through the project UNRAVEL (KR20AC0K18081). Simone Gingrich acknowledges funding from the ACRP through the project FOCAL POINTS (KR21KB0K00001).

Data availability

No data was used for the research described in the article.

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