The feasibility of climate action: Bridging the inside and the outside view through feasibility spaces

Citation for the original published paper (version of record):
Jewell, J., Cherp, A. (2023). The feasibility of climate action: Bridging the inside and the outside view through feasibility
spaces. WIREs Climate Change, 14(5). http://dx.doi.org/10.1002/wcc.838

Received: 13 August 2022 | Revised: 19 February 2023 | Accepted: 22 March 2023

DOI: 10.1002/wcc.838

ADVANCED REVIEW

WIREs CLIMATE CHANGE WILEY

The feasibility of climate action: Bridging the inside and the outside view through feasibility spaces

Jessica Jewell[1,2,3] | **Aleh Cherp**[4,5]

[1]Department of Space Earth and Environment, Chalmers University of Technology, Goteborg, Sweden

[2]Centre for Climate and Energy Transformations, University of Bergen, Bergen, Norway

[3]Advancing Systems Analysis, International Institute for Applied Systems Analysis, Laxenburg, Austria

[4]Department of Environmental Sciences and Policy, Central European University, Vienna, Austria

[5]International Institute for Industrial Environmental Economics, Lund University, Lund, Sweden

Correspondence
Jessica Jewell, Department of Space Earth and Environment, Chalmers University of Technology, Goteborg, Sweden.
Email: jewell@chalmers.se

Funding information
European Commission, Grant/Award Numbers: 950408, 821471; Stiftelsen för Miljöstrategisk Forskning, Grant/Award Number: MISTRAElectrification

Edited by: Simone Pulver, Domain Editor and Mike Hulme, Editor-in-Chief

Abstract

The feasibility of different options to reduce the risks of climate change has engaged scholars for decades. Yet there is no agreement on how to define and assess feasibility. We define feasible as "do-able under realistic assumptions." A sound feasibility assessment is based on causal reasoning; enables comparison of feasibility across climate options, contexts, and implementation levels; and reflexively considers the agency of its audience. Global climate scenarios are a good starting point for assessing the feasibility of climate options since they represent causal pathways, quantify implementation levels, and consider policy choices. Yet, scenario developers face difficulties to represent all relevant causalities, assess the realism of assumptions, assign likelihood to potential outcomes, and evaluate the agency of their users, which calls for external feasibility assessments. Existing approaches to feasibility assessment mirror the "inside" and the "outside" view coined by Kahneman and co-authors. The inside view considers climate change as a unique challenge and seeks to identify barriers that should be overcome by political choice, commitment, and skill. The outside view assesses feasibility through examining historical analogies (reference cases) to the given climate option. Recent studies seek to bridge the inside and the outside views through "feasibility spaces," by identifying reference cases for a climate option, measuring their outcomes and relevant characteristics, and mapping them together with the expected outcomes and characteristics of the climate option. Feasibility spaces are a promising method to prioritize climate options, realistically assess the achievability of climate goals, and construct scenarios with empirically-grounded assumptions.

This article is categorized under:

Climate, History, Society, Culture > Disciplinary Perspectives
Assessing Impacts of Climate Change > Representing Uncertainty
The Carbon Economy and Climate Mitigation > Decarbonizing Energy and/or Reducing Demand

KEYWORDS

climate change mitigation, climate scenarios, feasibility

1 | INTRODUCTION

Which options to avert dangerous climate change or adapt to its consequences are more and which are less feasible? The most recent IPCC reports mention feasibility over 500 times[1] (IPCC, 2022b, 2022d), but this question is not new—it has engaged scholars for decades (Anderer et al., 1981; Pielke et al., 2008; van Beek et al., 2020), recently encompassing the feasibility of negative emission technologies (Anderson & Peters, 2016; Fuss et al., 2014), low energy demand (Brockway et al., 2021; Semieniuk et al., 2021), rapid upscaling of renewables (Cherp et al., 2021; Hansen et al., 2017; Smil, 2016), land-based climate mitigation (Roe et al., 2021), and adaptation (Singh et al., 2020; Williams et al., 2021). Yet, there is no agreed approach to define or assess feasibility. To begin with, the distinction between feasible, possible, plausible, and probable is not always clear (Box 1, Figure 1). Additionally, a number of other questions have emerged: Should we presume the availability of all political and social choices or also assess whether these choices themselves are feasible? How should we compare the feasibility of very different options for example, de-growth versus negative emissions? How should we account for future technological developments and policy shifts?

Here we discuss how a meaningful definition of feasibility and the principles of an effective feasibility assessment emerge from the literature (Section 2). We also explain the challenges of incorporating these principles in assessing the feasibility of mitigation and adaptation options in long-term scenarios generated by integrated assessment models (IAMs) for the IPCC (Section 3). We draw parallels between today's feasibility debates and the dichotomy between the "inside" and the "outside" views coined by Daniel Kahneman and his colleagues (Kahneman & Lovallo, 1993), where the inside view seeks to understand detailed barriers to climate mitigation and adaptation as unique challenges and the

BOX 1 Feasibility, plausibility, probability, and related terms

The literature often uses the term "feasibility" interchangeably with "plausibility" (Hancock & Bezold, 1994; Napp et al., 2017), "probability" (Engels et al., 2023; Engels & Marotzke, 2023; Morgan & Keith, 2008), "attainability" (Riahi et al., 2021; Warszawski et al., 2021), and "achievability" (van Sluisveld et al., 2015), but these metonyms are rarely defined. Feasibility is a characteristic of an uncertain future which is related but not identical to the other characteristics (Figure 1).

Probability is the *likelihood* of a future outcome which factors in likely choices of relevant agents (Hancock & Bezold, 1994; Morgan & Keith, 2008; Nordhaus & Yohe, 1983).

Example: "Anna will probably cross the lake soon because she has a boat she can sail and needs to get something on the other shore".

Plausibility or *possibility* have a wide variety of meanings ranging from those close to probability (Pielke et al., 2021) to those close to feasibility (Hancock & Bezold, 1994; Napp et al., 2017; Semieniuk et al., 2021). In the classic definition, *plausible* means "occurable" or something that "could happen" (Henchey, 1978; Wiek et al., 2013) under internally consistent assumptions (Nakicenovic et al., 2000; Wack, 1985).[2] Plausibility is the guiding principle in the "what-if" logic of climate scenarios (Nakicenovic et al., 2000; O'Neill et al., 2017; Riahi et al., 2017; Rogelj et al., 2018). A further distinction is sometimes made between *plausible*, where assumptions are based on existing knowledge and *possible* which allows for the expansion of knowledge and wildcards into "science fiction" futures (Hancock & Bezold, 1994; McCollum et al., 2020; van Dorsser et al., 2018; Voros, 2003). Both *plausible* and *possible* require assuming certain choices of social actors.

Example: "It is *plausible* that Anna crosses the lake if she gets a boat and learns to sail".

Feasibility is defined by the IPCC as the "potential for a mitigation or adaptation option to be implemented" (IPCC, 2022c footnote 72).[3] It has a strong focus on agency (implementors) who will pursue future options (Hancock & Bezold, 1994, p. 24)[4] and thus can be rephrased as something "do-able." The second element of this definition is "potential," which signals objective constraints to and opportunities for action. Thus, *feasible* can also be defined as "*do-able under realistic assumptions*."[5] This makes feasible a subset of plausible with an additional requirement that the assumptions are backed by stronger evidence and not only by internal consistency.

Example: "It is *feasible* for Anna to cross the lake because she has a boat and is learning to sail."

outside view explores historical analogies to climate action. We also propose how the two views can be bridged through "feasibility spaces" (Section 4). Though this review does not assess feasibility of any specific climate option, it proposes a systematic approach that can form the basis of such assessments in future research.

2 | THE INTELLECTUAL HISTORY AND PRINCIPLES OF FEASIBILITY ASSESSMENT

The current debate on the feasibility of climate options has its roots in the 1980s, when the first global assessments and scenarios explored resource scarcity, energy geopolitics, and rising pollution (Anderer et al., 1981; Edmonds et al., 1984; Frisch, 1983; Goldemberg et al., 1985a; Lovins, 1976; Nordhaus & Yohe, 1983). These studies argued that proposed solutions should be feasible in real-world conditions. For example, the influential *Energy in a Finite World* only considered energy technologies that "would be feasible within the next fifty years" (Anderer et al., 1981, p. 21) and an early report from the EPA argued that for a climate option to be "desirable, it must be technologically, economically and politically feasible" (Seidel & Keyes, 1983, pp. 1–18). Over decades, the literature formulated three principles of scientific feasibility analysis: causal reasoning, comparability, and reflexive consideration of agency.

2.1 | Causal reasoning

The central role of causal reasoning can be illustrated by the early debate between "high supply" solutions stressing the rapid expansion of nuclear power, natural gas, and renewables (Edmonds et al., 1984; Frisch, 1983), and a "soft energy path" emphasizing energy efficiency and decentralization (Goldemberg et al., 1985a, 1985b, 1987; Lovins, 1976). For example, Goldemberg et al. (1985a, 1985b, 1987) argued that it would be more feasible to support developing countries through a "soft energy path" because: (1) a high growth in energy demand would require expansion of expensive infrastructure and energy imports, which would in turn undermine state budgets, slow down economies, and trigger conflicts; (2) advanced end-use technologies can deliver the same energy services at a fraction of primary energy; (3) such technologies are already widely used in developed countries; and (4) these technologies can diffuse to developing countries as some had already diffused to Brazil.

This logic illustrates *causal reasoning* using both inductive (2 and partially 3) and deductive (1, 4, and partially 3) logic in a specific combination that Sorrel (2018) calls "retroductive," and makes it possible to differentiate between theoretically postulated causalities on the basis of empirical evidence (see also Bhaskar (2014) and Mingers (2006) cited by Sorrel). Causal reasoning has since become a central pillar of scientific discussions of feasibility (e.g., Jewell &

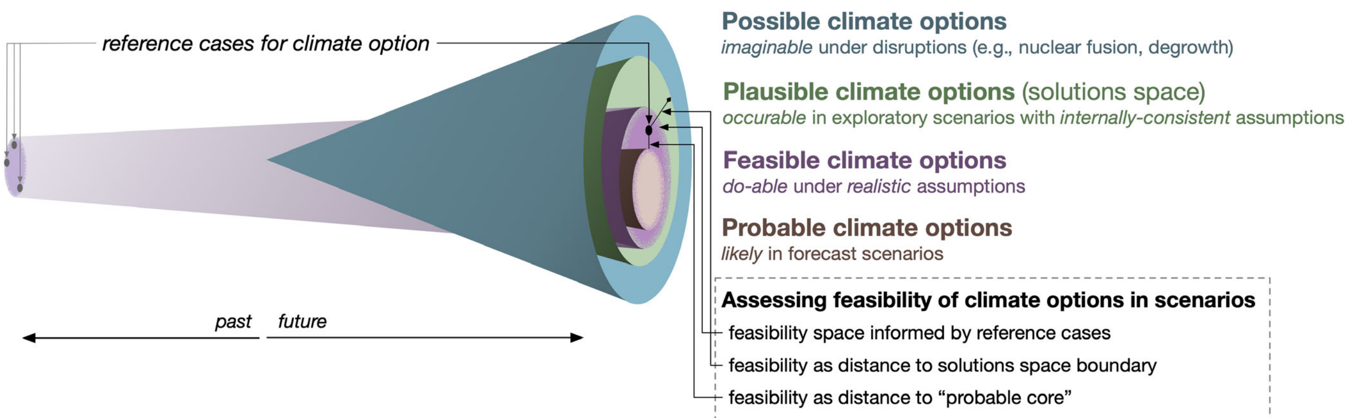


FIGURE 1 Feasible climate options are subset of possible and plausible options and wider than probable options. Modified from the "futures cone" (Hancock & Bezold, 1994; McCollum et al., 2020; van Dorsser et al., 2018; Voros, 2003) to include feasibility and reference cases. Note that feasible and probable climate options are depicted with fuzzy boundaries to depict their probabilistic nature. Feasibility of climate options in scenarios can be conceptualized as the "distance" to the outer boundary of "plausible options" or alternatively to "probable options" (Section 3.2). The feasibility space is informed by evidence from a set of reference case (Section 4.2).

Cherp, 2020; Roe et al., 2021; Stern et al., 2022).[6] A climate solution is either feasible or infeasible if there is a path, a causal chain of events, either leading to or blocking its implementation. Discussions about feasibility should therefore be structured around causal evidence (such as models of energy flows, economic calculations, and analogies from other countries).

2.2 | Comparability

As in early debates, contemporary literature compares the feasibility of two or more climate options or assesses the feasibility of a climate option by comparing it to a benchmark or threshold (Bager et al., 2021; Cherp et al., 2021; Jenkins, 2014; Odenweller et al., 2022; Semieniuk et al., 2021; Vinichenko et al., 2021). This is because a mere description of causal mechanisms blocking or enabling a climate solution is not enough to understand whether it is "do-able." For example, Jenkins (2014) investigates potential opposition from businesses and consumers to show that the maximum tolerable levels of carbon price in the United States are about two orders of magnitude below the social cost of carbon. He concludes that pricing carbon at an economically optimal level is politically infeasible and therefore other climate policies are also needed. Thus, Jenkins' quantitative analysis of feasibility results in policy advice which would not be possible through mere qualitative observation that carbon taxes face social resistance.

Jenkins succeeded in this remarkably informative quantification of feasibility because he analyzed a well-defined policy constrained by a well-understood causal mechanism. In case of more complex causal mechanisms, scholars use semi-qualitative analysis where indicators for relevant causal mechanisms are aggregated. Bager et al. (2021) use this approach for comparing the feasibility of 86 policy options to combat deforestation using three indicators of advocacy support, institutional complexity, and monetary costs. Roe et al. (2021) compare the feasibility of land-based mitigation across some 200 countries using 19 indicators for national capacities such as GDP per capita, rule of law, and agricultural productivity which they link to feasibility through causal reasoning, where "a clear logic [...] exist[s] in the direction of the relationship between the variable in question and the feasibility of implementation of a mitigation measure" (p. 12). The utility of this approach depends on selecting appropriate indicators and aggregation methods, as we further discuss in Section 3.4.

2.3 | Reflexive consideration of agency

According to political philosophers Gillabert and Lawford-Smith (2012), an outcome is feasible if there is an agent or group of agents who can carry out a set of actions which will lead to an outcome in a given context. Thus, the question of "feasible for whom?" is central to a meaningful feasibility assessment (Gilabert & Lawford-Smith, 2012; Jewell & Cherp, 2020). But what does this practically mean? Implementing any climate option involves many actors from policymakers to investors, entrepreneurs, and the public. Should the choices of these actors be analyzed alongside other feasibility constraints, or should a feasibility assessment seek to inform and influence these choices?

In fact, the literature contains both approaches. Some human actions are treated similarly to other causalities affecting the implementation of climate solutions. For example, Jenkins (2014) argues that businesses and households block carbon prices above a certain level and Bager et al. (2021) argue that bureaucrats fail to follow overly complex procedures. These constraints constrain feasibility in a similar manner to the scarcity of land or lack of resources since they are "not under the control of policymakers" (Majone, 1975, p. 261). The second approach assumes that actors can make free choices, for example, that US policy makers can set any carbon price and EU policymakers can implement diverse regulations on deforestation. Here, scholars do not seek to predict policy choices through analyzing pressure from voters, party ideologies, state imperatives or other such factors. Instead, these studies aim to *inform* policy makers about relevant constraints[7] and assume freedom of choice within that set of constraints. But why do the same studies treat different actors differently? The approach depends on the intended audiences and their role in implementing the climate option. Jenkins (2014) and Bager et al. (2021) grant freedom of choice to US and EU policy makers who are their audience but not to businesses, consumers, and bureaucrats—who are not.

Thus, answering the question "feasible for whom?" requires clarity not only about the actors who can potentially influence the climate option, but also about the audience of the feasibility assessment, as well as the relationship between these two groups (Figure 2). A meaningful feasibility assessment informs its audience about what is "do-able" under realistic assumptions without over-constraining their freedom of choice or unrealistically over-extending their

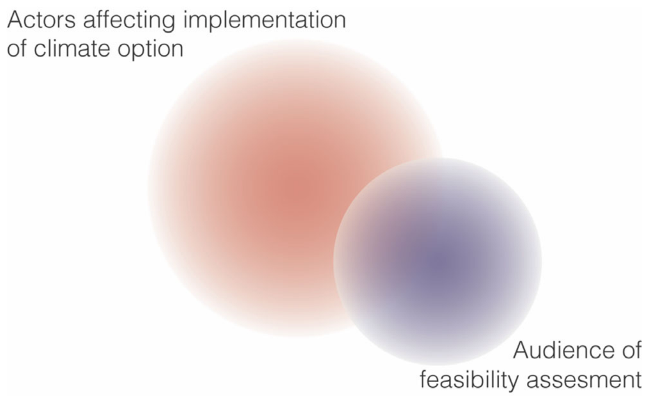


FIGURE 2 The audience of the feasibility assessment, the actors who have control over implementing the climate option, and their overlap.

agency to factors that are in reality outside of their control. This requires analysis of both the actors and the context including the stage in the policy cycle when the feasibility assessment is prepared (Lövbrand, 2011; Merton, 1945).

In summary, the following three principles of a sound feasibility assessment emerge from the literature discussed in this section:

1. Feasibility assessments are based on inductive and deductive *causal reasoning* that identifies assumptions under which climate options could be blocked or implemented and assesses the realism of these assumptions.
2. Feasibility assessments *compare feasibility* across climate options, their implementation levels, contexts, or with relevant benchmarks.
3. Feasibility assessments reflexively consider the *degree of control of their audiences* over the implementation of climate options avoiding on the one hand overextension of agency and on the other hand unintentionally constraining choices by prematurely ruling out or highlighting certain options.

3 | FEASIBILITY DEBATES IN GLOBAL SCENARIOS

Climate mitigation and adaptation require long-term efforts, which are commonly explored through global scenarios defined as "plausible description[s] of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships" (IPCC, 2019, pp.823). Contemporary global scenarios are normally developed with support from IAMs representing a multitude of complex causal relationships through mathematical algorithms (Guivarch et al., 2022; IPCC, 1992; Nakicenovic et al., 2000; Riahi et al., 2012). To which extent can these scenarios facilitate assessing the feasibility of climate options in accordance with the three principles outlined above?

3.1 | Causal reasoning in scenarios

Causal reasoning is central to climate scenarios and makes them a logical starting point for assessing feasibility. The role of a climate option in a scenario is typically determined by both external assumptions and internal model algorithms ensuring a consistent storyline. For example, responding to criticisms about assumptions on the feasibility of large deployment of negative emissions technologies in most 1.5°C scenarios, Grubler et al. (2018) constructed the prominent low-energy demand scenario (LED) where they assumed rapid worldwide diffusion of cutting-edge energy demand practices and argued that it's possible to achieve the 1.5°C target without negative emissions beyond afforestation. By varying their assumptions, IAMs can generate thousands of plausible scenarios (Byers et al., 2022; Guivarch et al., 2022; Riahi et al., 2022) each depicting hundreds of climate options designed to explore the "solution space"[8] (Edenhofer & Kowarsch, 2015). The scenario and modelling community understands the "solution space" here as the ultimate ensemble of scenarios and options including both those that have already been developed as well as those that should be explored in the future. The solution space is not static or set in stone and can change over time as new circumstances or knowledge emerge or as scenario audiences change their stance on meaningful assumptions to explore (Beck & Oomen, 2021; Cointe & Guillemot, 2023; Du et al., 2022; Ellenbeck & Lilliestam, 2019; Haasnoot et al., 2020; Keyßer & Lenzen, 2021; Livingston & Rummukainen, 2020; Lövbrand, 2011).

If a climate option falls outside of the solution space then there is no known causal path leading to its implementation, in other words, such an option is not feasible.[9] However, not all options *inside* the solution space are feasible (Figure 1). For example, the LED scenario may be infeasible because the underlying model does not account for potential barriers to rapid worldwide introduction of energy demand practices or for the rebound effect that may cancel out the benefits of energy efficiency (Brockway et al., 2021; Semieniuk et al., 2021). More generally, a typical solution space does not incorporate all relevant causalities and therefore contains many climate options that are not feasible in the real world (Anderson & Jewell, 2019; Geels et al., 2016; Hirt et al., 2020). While credibly representing techno-economic and geophysical processes, IAMs commonly fail to incorporate other causalities (Iyer et al., 2015; Loftus et al., 2015; van Sluisveld et al., 2015) such as public acceptance (Reusswig et al., 2016; Roddis et al., 2018), incumbent resistance (Geels, 2014; D. Lee & Hess, 2019), technological inertia (Iyer et al., 2015), technology readiness, investment requirements, infrastructure issues (Loftus et al., 2015), and political priorities (Cherp et al., 2018). In other words, plausibility in models "provides a useful context to understand technical and economic concerns [but] need[s] to be strictly differentiated from feasibility … in the real world, which hinges on a number of other factors, such as political and social concerns that might render […] model solutions unattainable" (Riahi et al., 2015, p. 19).

One strategy to respond to this criticism, has been to improve "model realism" by incorporating additional social causal mechanisms into models (Trutnevyte et al., 2019) or to produce scenarios by combining modelling with "socio-technical transitions" storylines (Geels et al., 2020). So far, this approach has not resulted in notable breakthroughs in assuring the feasibility of scenarios (Hirt et al., 2020; Keppo et al., 2021). An important reason might be that some social science knowledge is epistemologically incompatible with evidence that can be integrated in models (Geels et al., 2016), or does not meet the criteria for "retroductive" reasoning which differentiates between theoretically postulated and empirically observable causal mechanisms (Sorrell, 2018). These difficulties necessitate turning to other approaches of assessing the feasibility of climate options within the solution space as we discuss in Sections 3.4 and 4.1.

3.2 | Comparative assessment of feasibility in scenarios

A meaningful feasibility assessment should compare the feasibility of different climate options, or of the same option in different contexts or at different implementation levels. The solution space makes a step in this direction by filtering out clearly infeasible options, for which models cannot find internally consistent pathways. But how can the feasibility of climate options *within* the solution space be comparatively assessed?

One approach is to define feasibility "thresholds" for different climate options in terms of their implementation levels or contexts (Brutschin et al., 2021; Riahi et al., 2022; Warszawski et al. 2021). A straightforward source of such thresholds may be the model parameters themselves which constrain the solution space. For example, many IAMs impose limits on bioenergy use making it possible to differentiate between options that almost exceed these limits and those that are well within the limits: the former being judged as less feasible than the latter (Brutschin et al., 2021). Metaphorically speaking, this method measures the distance between the climate option and the boundary of the solution space (Figure 1). However, since the solution space does not account for all relevant constraints, scholars often search for feasibility thresholds based on evidence outside of models or scenario storylines. For example, several studies assess the feasibility of climate scenarios based on whether they impose too high carbon taxes (Jenkins, 2014), would lead to "drastic reductions in energy demand" (Iyer et al., 2015), would be socially unacceptable (Gambhir et al, 2017), or would require too high mitigation costs (Brutschin et al., 2021).

Setting feasibility thresholds is often challenging because it requires knowledge of the aggregate effect of all causal mechanisms driving and blocking a climate option. For example, Brutschin et al. (2021) note that the threshold for carbon price based on its macroeconomic effects does not consider social resistance to carbon taxes. There are attempts to address this challenge through establishing a comprehensive set of indicators reflecting diverse barriers and enablers (de Coninck et al., 2018), but it is not clear how to ensure that the indicators are comprehensive and consistent across climate options, how to set a threshold for each indicator, or how to aggregate across multiple indicators (see more in Section 3.4). Another problem is how to account for the dynamic, context dependent and malleable nature of thresholds. For example, thresholds that represent the costs of climate options, only make sense in relation to the motivations and capacities of actors to meet these costs in different contexts (Jewell & Cherp, 2020). Brutschin et al. (2021) illustrate an approach to address this challenge by proposing a threshold that combines the speed of emission reduction with the governance effectiveness, but such efforts can easily be mired in overwhelming complexity as the number of barriers, drivers and relevant contexts and capacities multiply.

An alternative method does not rely on setting thresholds but rather uses an intuitive notion that more *probable* options are also more *feasible*. Speaking metaphorically, instead of measuring the distance to the outer boundary of the solution space, this approach measures the distance to the "probable core" (Figure 1). Here, scholars sometimes turn to projections or outlooks (Pielke et al., 2022) as a depiction of the "probable" future implementation of a climate option. Such scenarios use assumptions or model parameters based on the strongest evidence (e.g., current trends, definite plans, or forecasts). Forecasts often identify a central or "most likely" scenario as well as a set of less likely scenarios. Climate options depicted in the central estimate can be considered more feasible because they are determined by the most probable combination of causal factors. For example, Pielke et al. (2021) uses this approach in arguing that based on IEA forecasts of emission trajectories, certain IPCC scenarios are implausible.

However, outlooks are not suitable to explore large uncertainties and unexpected developments, including technological breakthroughs, social change and policy choices that need to be considered in global climate scenarios. This is illustrated by the failure of early forecasts to accurately predict future energy demand (Morgan & Keith, 2008), the growth of nuclear power (Anderer et al., 1981; Wynne, 1984) and more recently—the costs of solar PV (Meng et al., 2021; Nemet, 2019). Another obstacle to assessing feasibility based on probability is that the majority of the IPCC scenarios are not probabilistic forecasts, but rather "exploratory scenarios" (Skea et al. (2021)), which means that their assumptions are deliberately varied to explore potential choices and uncertainties such as implementation of Nationally Determined Contributions (NDCs) (Ou et al., 2021; Roelfsema et al., 2020; Sognnaes et al., 2021) or future economic development, international cooperation, and technological progress (O'Neill et al., 2017; Riahi et al., 2017). The "normative" subset of exploratory scenarios explores assumptions relevant to achieving various levels of global warming (Riahi et al., 2022; Rogelj et al., 2018) or energy goals (IEA, 2021; Riahi et al., 2013). It is the feasibility of these "normative" scenarios that is often questioned by the literature (Anderson & Jewell, 2019; Anderson & Peters, 2016; Cherp et al., 2021; Semieniuk et al., 2021; Vinichenko et al., 2021).

There have long been calls to estimate the probability of different scenarios (Morgan & Keith, 2008; Nordhaus & Yohe, 1983; Schneider, 2001), which would facilitate analyzing the feasibility of climate options in normative and other exploratory scenarios. However, the mainstream scenario literature has rejected these calls on the basis that "[t]here are no independent observations and no repeat[] experiments" in social science for climate scenarios (Grübler & Nakicenovic, 2001, p. 15). This seriously hampers assessing the feasibility of climate options based on the information contained in most global scenarios. As we explain in Section 4, the "outside view" fills this gap by providing "natural experiments" based on independent observations and supported by inductive reasoning.

3.3 | Reflexive consideration of agency in scenarios

There are methodological parallels between considering agency in feasibility assessments and in scenarios even though the two perform different functions. Feasibility assessments aim to separate what is within versus outside of the policy-maker's control (Majone, 1975) and answer the question "feasible for whom?" (Gilabert & Lawford-Smith, 2012; Jewell & Cherp, 2020). Similarly, scenarios seek to separate "masterable" trends, which depend upon users' choices, from "dominant" trends, which do not (De Jouvenel, 1967). This distinction was clear already in Shell's pioneering work on future oil markets where dominant trends comprised oil demand, government policies, and economic developments and masterable trends—the company's corporate strategy (Wack, 1985). Global climate scenarios have attempted to maintain this distinction by capturing dominant trends within the shared socio-economic pathways (covering population, economic, political, and technological developments; O'Neill et al., 2014, 2017, 2020; Riahi et al., 2017) and masterable trends within the Shared climate policy assumptions (covering climate policies; Kriegler et al., 2014).

Global climate scenarios deal with much higher complexity than early corporate scenarios and their audiences are broader and harder to delineate,[10] though in practice scenarios are often developed in close collaboration with climate policy makers and international climate negotiators (Livingston & Rummukainen, 2020; Lövbrand, 2011; van Beek et al., 2022). This collaboration, often called knowledge co-production, helps both sides: policy makers rely on scenarios in formulating policy goals and agendas, while scientists benefit from the recognition of their role in policy-making and funding that often comes with it (Cointe & Guillemot, 2023; Lövbrand, 2011).

Unfortunately, when it comes to feasibility assessment, this mode of interaction between scenario scientists and policy makers can easily falter. For example, it is entirely acceptable for an exploratory scenario to depict achieving an ambitious climate goal requiring rapid global deployment of negative emission technologies. In contrast, the task of a feasibility analysis in this case would be to rigorously analyze the realism of underlying assumptions: who can invest in the required facilities? who can pass the carbon taxes making such investments profitable? who can mobilize industrial capacity to build the required infrastructure? and will such infrastructure be socially accepted? It may be difficult for scientists involved in knowledge co-production to seriously investigate these concerns because this involves questioning the degree of control their close partners have over each of these factors, where a multitude of other actors are involved. Furthermore, such investigation may lead to the inconvenient conclusion that the climate target is infeasible (Geden, 2015) or requires much more radical action than what policy makers are ready for (Anderson & Jewell, 2019; Stoddard et al., 2021).

Such risks may discourage scenario developers from engaging in rigorous feasibility assessments for the sake of maintaining close collaboration with policy makers. Scenario co-production without formal and rigorous feasibility assessment has been criticized for "performativity," when the mere inclusion of solutions such as negative emissions in scenarios already implied their feasibility (Beck & Mahony, 2018; Carton et al., 2020). Additional criticism highlights the "co-dependence" of scenario developers and climate policy makers, where normative scenarios are developed in response to political goals (such as 2 or 1.5°C targets) and then used to justify the feasibility of these goals even in the absence of a suitable feasibility assessment (Cointe & Guillemot, 2023; Lövbrand, 2011). Sometimes scenario developers defend this approach arguing that policy makers know better what is feasible. This misrepresents a large uncertainty over multiple interconnected and constrained choices for a "masterable" trend and therefore overextends the agency of scenario users without advancing our understanding of feasibility.

3.4 | Multidimensional feasibility assessment

The IPCC proposed a framework for analyzing the feasibility of climate options in its Special Report 1.5 (de Coninck et al., 2018; Solecki et al., 2018), which was subsequently refined by several teams of IPCC authors (Brutschin et al., 2021; Singh et al., 2020; Steg et al., 2022). This framework is called "multidimensional" because it is based on six categories ("dimensions")—economic, technological, socio-cultural, institutional, geophysical, and ecological/environmental—that aim to comprehensively capture all categories of causal factors that can affect the implementation of any climate option (Steg et al., 2022).

The origin of these dimensions can be traced to Majone (1975) who mentions political, economic, technological, and sociological constraints to policies. The six dimensions retain "economic" and "technological;" substitute "political" with "institutional;" "sociological" with "socio-cultural;" and add "geophysical" and "environmental/ecological" to reflect groups of IAM variables and the international climate change debate. Dimensions signal the relevance of several academic fields (economics, political science, sociology, ecology, engineering) to feasibility assessment, however, to reflect any specific causal mechanisms they need further operationalization, usually through indicators (Table 1). It is thus at the level of indicators that the comprehensiveness and relevance of the multidimensional framework can be analyzed.

Two distinct approaches to setting up indicators have emerged so far (Table 1). The first uses 3–4 generic indicators for each dimension (de Coninck et al., 2018; Khourdajie et al., 2022; Ley et al., 2022; Singh et al., 2020; Steg et al., 2022), for example "technological maturity," "scalability" and "simplicity" for the "technological" dimension. This approach standardizes feasibility concerns across climate options, but it runs the risk of neglecting barriers and enablers that are unique to specific options or contexts. In fact, when Majone (1975) first published his four categories of constraints he warned, "[i]t should be clear…that some kind of exhaustive listing [of all political, technological or economic constraints] would be … impossible and … pointless without reference to a specific policy problem" (p. 264). This reasoning rings even true with respect to climate options which have a wider scope than the policy problems Majone had in mind. Even at a high level, there are contrasting views on the main factors affecting climate options. For example, the majority of the eight overarching causes blocking the decline of global GHG emissions identified by Stoddard et al. (2021): geopolitics and militarism, economics and financialization, vested interests, inertia of energy systems, inequity, high-carbon lifestyles and social imaginaries, do not match any of the IPCC feasibility indicators. Likewise, most of the top-level variables explaining energy transitions (Cherp et al., 2018): energy infrastructure, supply–demand balance, technology diffusion, innovation systems, and state goals also do not directly match any of the indicators. The diversity

TABLE 1 Indicators used for six dimensions in selected recent studies.

	Economic	Technological	Socio-cultural	Institutional	Geophysical	Ecological
Generic indicators for *all* climate options						
Mitigation de Coninck et al. (2018)[a], Khourdajie et al. (2022)[b], and Steg et al. (2022)[b]	Costs and cost-effectiveness[a] in 2030 and long-term; Effects on employment; Absence of distributional effects[a]; Productivity enhancement potential[a]; Effects on economic growth[b]	Technical scalability; Maturity and technology readiness; Simplicity; Absence of risk[a]	Public acceptance; Social co-benefits/effects (health, education[a], wellbeing[b]) Social and regional inclusiveness[a]; Intergenerational equity[a]; Human capabilities[a]; Distributional effects[b]	Political acceptability; Legal and administrative feasibility; Institutional capacity (& governance[b]); Transparency and accountability potential[a] Cross-sectoral coordination[b]	Physical potential/ feasibility; Limited use of land; Limited use of scarce (geo) physical resources; Global spread[a]	Reduction of air pollution; Reduction of toxic waste; Reduction of water use; Improved biodiversity; Water quality[b] Eutrophication[b]
Adaptation de Connick et al. 2018, Singh et al. (2020), and Ley et al. (2022)	Microeconomic and macro-economic viability; Socio-economic vulnerability reduction potential; Employment and productivity enhancement potential	Technical resource availability; Risk mitigation potential	Social co-benefits; Sociocultural acceptability; return Social and regional inclusiveness; return Intergenerational equity	Political acceptability; return Legal, regulatory feasibility, institutional capacity and administrative feasibility; transparency and accountability	Physical feasibility; Land use change enhancement potential; Hazard risk reduction potential	Ecological capacity; Adaptive capacity; return Resilience building potential
Customized indicators for a *specific* feasibility assessment						
Land-based mitigation Roe et al. (2021)	GDP per capita; Forest rents; Agricultural value-added; Ease of doing business; Ease of obtaining a bank loan	Access to information and communication; Market access and infrastructure; Agricultural total factor productivity	Personal rights; Nutrition and basic medical care	Voice and accountability; return Political stability and absence of violence; return Government effectiveness; Regulatory quality; Rule of law; Control of corruption; Tenure insecurity	Total land-based mitigation potential	Environmental Performance Index
Scenarios Brutschin et al. (2021)	Carbon price; GDP losses; Energy investments; return Stranded coal assets	Scale-up of wind, solar, nuclear, biomass, CCS with coal, BECCS, biofuels, and electricity in transport	Demand decline: total, transport, industry, residential sector Decline of livestock share in foot, forest cover increase, pasture cover decrease	Governance level and per capita CO_2 emission reductions over a decade	Wind energy generation, solar energy generation, and biomass energy generation	

[a]Some generic indicators for mitigation options vary slightly by reference. (a) marks Indicators which are only present in de Coninck et al. (2018).
[b]Some generic indicators for mitigation options vary slightly by reference. (b) marks indicators present in Steg et al. (2022) and Khourdajie et al. (2022).

of scientific perspectives would always make it difficult to reach an agreement on a set of indicators applicable to all mitigation and adaptation options.

In the second approach to applying the multi-dimensional framework, the six dimensions are used as a guidance to elaborate specific indicators for a specific feasibility question, such as the systemic feasibility of scenarios (Brutschin et al., 2021), or suitability of various contexts to a particular climate option (Roe et al., 2021; Thoni et al., 2020). This avoids the problems with generic indicators, but requires scientific agreement concerning the process for selecting the indicators. The six dimensions may serve as input into such a process, if they are used in retroductive identification of relevant concerns, rather than in abductive rationalization of ad hoc indicators.[11]

The users of the multidimensional framework typically evaluate and then aggregate indicators using a "traffic light" or similar semi-quantitative scores (Brutschin et al., 2021; de Coninck et al., 2018; IPCC, 2022a; Pathak et al., 2022; Roe et al., 2021; Singh et al., 2020). This produces an easy-to-communicate assessment where the complexity of underlying causal mechanisms is reduced to a few simple variables. However, this approach raises two methodological challenges: (a) how to consistently assign scores for individual indicators across different climate options and (b) how to aggregate the scores across multiple indicators for the same option. The first problem can be illustrated through Steg's et al.'s (2022) argument that electric vehicles and industry electrification face barriers of public acceptance, legal and institutional capacity, while solar electricity does not face any such barriers. This claim is difficult to justify (Baldwin et al., 2016; Cousse, 2021) unless there are dedicated studies systematically analyzing the three options against the three criteria. In reality, this finding is based on expert views and literatures likely using different definitions and methods of measuring public acceptance and institutional capacities for different options, which makes credible comparison across options difficult if not impossible. The second challenge relates to aggregating the scores across feasibility indicators. In case of generic indicators similar for all options, it requires assigning consistent weights which reflect the importance of different factors for different climate options or contexts. When indicators are option- or context-specific, consistent aggregation becomes even more challenging. The lack of an agreed and reliable method of comparative feasibility assessment makes it unsurprising that there are conflicting conclusions on the feasibility of different pathways (Livingston & Rummukainen, 2020; van Beek et al., 2022).

With respect to reflexively addressing the agency of their users, the studies using the multidimensional framework have so far aimed to inform a similarly broad audience as global climate scenarios. For example, Roe et al. (2021) propose to use their analysis of land-use mitigation feasibility "to plan and prioritize country-specific policies and measures" and offer "key considerations for external actors who seek to help [developing] countries mobilize their mitigation potential." Singh et al.'s (2020) feasibility assessment of adaptation aims at "global and national policymakers as well as nongovernmental adaptation decision-makers and practitioners." The methods and findings of such assessments are presented alongside global scenarios in the IPCC reports however, their stated purpose shifted from assessing feasibility (as in SR1.5 see de Coninck et al. (2018) and IPCC AR6 Annex II IPPC (2022a)) to "identify[ing] barriers to and enablers of implementing climate [...] options" and to "provide[ing] critical information to governments and decision makers on what factors would need to be targeted to improve the feasibility of options to ensure [they] can be implemented at scale on a timely basis" (Steg et al., 2022, p. 1218). This may signal a shift of the IPCC away from assessing the feasibility of what is possible, potentially reflecting the limitation of science-policy interactions discussed in the previous section.

4 | THE OUTSIDE VIEW AND THE FEASIBILITY SPACE

4.1 | The inside and the outside view

A distinct approach to assessing the feasibility of climate options in global scenarios focuses on comparing them with historical analogies. Concern about the historically unprecedented speeds of carbon intensity decline envisioned in climate mitigation scenarios was first raised by Pielke et al. (2008) and echoed by the argument that historical transitions to new energy sources were much slower than required in scenarios (Smil, 2010). A multitude of subsequent studies have compared historical transitions to those in scenarios to support (Höök et al., 2012; Kramer & Haigh, 2009; Napp et al., 2017; van der Zwaan et al., 2013), reject (Loftus et al., 2015; Wilson et al., 2013), or provide mixed evidence (Iyer et al., 2015; van Sluisveld et al., 2015) to this argument (Table 2). Similar analysis has been done comparing historical observations to scenarios for the decline of energy (Loftus et al., 2015; Semieniuk et al., 2021; Steckel et al., 2013) and emission intensity (Loftus et al., 2015; Pielke et al., 2008, 2021), as well as the rate of fossil fuel decline (Vinichenko et al., 2021, 2023).

Using historical evidence for feasibility assessment has faced two criticisms. The first is that such evidence may not exactly clarify the causes of historical developments (van Sluisveld et al., 2015, p. 448). For example, though Vinichenko et al. (2021) note that the oil crises, state-ownership of electric utilities, and the scalability of nuclear power can explain the rapid decline of coal and oil use in France, Japan, and Sweden in the 1970–1980s, they do not investigate which of these factors was most important. Yet, inductive reasoning by analogy has the same epistemological validity as mechanistic reasoning (Knachel, 2021). The second criticism is that the future will be inevitably different from the past. For example, future energy transitions can be accelerated by strong climate policies (Fouquet & Pearson, 2012; Kern & Rogge, 2016), the costs of renewables could rapidly decline (Creutzig et al., 2017; Victoria et al., 2021), and developing economies could swiftly "leapfrog" to clean energy learning from experience of frontrunners (Goldemberg, 1998; Ockwell & Mallett, 2012). However, similar forces have already influenced historical outcomes: policies also shaped past transitions (Cherp et al., 2017; Ikenberry, 1986), cost declines propelled past technological growth (Fouquet, 2016), and developing countries introduced advanced technologies (Comin & Mestieri, 2018). At the same time, past policies were constrained by vested interests (Jacobsson & Lauber, 2006), past cost declines cancelled out by geophysical constraints and countervailing resistance (Kramer & Haigh, 2009; Lauber & Jacobsson, 2016; Markard, 2018; Wüstenhagen et al., 2007), and the institutional constraints in developing economies hindered leapfrogging (Cherp et al., 2021; Comin & Mestieri, 2018; van Benthem, 2015). What we really need to understand is whether and why the combined outcome of these factors will be different in the future?

The stalemate in this debate has no obvious solution. On the one hand, the future will definitely be different from the past, which justifies exploring future opportunities and uncertainties in forward-looking scenarios less constrained by past experience. On the other hand, scenarios may fail to anticipate key historical forces that shaped the past and are likely to affect the future. From this standpoint, historical experience can serve as a benchmark for scenario realism. This dichotomy has been captured beyond the climate literature by Daniel Kahneman who coined the terms "inside view" and "outside view" to capture distinct approaches to developing forecasts and plans (Kahneman & Lovallo, 1993). The inside view:

> focus[es] on the [unique] case at hand, by considering the plan and the obstacles to its completion, by constructing scenarios of future progress… [and] …views risk as a challenge to be overcome by the exercise of skill and choice as a commitment to a goal (Kahneman & Lovallo, 1993, p. 25).

It is easy to see the parallels between the global climate scenarios literature and the inside view, including the perception of climate change as a unique policy problem, "constructing scenarios of future progress" as normative "climate mitigation pathways" (Clarke et al., 2014; Riahi et al., 2022) as well as the expectation that policy makers could overcome risks and barriers through their skill, choice, and commitment to climate goals.

The efforts to improve model realism and identification of "multidimensional" barriers entrenches rather than transcends the inside view. This is because contrary to what one would expect, the availability bias may result in assigning higher probabilities to outcomes with more constraints (Fox & Birke, 2002; Redelmeier et al., 1995; Slovic et al., 1977; Tversky & Kahneman, 1983). Thus, providing more complex models and more details on barriers may paradoxically increase over-confidence in the likelihood of a given storyline (Morgan & Keith, 2008) and is more likely to solidify the perception of scenarios as realistic, rather than improve their actual realism. Some studies attempt to overcome this limitation through expert or stakeholder "elicitation" (Steg et al., 2022), but this introduces another problem. Whereas overly knowledgeable experts may exhibit the availability bias, outside stakeholders unfamiliar with the details are even less likely to provide informative opinions (Morgan, 2014).

In contrast, the literature comparing historical analogies to future scenarios has much in common with the outside view, which:

> ignores the details of the case at hand, and … instead focuses on the statistics of a class of cases chosen to be similar in relevant respects to the present one (Kahneman & Lovallo, 1993, p. 25).

Instead of focusing on specific model assumptions or investigating barriers or enablers this literature searches for historical precedents, which are "similar in relevant respects" to the solutions envisioned in scenarios. It then establishes a range of outcomes in these precedents as realistic benchmarks for scenarios (Napp et al., 2017, Vinichenko et al., 2021; Loftus et al., 2015; Cherp et al., 2021).

Kahneman and his colleagues argued that the inside and the outside views correspond to two different modes of human cognition called "narrow" versus "broad framing." They believed that a meaningful collaboration between the inside and the outside view can improve forecasting and decision-making (Kahneman & Lovallo, 1993; Lovallo et al., 2012). In the next section, we propose a methodological tool—a feasibility space—for facilitating such collaboration with respect to climate solutions.

4.2 | Feasibility space

The feasibility space is a tool for assessing the feasibility of a climate option by its characteristics, context, or implementation levels. Like the solution space (see Section 3.2 and Figure 1), the feasibility space is a virtual multidimensional space, where the position of a climate option determines its feasibility. Both the solution and the feasibility space are dynamic and evolve over time as new evidence becomes available. There are, however, three important differences between the feasibility and the solution space.

- First, the solutions space is constructed by modelling an internally consistent ("solvable") set of parameters, while the feasibility space adds boundaries based on additional causal reasoning derived from empirical and other evidence not necessarily used in scenario models. This results in the feasibility space being "narrower" or "more constrained" than the solution space (see Figure 1);
- Second, the solution space typically depicts pathways or scenarios, which are combinations of different climate options deployed together. The feasibility space typically depicts a single climate option or a few options for comparison. There are, however, exceptions, for example, Brutschin et al. (2021) visualize feasibility of entire scenarios.
- Third, the solution space is normally binary, that is, it has an external border but no internal structure, so that it does not differentiate between pathways or solutions that are judged "plausible." In contrast, the feasibility space can be internally structured: it may contain for example "feasibility zones" (Vinichenko et al., 2021) separating more feasible from less feasible solutions.

The original proposal for assessing feasibility of climate mitigation through "feasibility spaces" (Jewell & Cherp, 2020) provided few operational details. Here we elaborate the five steps of constructing a feasibility space (Figure 3) using illustrations from recent literature.

4.2.1 | Step 1. Define the target case: implementation of a climate option

The first step in constructing a feasibility space is to clearly define the climate option and its required implementation, called the "target case." Climate options can be defined at different levels of granularity, and their implementation includes the scale, geographical extent, and timing. This answers the first two questions of feasibility assessment: "Feasibility of what?" and "Feasibility when and where?" (Gilabert & Lawford-Smith, 2012; Jewell & Cherp, 2020). Feasibility assessments often focus on the implementation of climate options prescribed in national targets or normative scenarios. For example, Odenweller et al. (2022) evaluate the feasibility of the EU target for hydrogen production and Semieniuk et al. (2021) evaluate the levels of energy demand envisioned in *IPCC SR* 1.5°C-compatible scenarios (Table 2). An excellent inventory of global and regional climate options associated with different temperature outcomes is the IPCC climate scenarios database (Byers et al., 2022), which contains over 1200 scenarios, depicting the implementation of hundreds of climate options in 2020–2100 in 10 world regions.

4.2.2 | Step 2. Identify relevant reference cases

The second step is identifying reference cases[12] that should be "similar in relevant respects" (Kahneman and Lovallo (1993)) to the target case. While it is impossible to exactly match future and past analogies, reference cases should represent the same broad class of social processes[13] and causal mechanisms as the target case. For example, the

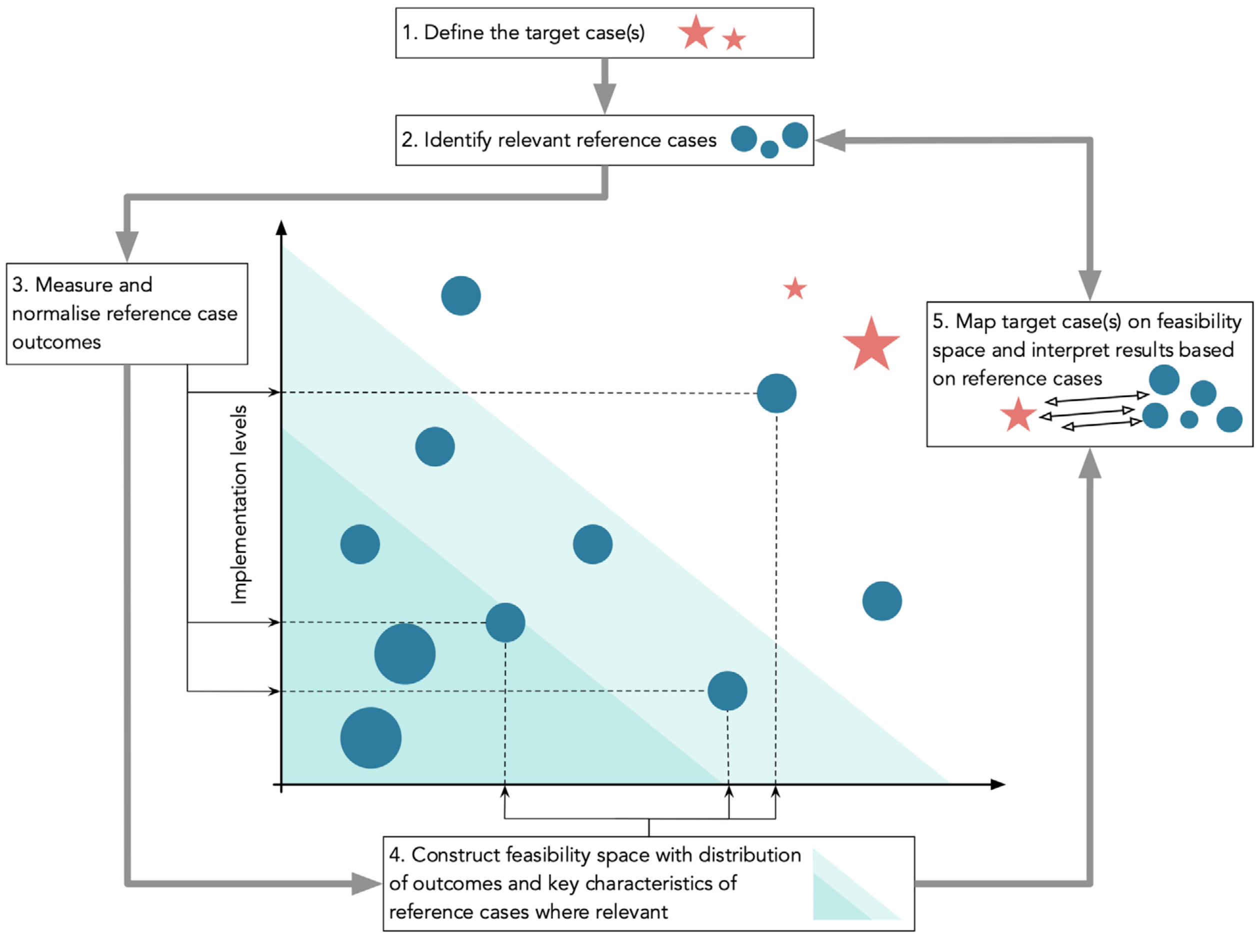


FIGURE 3 Five steps in constructing a feasibility space.

substitution of high- for low-carbon technologies is a technological transition and therefore it is logical to look for reference cases among past technological transitions (Grubler et al., 1999; Kramer & Haigh, 2009; Loftus et al., 2015; Wilson et al., 2013). Likewise, energy demand growth is linked to socio-economic development (Csereklyei et al., 2016) and therefore it is logical to search for reference cases of energy use in past episodes of economic development (Semieniuk et al., 2021). Similarly, behavioral and lifestyle changes such as dietary and transportation choices may use reference cases of historical changes in behavior such as smoking and seatbelt use (Nelson & Allwood, 2021).

Beyond causal or process similarity, there is no fail-safe algorithm for identifying reference cases. It is generally recommended to search for similar outcomes in similar contexts (Kahneman & Lovallo, 1993; Kahneman & Tversky, 1982; Lovallo et al., 2012) as schematically illustrated in Table 3. "Similar outcome", which refers to the similarity between the reference case analogies and the climate option, can be interpreted in narrow or broader terms. For example, many authors use the growth of historical power technologies as reference cases for renewable electricity development (Iyer et al., 2015; Loftus et al., 2015; van Sluisveld et al., 2015; Wilson et al., 2013), Loftus et al. (2015) use diesel engines as a reference case for electric vehicles and oil and gas drilling and pipelines as reference for CCS storage and transportation, and van Ewijk and McDowall (2020) use flue-gas desulfurization as a reference case for CO_2 capture. Odenweller et al. (2022) use much broader historical analogies of diverse technologies such as nuclear weapons and high-speed railways as reference cases for hydrogen production.

Reference cases should also ideally come from similar contexts with respect to system size, wealth, institutional configurations, etc. At the same time, broadening the search to diverse contexts, often makes it possible to find reference cases when a climate option or its analogue was implemented on a smaller scale or in a more favorable environment. Cherp and Vetier (2021) analyze the feasibility of climate options in six target countries by comparing with the same options in reference countries which are either similar or demonstrate best practice. For some global climate options, their national deployment provides useful reference cases. For example, Brook (2012) compares the deployment of

TABLE 2 Selected studies that use historical comparisons to assess the feasibility of climate options in scenarios.

Study	Reference cases	Target case(s)	Metrics and normalization	Other characteristics of reference cases
Kramer & Haigh (2009)	Major energy sources globally	New renewables in Shell decarbonization scenarios globally	Growth in primary energy supply from given source, absolute, Exajoules	-
Wilson et al. (2013)	Energy and related technologies for example, oil refineries and coal power globally and in technologically advanced regions	Low-carbon energy technologies in 450 ppm scenarios globally and in core regions	"Duration of transition" Δt, years	"The normalized extent": installed capacity relative to total primary energy production; differentiation between technological core and periphery
Loftus et al. (2015)	Power technologies, energy and carbon intensity globally	Solar and wind power, energy and carbon intensity in various scenarios globally	Growth in installed capacity, energy demand, and emissions normalized to GDP	-
van Sluisveld et al. (2015)	PV, wind, nuclear, biomass, fossil fuels, supply-side investments globally, emission decline rates global and national	PV, Wind, Nuclear, Biomass, Fossil fuels, CCS, investment, emissions globally and in selected regions in 450 ppm scenarios	Growth of installed capacity, investments both absolute and normalized to GDP, emissions normalized to GDP	-
Iyer et al. (2015)	Over 35 technologies ranging from home air conditioning to railways globally and in USA, France, Russia, Japan, UK, and Denmark	Power generation technologies: renewables, nuclear, biomass and CCS in 450 ppm scenarios globally	Average year-on-year growth rate	"Fast" growth under strong government intervention versus "slow" growth driven by market and technology factors alone
Napp et al. (2017)	Same as in Kramer & Haigh (2009), Wilson et al. (2013), and Iyer et al. (2015)	Low-carbon energy supply and CCS in 2°C scenarios globally	Year-on-year growth rates, capacity additions, duration of transition, energy supply growth from given technologies	-
Jewell et al. (2019)	National pledges to phase-out unabated coal power	Phasing out unabated coal power in major coal consumers	Presence of coal phase-out pledges	Functioning of government, GDP/capita, share of coal per capita, and other aspects of the coal sector
van Ewijk & McDowall (2020)	Flue gas desulphurization (FGD) nationally	Carbon capture in CCS in 1.5°C scenarios globally	Power generation capacity fitted with CCS or FGD normalized to GDP	-
Semieniuk et al. (2021)	Energy demand in different time periods globally	Energy demand in 1.5°C scenarios globally and in low-income countries	Final energy per capita and its growth trajectories	Phase of economic development

TABLE 2 (Continued)

Study	Reference cases	Target case(s)	Metrics and normalization	Other characteristics of reference cases
Cherp et al. (2021)	Wind and solar power growth nationally	Wind and solar power growth in 1.5° and 2°C scenarios globally and regionally	Maximum growth rates on the S-curve normalized to electricity generation	Time of introducing solar and wind power (frontrunners vs. newcomers)
Vinichenko et al. (2021)	Decline of fossil fuels use in power systems nationally, regionally, globally	Decline of coal, gas, and oil use in power systems in 1.5°C scenarios regionally	Decadal decline in generation normalized to total electricity supply	Electricity system size, electricity demand growth
Pielke et al. (2022)	Trend for CO_2 emission (from fossil fuel and industry—FFI) growth historically and under IEA stated policy projections	CO_2 emissions from scenarios of IPCC AR5 and AR6	Global growth trajectories of FFI CO_2 emissions with ±0.1% and 0.3%/year divergence tolerances	-
Odenweller et al. (2022)	Diverse technologies for example nuclear weapons, smartphones and solar power	Hydrogen production by electrolysis in the EU plans for 2035	"Emergence rate" approximating year-on-year growth in the beginning of logistic growth curve	"Emergency" or "conventional" technology deployment

TABLE 3 Selected features of outcome and context for identifying reference cases.

Similarity of outcome	*Technologies*: function (e.g., provision of electricity or mobility), granularity (Wilson et al., 2020), complexity (Malhotra & Schmidt, 2020), structure of global innovation systems (Binz & Truffer, 2017), stage of technology lifecycle (Markard, 2020) *Policies*: regulatory, market, or voluntary instruments (Cocklin et al., 2009; Sterner and Robinson, 2018). *Behavior and other social practices*: travel, diet, and other consumption practices (Nelson & Allwood, 2021; Wynes & Nicholas, 2017).
Similarity of context	Scale of implementation and system size (e.g., global, macro-regional, national, city; large or small cities or countries). Wealth and economic resources (e.g., GDP per capita). Other relevant features (e.g., energy import dependence, level of democracy, solar potential).

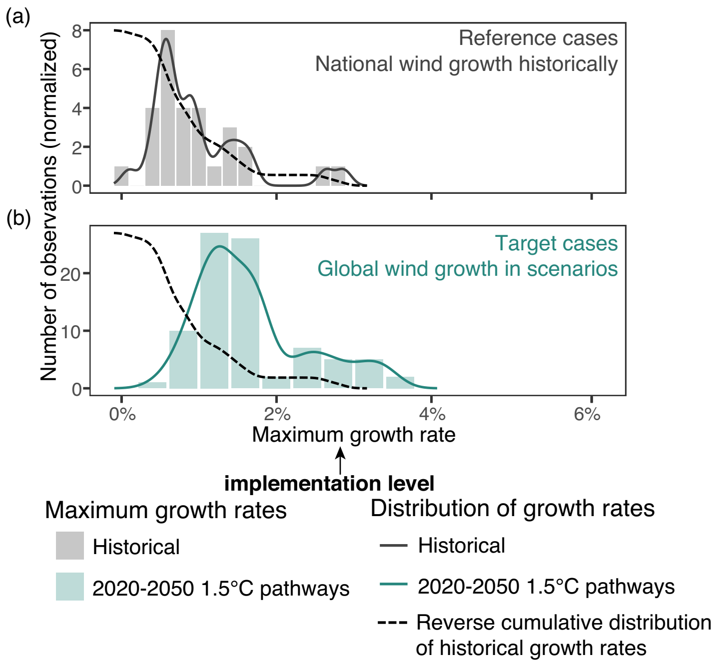


FIGURE 4 A feasibility space for wind power growth in 1.5°C scenarios (from Cherp et al., 2021) using national maximum growth rates as reference cases (panel a) and maximum growth of wind power between 2020 and 2050 in scenarios as a target case (panel b). Maximum growth rates are measured as annual additions of generation expressed as shares of total generation.

nuclear power in France to global scenarios. Iyer et al. (2015) use reference cases from the US and other selected countries for global technology deployment. Cherp et al. (2021) analyze reference cases of wind and solar power growth in 60 individual countries accounting for about 95% of global electricity supply to assess its feasibility globally (Figure 4) and Vinichenko et al. (2021) analyze national reference cases for fossil fuel decline in global macro-regions (Figure 5). Looking even further back in the history of the same country can also provide a reference case. For example, Hyun et al. (2023) analyze the historical deployment of nuclear power in Korea as a reference case for possible scenarios of its future deployment.

The selection of reference cases should strike a balance between their similarity to the target case and their number. Close similarity seemingly increases the validity of comparison but limits the number of reference cases which hinders a meaningful statistical analysis and limits the ability to account for unobservable factors. On the other hand, relaxing similarity criteria makes it more difficult to defend their relevance. For example, there is no global-scale reference case for the fossil fuel decline envisioned in climate scenarios[14] and therefore Vinichenko et al. (2021) relax the similarity criteria to include national and regional electricity systems (Figure 5). On the other hand, among the hundreds of such decline cases, the majority happen in relatively small countries, which are too dissimilar from the target case of global decline and are therefore excluded from constructing the feasibility space. Even among the remaining cases, the authors exclude fossil fuel decline resulting from wars or socio-economic collapse because these developments are too dissimilar to what is depicted in climate mitigation scenarios (Figure 6).

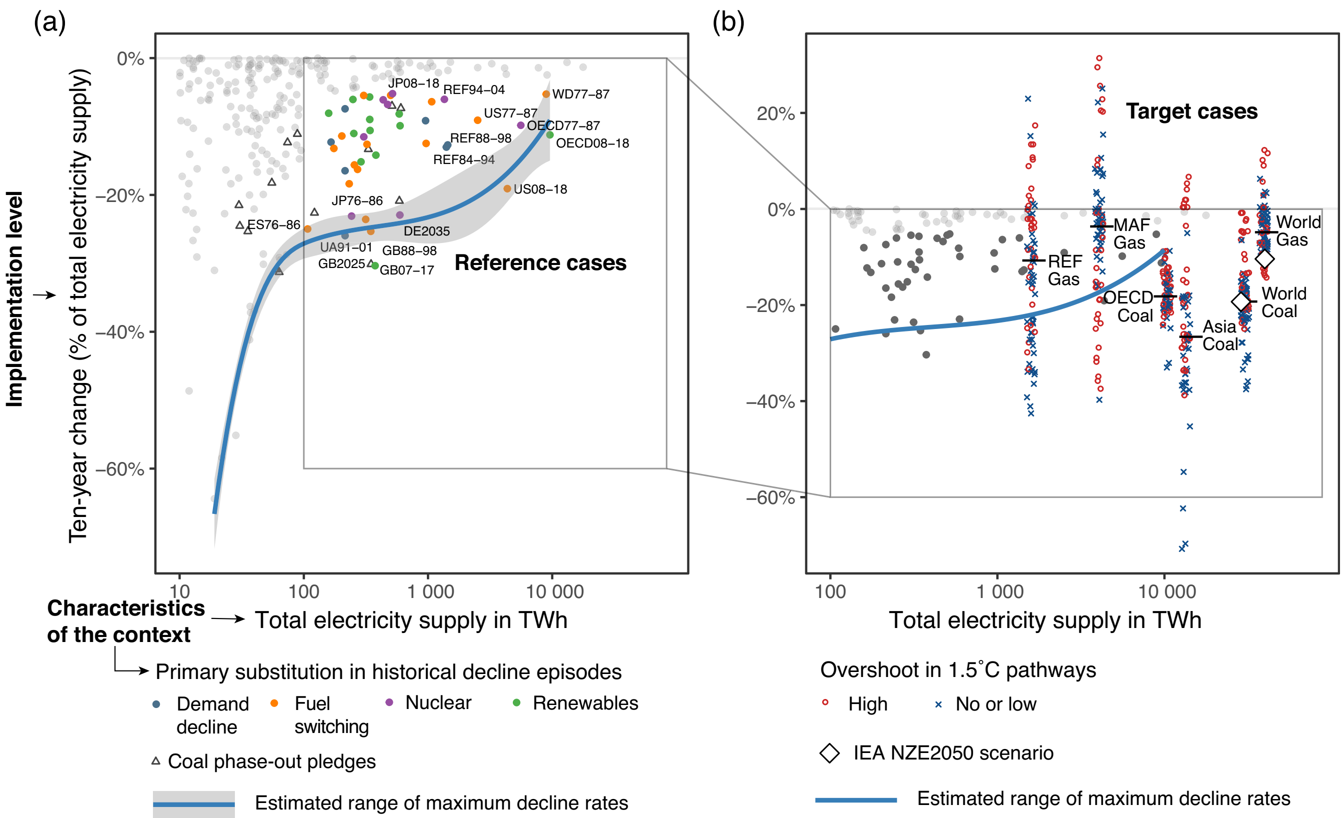


FIGURE 5 A feasibility space for fossil fuel decline in electricity (from Vinichenko et al., 2021). Reference cases are all cases of decline in systems over 100 TWh of electricity supply with decline over 5% of the electricity system. Target cases are coal and gas decline in all world regions (the largest declines shown) in 1.5°C scenarios. The feasibility space displays the outcome (the decline rate) and the relevant characteristic (electricity system size) of the reference and target cases.

In addition to similar outcomes in different contexts, reference cases can also include trends, official plans, or projections from the same system (e.g., Grubb et al., 2020; Pielke et al., 2022; Sognnaes et al., 2021). For example, Figure 7 uses coal phase-out commitments to construct a feasibility space (Vinichenko et al., 2023). The advantage of this approach is that trends, plans and projections often aggregate key causalities affecting the climate option in the near future. Risks include potential misinterpretation of trends (see discussion concerning Grubb's et al.'s interpretation of trends in renewables in Cherp et al. (2021)) and the potential circularity of the argument when reference and target cases overlap (for example, plans are based on scenarios or scenarios on plans). Though many reference cases are usually required to construct a feasibility space, even one or a few carefully identified and normalized reference cases can meaningfully inform feasibility assessment (Box 2).

4.2.3 | Step 3. Measure reference case outcomes to compare scale and speed of change

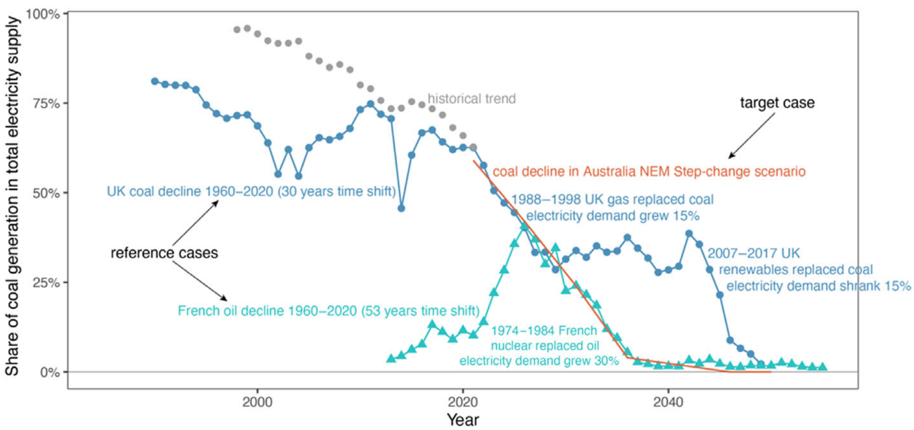
The outcomes of reference cases should be comparable to each other and to the target case. For climate solutions such as carbon prices (Jenkins, 2014) or coal phase-out pledges (Jewell et al., 2019; Vinichenko et al., 2023) this comparison is straightforward, but in most cases, it requires normalization and appropriate metrics of the speed of change. Normalization is necessary to account for different system sizes within reference cases as well as between reference and target cases. When comparing energy technologies, it is common to normalize their output or capacity to total primary energy (Kramer & Haigh, 2009), electricity supply (Cherp et al., 2021; Vinichenko et al., 2021), or GDP (Loftus et al., 2015; van Ewijk & McDowall, 2020; van Sluisveld et al., 2015). Normalization is more difficult for more diverse reference cases such as different technologies ranging from jet aircrafts to oil refineries (Wilson et al., 2013), home air conditioners to railways (Iyer et al., 2015), and nuclear weapons to smartphones (Odenweller et al., 2022).

BOX 2 Using reference cases to assess the feasibility of coal phase-out and wind growth the Step Change Scenario in Australia

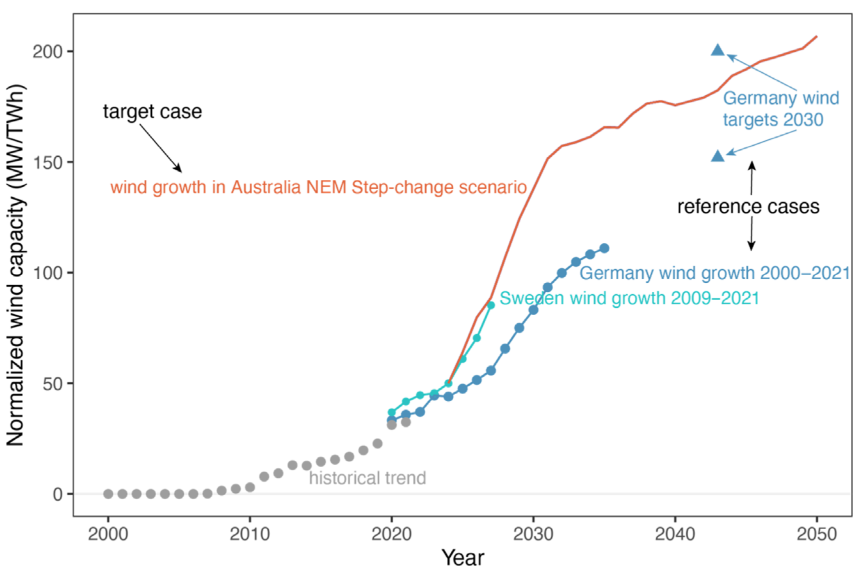
The Integrated System Plan for Australian National Electricity Market (NEM) considers an ambitious Step Change Scenario (SCS) where coal power is replaced by solar and wind (Australian Energy Market Operator (AEMO), 2022). Here we illustrate use of reference cases to assess the feasibility of this scenario (Jewell & Cherp, 2022). The SCS (target case, red lines) is shown together with the historical trend of coal (a) and wind (b) in NEM in 1998–2021 (black dots). The reference cases include (a) coal power in the UK and oil power in France (1960–2020) and (b) wind power in Germany (2000–2021 and 2030 targets) and Sweden (2009–2021). The timeseries in all reference cases are shifted to reflect different timing of transitions in reference countries and Australia.

The SCS's early phase (2021–2029) is similar to UK's coal decline in 1988–1998 and the later phase (2029–2040) is similar to the UK's coal decline in 2007–2017 and France's oil decline in 1974–1984. However, the UK decline was intercepted by a stagnation period and its later part was during shrinking electricity demand and the French decline was driven primarily by nuclear, while neither drop in demand nor nuclear is envisioned in Australia. For wind power, the SCS envisions a significant acceleration of the current trends while staying on the trajectory comparable to Sweden and to Germany's planned developments, but significantly faster than historical developments in Germany.

(a)



(b)



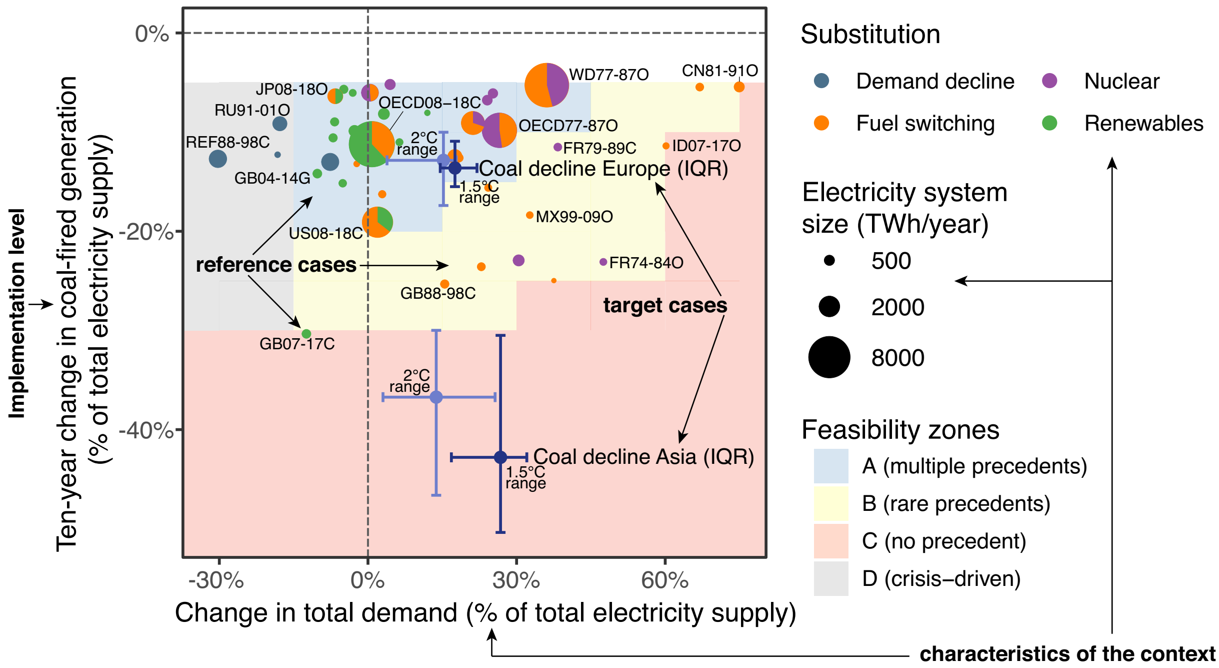


FIGURE 6 Feasibility space for fossil fuel decline based on three context characteristics (from Vinichenko et al., 2021). Reference cases are historical cases of fossil fuel decline in electricity and target cases are coal decline in Europe and Asia in the IPCC scenarios (Byers et al., 2022). The feasibility space displays the implementation level (the decline rate) and the relevant characteristics (electricity demand growth, size of the system and the substituting energy source) of the reference and target cases.

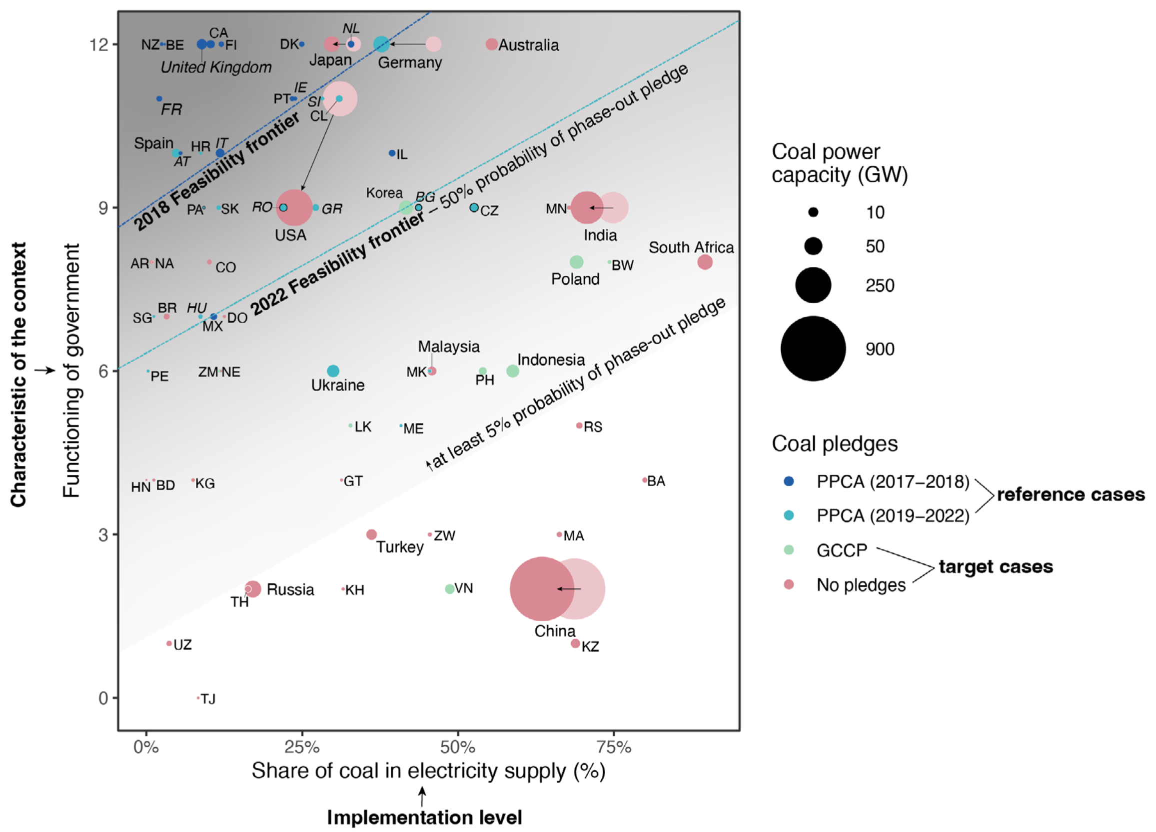


FIGURE 7 Feasibility space for coal phase-out pledges (Vinichenko et al., 2023). Reference cases are countries which have joined the Powering Past Coal Alliance or have similar coal phase-out plans. Target cases are all other countries with coal power. The feasibility frontier depicts at least a 50% probability of pledging to phase-out coal. The feasibility space displays the outcome (the presence and timing of the coal phase-out pledge shown by color) and the relevant characteristic (share of coal and functioning of government) of the reference and target cases.

The other problem that needs to be addressed in comparing the outcomes of reference and target cases is non-linearity of upscaling most climate options. Scholars often assume medium-term (often decadal) linear trends for technology growth (Loftus et al., 2015; van Ewijk & McDowall, 2020; van Sluisveld et al., 2015) and decline (Vinichenko et al., 2021). Measuring nonlinear growth, typical for emerging technologies, is more challenging and different approaches may yield different results (Cherp et al., 2021; Grubb et al., 2020; Odenweller et al., 2022; Wilson et al., 2013) for different metrics.

4.2.4 | Step 4. Construct feasibility space with key characteristics of reference cases

Feasibility spaces (Figure 4–6) depict the distribution of implementation levels and where necessary relevant contextual characteristics of the reference cases (Figure 4-7). For example, Figure 4 displays the distribution of maximum rates of wind power growth in countries where this growth has stabilized (Cherp et al., 2021).[16] Considering certain characteristics of reference cases can help to assess the similarity between the reference and the target cases. Such characteristics should be causally linked to outcomes. For example, Figure 7 shows how the presence of national coal phase-out pledges for various shares of coal in power generation depend the functioning of government index. In addition to these methodological considerations, it is important to use comparable data (based on the same definitions and timeseries) for the reference and target cases as Semieniuk (2022) illustrates for GDP growth rates.

Other examples of context characteristics include the system size (Figure 5) and the rate of electricity demand growth (Figure 6) which affect the rates of fossil fuel decline (Vinichenko et al., 2021); the level and pace of economic development which strongly correlate with energy consumption (Semieniuk et al., 2021); and the social functions of technologies ("emergency" versus "conventional") which influence the year-on-year rates of their initial growth (Odenweller et al., 2022).

Where these characteristics can be quantitatively displayed, they allow constructing visual feasibility spaces. Feasibility spaces can be divided into zones according to the number of reference cases with certain outcomes and characteristics. The simplest way to construct feasibility zones is to separate the area of the feasibility space that contains no or few reference cases through drawing a feasibility frontier (Figures 5 and 7) Alternatively, feasibility zones can reflect the distribution of references cases through augmented density mapping proposed by Vinichenko et al. (2021) (Figure 6).

4.2.5 | Step 5. Map target case(s) on feasibility space and account for additional evidence

Mapping the target cases onto feasibility spaces makes it possible to directly compare implementaion levels in target and reference cases. For example, Figure 4 shows the distribution of global wind power growth rates in scenarios in comparison with those observed in individual countries. Some feasibility spaces also map characteristics of the contexts of target and reference cases, which can help analysing the similarity between the two (e.g. Figures 5 and 6).

To conclude the feasibility assessment, it is often necessary to adjust the information depicted on feasibility spaces considering additional unique characteristics of the target case (Kahneman & Lovallo, 1993). This requires bringing back "the inside view" with its attention to specific causal mechanisms affecting the target case. It is especially important, when such causal explanation is needed to assess the feasibility of bridging significant divergence between the target and reference cases. For example, Semieniuk et al. (2021) call for an explanation of the unprecedented low energy demand envisioned by some climate scenarios for developing countries:

> "Development economics tells a cautionary tale about assuming efficient growth without explaining how it is achieved. … Since IAMs cannot test their results against data that are not yet generated, they must convince with strong explanatory power that their pathways are plausible … details of near-term 'development without energy' need to be better understood for making plausible assumptions" (pp. 4 and 5).

In another example, the reference cases for our analysis of renewables growth (Cherp et al., 2021) mostly come from developed countries that pioneered solar and wind energy. However, in climate scenarios most of the growth occurs in developing and emerging economies, which were late in introducing renewables but could possibly expand them faster by benefitting from frontrunners' technological learning (Grubler et al., 2016; Pye et al., 2022). Thus, the feasibility space in Figure 4 was supplemented with an analysis of whether follower countries reach higher maximum growth rates in spite of their less favorable conditions (Griliches, 1957). While strengthening the evidence from the reference cases, it is of course not the final word in the argument, since future studies may demonstrate other realistic causal mechanisms that would accelerate future growth of renewables.

5 | CONCLUSION

The increasing attention to the feasibility of climate options requires a rigorous definition and application of the concept. We define feasible as do-able under realistic assumptions (Box 1). We argue that a sound analysis of feasibility should use causal reasoning, strive for comparability, and reflexively consider the agency of its audience and other actors. We show that global climate scenarios based on IAMs face difficulties in representing all relevant causalities and assessing the realism of their increasingly complex assumptions. Furthermore, the co-dependence of the scenario community and climate policy makers may hinder reflexive consideration of agency. The main strategies of dealing with these challenges: increasing model realism, identifying broad categories (dimensions) of generic feasibility barriers, and eliciting expert or stakeholder opinions have so far had limited success.

Another strategy has been assessing the feasibility of climate solutions through historical analogies. This strategy matches the concept of the "outside view" in decision-making and planning psychology. In contrast, assessing feasbility using climate scenarios and the multidimensional feasibility framework have parallels with the "inside view" that considers climate change as a unique policy problem. The tensions between the inside and the outside view are not unique to climate debates. "[P]eople are strongly biased in favor of the inside view … as a serious attempt to come to grips with the complexities of the unique case at hand" and "the outside view is [often] rejected for relying on crude analogy from superficially similar instances" (Kahneman & Lovallo, 1993, pp. 26 and 30). Yet, it is wrong to neglect the outside view in the feasibility debate, because "when both methods are applied with equal intelligence and skill, the outside view is much more likely to give a realistic estimate" (Kahneman & Lovallo, 1993, p. 25). In this article, we show how three tensions between the inside and outside views can be channeled into a productive dialogue using feasibility spaces.

The first tension relates to the depiction of *causality*. The strength of the inside view is that IAMs can represent and quantify many causalities which affect climate options under given assumptions. The corresponding weakness is that it is impossible to account for *all* relevant causalities (including unobservables) and difficult to assess the realism of assumptions, especially in the case of exploratory scenarios. The outside view can capture the aggregate outcomes of all combined causalities in reference cases thus facilitating inductive reasoning by analogy. The corresponding weakness is that it cannot provide a detailed representation of causalities and project this to the future. The feasibility space moves toward resolving this tension by identifying and comparing those characteristics of target and reference cases that reflect key causalities.

The second tension relates to *comparative assessment of feasibility*. IAMs quantify the levels of implementation of climate solutions in either most probable or in normative/exploratory scenarios. However, the scenario community typically resists the long-standing calls (Morgan & Keith, 2008; Nordhaus & Yohe, 1983; Schneider, 2001; Sognnaes, 2022) to estimate the likelihood of scenarios. The main basis for this rejection is that "[t]here are no independent observations and no repeat experiments" in social science that are relevant to climate scenarios (Grübler & Nakicenovic, 2001, p. 15). The outside view can provide such observations and "natural experiments" (Dunning, 2012; A. S. Lee, 1989) in the form of reference cases. The feasibility space structures this "experiment-like" evidence, where it can be directly compared with climate options in scenarios.

The third tension refers to the reflexive representation of *agency*. The inside view tends to over-extend agency in normative scenarios by assuming a higher degree of control of scenario users over the outcomes. This may motivate scenario users for climate action, but it may also be misleading about realistic priorities and capacities and suffers from the "performativity" problem when resources and attention are attracted to what is depicted in scenarios, not necessarily to what is realistic. To correct for this potential bias, the outside view documents the outcomes of reference cases which were brought about by real-life actors in real-life situations, but this historical evidence may be perceived as restricting the freedom of future choices. The feasibility space addresses this tension by depicting a freedom of choice within feasibility zones and signaling the zone of "unprecedented effort," which users are nevertheless free to pursue. It also points to "role models" among reference cases, such as the UK's experience of rapid coal power phase-out and Sweden's experience of rapid wind power expansion (Box 2).

In summary, the feasibility space has the potential for channeling the tensions around feasibility into a productive dialogue between the inside and the outside view that would strengthen both approaches. The inside view of the IAM community can be strengthened by articulating and stress-testing their causal assumptions through evidence from reference cases and feasibility spaces. The "outside view" needs to continuously improve the causal understanding of the outcomes in reference cases to make them more relatable to future scenarios. In this way, both traditions can combine their strengths in identifying realistic solutions for reducing the risks of climate change. A particularly welcome development would be to extend the application of feasibility spaces to a broader range of technological solutions, policies, and social practices. There are also promising advances in using the feasibility space to develop new scenarios based on assumptions grounded in empirical examination of reference cases (Bi et al., 2023; Muttitt et al., 2023; Vinichenko et al., 2023). In the future we hope that the science and art of constructing feasibility spaces will be critically examined and continuously improved by diverse scientific communities dealing with both climate mitigation and adaptation.

AUTHOR CONTRIBUTIONS

Jessica Jewell: Conceptualization (equal); funding acquisition (equal); methodology (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). **Aleh Cherp:** Conceptualization (equal); funding acquisition (equal); methodology (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal).

ACKNOWLEDGMENTS

The authors thank participants of the Scenarios Forum 2022, ECPR conference 2022, members of the POLET research group (polet.network), Håvard Haarstad, Kacper Szulecki, and Martin Persson for feedback and discussions on ideas developed in this article. We also acknowledge M. Vetier and V. Vinichenko for helping to produce Figures on the manuscript.

FUNDING INFORMATION

The research that led to this publication received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 821471 (project Exploring National and Global Actions to Reduce Greenhouse Gas Emissions [ENGAGE]) and from MISTRA Electrification research programme funded by the Swedish foundation for strategic environmental research (MISTRA). Jessica Jewell received funding from the European Union's Horizon 2020 ERC Starting Grant programme under grant agreement no. 950408 for Mechanisms and Actors of Feasible Energy Transitions (MANIFEST).

CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Jessica Jewell https://orcid.org/0000-0003-2846-9081
Aleh Cherp https://orcid.org/0000-0002-9299-9792

RELATED WIREs ARTICLES

A critical review of global decarbonization scenarios: what do they tell us about feasibility?
A history of the 1.5°C target
On the political feasibility of climate change mitigation pathways: Is it too late to keep warming below 1.5°C?

ENDNOTES

[1] This includes counts of both "feasibility" and "feasible."

[2] Note that this diverges from a recent suggestion to equate "feasible" futures with "possible" futures and define "plausible" futures as those which empirical evidence about recent trends in key drivers and enabling conditions point to (Engels et al., 2023; Engels & Marotzke, 2023; Stammer et al., 2021). In futures studies, futures which result from

recent empirical trends are normally defined as "probable" (Dorsser et al., 2018; Hancock & Bezold, 1994; Henchey, 1978; Voros, 2003)—See Box 1.

[3] We use "climate option" instead of "mitigation and adaptation option."

[4] Note that Hancock and Bezold (1990) use the term "plausible" rather than "feasible," however, their definition of plausibility is implies that all future options are realistic choices since they say plausible scenarios give users the option: "to compare a range of quite plausible future options and to choose among them."

[5] Our method follows the critical realism tradition, while interpretivist or other traditions may have different approaches to investigating what is "doable" and "realistic."

[6] Early literature was not explicit about the use of causal reasoning or pathways though this logic was often implicitly used in analysis as we illustrate with the discussion of Goldemberg et al. (1985a, 1985b, 1987).

[7] Constraints here are defined as "features of the environment that (a) affect the outcome [causal mechanisms in our language] and (b) are outside of the control of policy makers" (Majone, 1975).

[8] The term "solutions space" originally comes from optimization modelling designating a set of near-optimal solutions (DeCarolis, 2011; Ng et al., 2007; Xu & Rahmat-Samii, 2007), but in the climate community it has acquired the meaning of all scenarios and options compatible with given set of assumptions (Edenhofer & Kowarsch, 2015; Haasnoot et al., 2020). Sometimes the solutions space is called "the possibility space" (Beek et al., 2022; Guivarch et al., 2022; Keppo et al., 2021). Here we avoid using this term because it has a different meaning in formal analysis of fuzzy sets (Yang & Liu, 1998; Yian-Kui & Baoding, 2002).

[9] Morgan and Keith (2008) and Sognnaes (2022) pointed out that this implies estimating the probability of "feasible" futures as non-zero which invalidates the argument that the "what-if" logic cannot use probability judgements (Grübler & Nakicenovic, 2001). Note that in contrast to the focus of this paper, the IAM community mostly focuses on the feasibility of entire pathways (Brutschin et al., 2021; Riahi et al., 2015; Warszawski et al., 2021) rather than on the feasibility of climate options. Under such an approach, scenarios are viewed as "systems" where certain assumptions about one solution can make the required level of implementation of another component less feasible. IAMs are excellent tools to highlight such interconnections, but this requires external inputs on the feasibility of individual options (Brutschin et al., 2021; Warszawski et al., 2021).

[10] The audience for global climate scenarios is generally broad, fluid, and diverse which is why it is sometimes not explicitly defined even when stressing the need for interaction with "users" (Guivarch et al., 2022). For example, the audience for scenarios included in the IPCC reports includes governments of all countries but also businesses, cities, civil society, and academia and the targeted users from a recent project on co-designing scenarios of the Sustainable Development Pathways are "actors from governmental and non-governmental sectors alike" (SHAPE-project, 2020).

[11] For example, Brutschin et al. (2021) assign the speed of wind and solar power deployment to "technological" dimension, while it is clearly affected by economic, geophysical, sociocultural, and institutional factors (Cherp et al., 2021; Lund, 2015; Wüstenhagen et al., 2007).

[12] Although they did not use the term, Goldemberg et al. (1985b) already demonstrated a reference case approach when they identified Brazil as an example of a developing country able to introduce advanced energy technology. "Reference points" are also mentioned by Iyer et al. (2015).

[13] The broad classes of social processes are captured by the "mid-range" scientific theories (Merton, 1968).

[14] One reason why past energy transitions are aptly called "energy additions" (Fouquet & Pearson, 2012; Newell & Raimi, 2018).

[18] See similar illustrations in Loftus et al. (2015) in Figures 3 and 6.

[19] See similar illustrations in Loftus et al. (2015).

REFERENCES

Anderer, J., McDonald, A., & Nakicenovic, N. (1981). In W. Hafele (Ed.), *Energy in a finite world: Paths to sustainable future* (Vol. 1, 1st ed.). Ballinger Publishing.

Anderson, K., & Jewell, J. (2019). Climate-policy models debated. *Nature*, *573*, 448–449.

Anderson, K., & Peters, G. (2016). The trouble with negative emissions. *Science*, *354*(6309), 182–183. https://doi.org/10.1126/science.aah4567

Australian Energy Market Operator (AEMO). (2022). *2022 Integrated System Plan ISP*. https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

Bager, S. L., Persson, U. M., & Reis, T. N. P. (2021). Eighty-six EU policy options for reducing imported deforestation. *One Earth*, *4*(2), 289–306. https://doi.org/10.1016/j.oneear.2021.01.011

Baldwin, E., Carley, S., Brass, J. N., & MacLean, L. M. (2016). Global renewable electricity policy: A comparative policy analysis of countries by income status. *Journal of Comparative Policy Analysis: Research and Practice*, *19*(3), 1–22. https://doi.org/10.1080/13876988.2016.1166866

Beck, S., & Mahony, M. (2018). The IPCC and the new map of science and politics. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(6), 253–262. https://doi.org/10.1002/wcc.547

Beck, S., & Oomen, J. (2021). Imagining the corridor of climate mitigation—What is at stake in IPCC's politics of anticipation? *Environmental Science & Policy*, *123*, 169–178. https://doi.org/10.1016/j.envsci.2021.05.011

Bhaskar, R. (2014). *The possibility of naturalism: A philosophical critique of the contemporary human sciences*. Taylor and Francis.

Bi, S. L., Bauer, N., & Jewell, J. (2023). Coal-exit alliance must confront freeriding sectors to propel Paris-aligned momentum. *Nature Climate Change*, *13*(2), 130–139. https://doi.org/10.1038/s41558-022-01570-8

Binz, C., & Truffer, B. (2017). Global innovation systems—A conceptual framework for innovation dynamics in transnational contexts. *Research Policy*, *46*(7), 1284–1298. https://doi.org/10.1016/j.respol.2017.05.012

Brockway, P. E., Sorrell, S., Semieniuk, G., Heun, M. K., & Court, V. (2021). Energy efficiency and economy-wide rebound effects: A review of the evidence and its implications. *Renewable and Sustainable Energy Reviews*, *141*, 110781. https://doi.org/10.1016/j.rser.2021.110781

Brook, B. W. (2012). Could nuclear fission energy, etc., solve the greenhouse problem? The affirmative case. *Energy Policy*, *42*, 4–8. https://doi.org/10.1016/j.enpol.2011.11.041

Brutschin, E., Pianta, S., Tavoni, M., Riahi, K., Bosetti, V., Marangoni, G., & Van Ruijven, B. J. (2021). A multidimensional feasibility evaluation of low-carbon scenarios. *Environmental Research Letters*, *16*(6), 064069. https://doi.org/10.1088/1748-9326/abf0ce

Byers, E., Krey, V., Kriegler, E., Riahi, K., Schaeffer, R., Kikstra, J., Lamboll, R., Nicholls, Z., Sandstad, M., Smith, C., Wijst, K., van der Lecocq, F., Portugal-Pereira, J., Saheb, Y., Stromann, A., Winkler, H., Auer, C., Brutschin, E., Lepault, C., … Skeie, R. (2022). *AR6 Scenarios Database*. https://doi.org/10.5281/zenodo.5886912

Carton, W., Asiyanbi, A., Beck, S., Buck, H. J., & Lund, J. F. (2020). Negative emissions and the long history of carbon removal. *Wiley Interdisciplinary Reviews: Climate Change*, *11*(6), 1–25. https://doi.org/10.1002/wcc.671

Cherp, A., & Vetier, M. (2021). *Feasibility of national strategies. Deliverable 4.3 for ENGAGE project*. Central European University http://www.engage-climate.org

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. K. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions—A meta-theoretical framework. *Energy Research & Social Science*, *37*(175), 190. https://doi.org/10.1016/j.erss.2017.09.015

Cherp, A., Vinichenko, V., Jewell, J., Suzuki, M., & Antal, M. (2017). Comparing electricity transitions: A historical analysis of nuclear, wind and solar power in Germany and Japan. *Energy Policy*, *101*, 612–628. https://doi.org/10.1016/j.enpol.2016.10.044

Cherp, A., Vinichenko, V., Tosun, J., Gordon, J. A., & Jewell, J. (2021). National growth dynamics of wind and solar power compared to the growth required for global climate targets. *Nature Energy*, *6*(7), 742–754. https://doi.org/10.1038/s41560-021-00863-0

Clarke, L. E., Jiang, K., Akimoto, K., Babiker, M., Blanford, G., Fisher-Vanden, K., Hourcade, J.-C., Krey, V., Kriegler, E., Löschel, A., McCollum, D., Paltsev, S., Rose, S., Shukla, P. R., Tavoni, M., van der Zwaan, B. C. C., & van Vuuren, D. P. (2014). Assessing transformation pathways. In IPCC (Ed.). In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 413–510). Cambridge University Press http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Assessing+Transformation+Pathways#4

Cocklin, C. (2009). Environmental policy. In *If we were going to do it, turn it into a debate: Is hydrogen hype or hope?* (pp. 540–545). Elsevier. https://doi.org/10.1016/b978-008044910-4.00569-1

Cointe, B., & Guillemot, H. (2023). A history of the 1.5°C target. *Wiley Interdisciplinary Reviews: Climate Change*, *e824*, 1–11. https://doi.org/10.1002/wcc.824

Comin, D., & Mestieri, M. (2018). If technology has arrived everywhere, why has income diverged? *American Economic Journal: Macroeconomics*, *10*(3), 137–178. https://doi.org/10.1257/mac.20150175

Cousse, J. (2021). Still in love with solar energy? Installation size, affect, and the social acceptance of renewable energy technologies. *Renewable and Sustainable Energy Reviews*, *145*, 111107. https://doi.org/10.1016/j.rser.2021.111107

Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. C. (2017). The underestimated potential of solar energy to mitigate climate change. *Nature Energy*, *2*(9), 17140. https://doi.org/10.1038/nenergy.2017.140

Csereklyei, Z., Rubio-Varas, M. D., & Stern, D. I. (2016). Energy and economic growth: The stylized facts. *The Energy Journal*, *37*(2), 1–34. https://doi.org/10.5547/01956574.37.2.zcse

de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., Dong, W., Ford, J., Fuss, S., Hourcade, J.-C., Ley, D., Mechler, R., Newman, P., Revokatova, A., Schultz, S., Steg, L., & Sugiyama, T. (2018). Chapter 4—Strengthening and implementing the global response. In: Global warming of 1.5°C. *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change*, pp. 313–443. https://www.ipcc.ch/site/assets/uploads/sites/2/2018/11/SR15_Chapter4_Low_Res.pdf

De Jouvenel, B. (1967). *The art of conjecture* (N. Lary, Trans.). Basic Books.

DeCarolis, J. F. (2011). Using modeling to generate alternatives (MGA) to expand our thinking on energy futures. *Energy Economics*, *33*(2), 145–152. https://doi.org/10.1016/j.eneco.2010.05.002

Du, H., Triyanti, A., Hegger, D. L. T., Gilissen, H. K., Driessen, P. P. J., & van Rijswick, H. (2022). Enriching the concept of solution space for climate adaptation by unfolding legal and governance dimensions. *Environmental Science & Policy*, *127*, 253–262. https://doi.org/10.1016/j.envsci.2021.10.021

Dunning, T. (2012). *Natural experiments in the social sciences: A design-based approach*. Cambridge University Press.

Edenhofer, O., & Kowarsch, M. (2015). Cartography of pathways: A new model for environmental policy assessments. *Environmental Science & Policy*, *51*, 56–64. https://doi.org/10.1016/j.envsci.2015.03.017

Edmonds, J., Reilly, J., Trabalka, J., & Reichle, D. (1984). An analysis of possible future atmospheric retention of fossil fuel CO_2. United States Department of Energy.

Ellenbeck, S., & Lilliestam, J. (2019). How modelers construct energy costs: Discursive elements in energy system and integrated assessment models. *Energy Research & Social Science*, *47*, 69–77. https://doi.org/10.1016/j.erss.2018.08.021

Engels, A., & Marotzke, J. (2023). Assessing the plausibility of climate futures. *Environmental Research Letters*, *18*(1), 011006. https://doi.org/10.1088/1748-9326/acaf90

Engels, A., Martozke, J., Gresse, E. G., López-Rivera, A., Pagnone, A., & Wilkens, J. (Eds.). (2023). *Hamburg Climate Futures Outlook 2023: The plausibility of a 1.5°C limit to global warming: Social drivers and physical processes*. Cluster of Excellence, Climate, Climatic Change, and Society.

Fouquet, R. (2016). Historical energy transitions: Speed, prices and system transformation. *Energy Research & Social Science*, *22*, 7–12. https://doi.org/10.1016/j.erss.2016.08.014

Fouquet, R., & Pearson, P. J. G. (2012). Past and prospective energy transitions: Insights from history. *Energy Policy*, *50*, 1–7. https://doi.org/10.1016/j.enpol.2012.08.014

Fox, C. R., & Birke, R. (2002). Forecasting trial outcomes: Lawyers assign higher probability to possibilities that are described in greater detail. *Law and Human Behavior*, *26*(2), 159–173. https://doi.org/10.1023/a:1014687809032

Frisch, J.-R. (1983). *Energy 2000–2020: World prospects and regional stresses* (pp. 33–97). Springer. https://doi.org/10.1007/978-94-009-5624-7_3

Fuss, S., Canadell, J. G., Peters, G. P., Tavoni, M., Andrew, R. M., Ciais, P., Jackson, R. B., Jones, C. D., Kraxner, F., Nakicenovic, N., Quéré, C. L., Raupach, M. R., Sharifi, A., Smith, P., & Yamagata, Y. (2014). Betting on negative emissions. *Nature Climate Change*, *4*(10), 850–853. https://doi.org/10.1038/nclimate2392

Gambhir, A., Drouet, L., McCollum, D., Napp, T., Bernie, D., Hawkes, A., Fricko, O., Havlik, P., Riahi, K., Bosetti, V., & Lowe, J. (2017). Assessing the feasibility of global long-term mitigation scenarios. *Energies*, *10*(1), 89. https://doi.org/10.3390/en10010089

Geden, O. (2015). Policy: Climate advisers must maintain integrity. *Nature*, *521*(7550), 27–28. https://doi.org/10.1038/521027a

Geels, F. W. (2014). Regime resistance against low-carbon transitions: Introducing politics and power into the multi-level perspective. *Theory, Culture & Society*, *31*(5), 21–40. https://doi.org/10.1177/0263276414531627

Geels, F. W., Berkhout, F., & Vuuren, D. P. v. (2016). Bridging analytical approaches for low-carbon transitions. *Nature Climate Change*, *6*(6), 1 8–1 583. https://doi.org/10.1038/nclimate2980

Geels, F. W., McMeekin, A., & Pfluger, B. (2020). Socio-technical scenarios as a methodological tool to explore social and political feasibility in low-carbon transitions: Bridging computer models and the multi-level perspective in UK electricity generation (2010–2050). *Technological Forecasting and Social Change*, *151*, 119258. https://doi.org/10.1016/j.techfore.2018.04.001

Gilabert, P., & Lawford-Smith, H. (2012). Political feasibility: A conceptual exploration. *Political Studies*, *60*(4), 809–825. https://doi.org/10.1111/j.1467-9248.2011.00936.x

Goldemberg, J. (1998). Leapfrog energy technologies. *Energy Policy*, *26*(10), 729–741. https://doi.org/10.1016/s0301-4215(98)00025-1

Goldemberg, J., Johansson, T. B., Reddy, A., & Williams, R. H. (1985b). Basic needs and much more with one kilowatt per capita. *AMBIO.*, *14*(4/5), 190–200.

Goldemberg, J., Johansson, T. B., Reddy, A. K., & Williams, R. H. (1987). *Energy for a sustainable world*. World Resources Institute.

Goldemberg, J., Johansson, T. B., Reddy, A. K. N., & Williams, R. H. (1985a). An end-use oriented global energy strategy. *Annual Review of Energy*, *10*(1), 613–688. https://doi.org/10.1146/annurev.eg.10.110185.003145

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica*, *25*(4), 501. https://doi.org/10.2307/1905380

Grubb, M., Drummond, P., & Hughes, N. (2020). *The shape and pace of change in the electricity transition*.

Grübler, A., & Nakicenovic, N. (2001). Identifying dangers in an uncertain climate. *Nature*, *412*(6842), 15. https://doi.org/10.1038/35083752

Grubler, A., Nakićenović, N., & Victor, D. G. (1999). Dynamics of energy technologies and global change. *Energy Policy*, *27*(5), 247–280. https://doi.org/10.1016/s0301-4215(98)00067-6

Grubler, A., Wilson, C., Bento, N., Boza-Kiss, B., Krey, V., McCollum, D. L., Rao, N. D., Riahi, K., Rogelj, J., Stercke, S. D., Cullen, J., Frank, S., Fricko, O., Guo, F., Gidden, M., Havlík, P., Huppmann, D., Kiesewetter, G., Rafaj, P., … Valin, H. (2018). A low energy demand scenario for meeting the 1.5°C target and sustainable development goals without negative emission technologies. *Nature Energy*, *3*(6), 515–527. https://doi.org/10.1038/s41560-018-0172-6

Grubler, A., Wilson, C., & Nemet, G. (2016). Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions. *Energy Research & Social Science*, *22*, 18–25. https://doi.org/10.1016/j.erss.2016.08.015

Guivarch, C., Gallic, T. L., Bauer, N., Fragkos, P., Huppmann, D., Jaxa-Rozen, M., Keppo, I., Kriegler, E., Krisztin, T., Marangoni, G., Pye, S., Riahi, K., Schaeffer, R., Tavoni, M., Trutnevyte, E., van Vuuren, D., & Wagner, F. (2022). Using large ensembles of climate change mitigation scenarios for robust insights. *Nature Climate Change*, *12*(5), 428–435. https://doi.org/10.1038/s41558-022-01349-x

Haasnoot, M., Biesbroek, R., Lawrence, J., Muccione, V., Lempert, R., & Glavovic, B. (2020). Defining the solution space to accelerate climate change adaptation. *Regional Environmental Change*, *20*(2), 37. https://doi.org/10.1007/s10113-020-01623-8

Hancock, T., & Bezold, C. (1994). Possible futures, preferable futures. *The Healthcare Forum Journal*, *37*(2), 23–29.

Hansen, J. P., Narbel, P. A., & Aksnes, D. L. (2017). Limits to growth in the renewable energy sector. *Renewable and Sustainable Energy Reviews*, *70*, 769–774. https://doi.org/10.1016/j.rser.2016.11.257

Henchey, N. (1978). Making sense of future studies. *Alternatives: Perspectives on Society, Technology and Environment*, *7*(2), 24–27.

Hirt, L. F., Schell, G., Sahakian, M., & Trutnevyte, E. (2020). A review of linking models and socio-technical transitions theories for energy and climate solutions. *Environmental Innovation and Societal Transitions*, *35*, 162–179. https://doi.org/10.1016/j.eist.2020.03.002

Höök, M., Li, J., Johansson, K., & Snowden, S. (2012). Growth rates of global energy systems and future outlooks. *Natural Resources Research*, *21*(1), 23–41. https://doi.org/10.1007/s11053-011-9162-0

Hyun, M., Cherp, A., Jewell, J., Kim, Y. J., & Eom, J. (2023). Feasibility trade-offs in decarbonising the power sector with high coal dependence: The case of Korea. *Renewable and Sustainable Energy Transition*, *3*, 100050. https://doi.org/10.1016/j.rset.2023.100050

IEA. (2021). *Net zero by 2050—A roadmap for the global energy sector* (p. 224). https://iea.blob.core.windows.net/assets/beceb956-0dcf-4d73-89fe-1310e3046d68/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

Ikenberry, G. J. (1986). The irony of state strength: Comparative responses to the oil shocks in the 1970s. *International Organization*, *40*(1), 105–137. https://doi.org/10.1017/S0020818300004495

IPCC. (1992). *1992 IPCC Supplement*. World Meteorological Organization/United Nations Environment Program.

IPCC. (2019). Annex I: Glossary. In Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. van Diemen, R. P. Shukla, J. Skea, E. C. Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. P. Pereira, P. Vvyas, E. Huntley, et al. (Eds.), *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* https://doi.org/10.1017/9781009157988.010.

IPCC. (2022a). Annex II: Definitions, units and conventions. In A. A. Khourdajie, R. van Diemen, W. F. Lamb, M. Pathak, A. Reisinger, C. de la Rue du, J. Skea, R. Slade, & S. Some (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157926.021

IPCC. (2022b). In H.-O. Pörtner, D. C. Roberts, M. Tignore, E. S. Poloczanka, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

IPCC. (2022c). Summary for policymakers. In P. R. Shukla, J. Skea, R. Slade, A. A. Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

IPCC. (2022d). *Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC.

Iyer, G., Hultman, N., Eom, J., McJeon, H., Patel, P., & Clarke, L. (2015). Diffusion of low-carbon technologies and the feasibility of long-term climate targets. *Technological Forecasting and Social Change*, *90*, 103–118. https://doi.org/10.1016/j.techfore.2013.08.025

Jacobsson, S., & Lauber, V. (2006). The politics and policy of energy system transformation—Explaining the German diffusion of renewable energy technology. *Energy Policy*, *34*(3), 256–276. https://doi.org/10.1016/j.enpol.2004.08.029

Jenkins, J. D. (2014). Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design? *Energy Policy*, *69*, 467–477. https://doi.org/10.1016/j.enpol.2014.02.003

Jewell, J., & Cherp, A. (2020). On the political feasibility of climate change mitigation pathways: Is it too late to keep warming below 1.5°C? *Wiley Interdisciplinary Reviews: Climate Change*, *11*(1), e621. https://doi.org/10.1002/wcc.621

Jewell, J., & Cherp, A. (2022). *Feasibility spaces for climate action: A bridge between the inside and outside view*. Paper Presented at Scenarios Forum 2022.

Jewell, J., Vinichenko, V., Nacke, L., & Cherp, A. (2019). Prospects for powering past coal. *Nature Climate Change*, *9*(8), 592–597. https://doi.org/10.1038/s41558-019-0509-6

Kahneman, D., & Lovallo, D. (1993). Timid choices and bold forecasts: A cognitive perspective on risk taking. *Management Science*, *39*(1), 17–31. https://doi.org/10.1287/mnsc.39.1.17

Kahneman, D., & Tversky, A. (1982). *Intuitive prediction: Biases and corrective procedures* (pp. 414–421). Cambridge University Press. https://doi.org/10.1017/cbo9780511809477.031

Keppo, I., Butnar, I., Bauer, N., Caspani, M., Edelenbosch, O., Emmerling, J., Fragkos, P., Guivarch, C., Harmsen, M., Lefèvre, J., Gallic, T. L., Leimbach, M., McDowall, W., Mercure, J.-F., Schaeffer, R., Trutnevyte, E., & Wagner, F. (2021). Exploring the possibility space: Taking stock of the diverse capabilities and gaps in integrated assessment models. *Environmental Research Letters*, *16*(5), 053006. https://doi.org/10.1088/1748-9326/abe5d8

Kern, F., & Rogge, K. S. (2016). The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? *Energy Research & Social Science*, *22*, 13–17. https://doi.org/10.1016/j.erss.2016.08.016

Keyßer, L. T., & Lenzen, M. (2021). 1.5°C degrowth scenarios suggest the need for new mitigation pathways. *Nature Communications*, *12*(1), 2676. https://doi.org/10.1038/s41467-021-22884-9

Khourdajie, A. A., van Diemen, R., Lamb, W. F., Pathak, M., Reisinger, A., Can, S., de la Rue du, C., Skea, J., Slade, R., Some, S., & Steg, L. (2022). Annex II: Definitions, units & conventions. In J. Skea, P. R. Shukla, A. Reisinger, R. Slade, M. Pathak, A. A. Khourdajie, R. van Diemen, A. Abdulla, K. Akimoto, M. Babiker, & A. Abdulla (Eds.), *Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2769–2807). Cambridge University Press https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_Annex-II.pdf

Knachel, M. (2021). Fundamental methods of logic. *LibreText Humanities*. https://human.libretexts.org/Bookshelves/Philosophy/Fundamental_Methods_of_Logic_(Knachel)

Kramer, G. J., & Haigh, M. (2009). No quick switch to low-carbon energy In the first of two pieces on reducing greenhouse-gas emissions. *Nature*, *462*(3), 568–569. https://doi.org/10.1038/462568a

Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K. L., Kram, T., Riahi, K., Winkler, H., & Van Vuuren, D. P. (2014). A new scenario framework for climate change research: The concept of shared climate policy assumptions. *Climatic Change*, *122*(3), 401–414. https://doi.org/10.1007/s10584-013-0971-5

Lauber, V., & Jacobsson, S. (2016). The politics and economics of constructing, contesting and restricting socio-political space for renewables—The German renewable energy act. *Environmental Innovation and Societal Transitions*, *18*(147), 163. https://doi.org/10.1016/j.eist.2015.06.005

Lee, A. S. (1989). Case studies as natural experiments. *Human Relations*, *42*(2), 117–137. https://doi.org/10.1177/001872678904200202

Lee, D., & Hess, D. J. (2019). Incumbent resistance and the solar transition: Changing opportunity structures and framing strategies. *Environmental Innovation and Societal Transitions*, *33*, 183–195. https://doi.org/10.1016/j.eist.2019.05.005

Ley, D., Adams, H., Araos, M., Basu, R., Bazaz, A., Conte, L., Davis, K., Dockendorff, C., Ford, J., Fuss, S., Gilmore, E. A., Bolaños, T. G., Hoegh-Guldberg, O., Howden, M., Kalyan, B., Moro, L., Mosurska, A., Mechler, R., Portugal-Pereira, J., … Sugiyama, M. (2022). Cross-chapter box feasib|feasibility assessment of adaptation options: An update of the SR1.5. In H. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate Resilient Development Pathways. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2769–2807). Cambridge University Press https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter18.pdf

Livingston, J. E., & Rummukainen, M. (2020). Taking science by surprise: The knowledge politics of the IPCC Special Report on 1.5 degrees. *Environmental Science & Policy*, *112*, 10–16. https://doi.org/10.1016/j.envsci.2020.05.020

Loftus, P. J., Cohen, A. M., Long, J. C. S., & Jenkins, J. D. (2015). A critical review of global decarbonization scenarios: What do they tell us about feasibility? *Wiley Interdisciplinary Reviews: Climate Change*, *6*(1), 93–112. https://doi.org/10.1002/wcc.324

Lovallo, D., Clarke, C., & Camerer, C. (2012). Robust analogizing and the outside view: Two empirical tests of case-based decision making. *Strategic Management Journal*, *33*(5), 496–512. https://doi.org/10.1002/smj.962

Lövbrand, E. (2011). Co-producing European climate science and policy: A cautionary note on the making of useful knowledge. *Science and Public Policy*, *38*(3), 225–236. https://doi.org/10.3152/030234211x12924093660516

Lovins, A. (1976). Energy strategy: The road not taken? *Foreign Affairs*, *55*, 65.

Lund, P. (2015). Energy policy planning near grid parity using a price-driven technology penetration model. *Technological Forecasting and Social Change*, *90*, 389–399. https://doi.org/10.1016/j.techfore.2014.05.004

Majone, G. (1975). On the notion of political feasibility. *European Journal of Political Research*, *3*(3), 259–274. https://doi.org/10.1111/j.1475-6765.1975.tb00780.x

Malhotra, A., & Schmidt, T. S. (2020). Accelerating low-carbon innovation. *Joule*, *4*, 2259–2267. https://doi.org/10.1016/j.joule.2020.09.004

Markard, J. (2018). The next phase of the energy transition and its implications for research and policy. *Nature Energy*, *3*(8), 628–633. https://doi.org/10.1038/s41560-018-0171-7

Markard, J. (2020). The life cycle of technological innovation systems. *Technological Forecasting and Social Change*, *153*, 119407. https://doi.org/10.1016/j.techfore.2018.07.045

McCollum, D. L., Gambhir, A., Rogelj, J., & Wilson, C. (2020). Energy modellers should explore extremes more systematically in scenarios. *Nature Energy*, *5*(2), 104–107. https://doi.org/10.1038/s41560-020-0555-3

Meng, J., Way, R., Verdolini, E., & Anadon, L. D. (2021). Comparing expert elicitation and model-based probabilistic technology cost forecasts for the energy transition. *Proceedings of the National Academy of Sciences*, *118*(27), e1917165118. https://doi.org/10.1073/pnas.1917165118

Merton, R. K. (1945). Role of the intellectual in public bureaucracy. *Social Forces*, *23*(4), 405–415. https://doi.org/10.2307/2571834

Merton, R. K. (1968). *On sociological theories of the middle range*. The Free Press.

Mingers, J. (2006). *Realising systems thinking: Knowledge and action in management science*. Springer.

Morgan, M. G., & Keith, D. W. (2008). Improving the way we think about projecting future energy use and emissions of carbon dioxide. *Climatic Change*, *90*(3), 189–215. https://doi.org/10.1007/s10584-008-9458-1

Morgan, M. G. (2014). Use (and abuse) of expert elicitation in support of decision making for public policy. *Proceedings of the National Academy of Sciences*, *111*(20), 7176–7184. https://doi.org/10.1073/pnas.1319946111

Muttitt, G., Price, J., Pye, S., & Welsby, D. (2023). Socio-political feasibility of coal power phase-out and its role in mitigation pathways. *Nature Climate Change*, *13*(2), 140–147.

Nakicenovic, N., Alcamo, J., Davis, G., De Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., June, T. Y., Kram, T., Rovere, E. L. L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., … Dadi, Z. (2000). *Special report on emissions scenarios*. Cambridge University Press.

Napp, T., Bernie, D., Thomas, R., Lowe, J., Hawkes, A., & Gambhir, A. (2017). Exploring the feasibility of low-carbon scenarios using historical energy transitions analysis. *Energies*, *10*(1), 116. https://doi.org/10.3390/en10010116

Nelson, S., & Allwood, J. M. (2021). The technological and social timelines of climate mitigation: Lessons from 12 past transitions. *Energy Policy*, *152*, 112155. https://doi.org/10.1016/j.enpol.2021.112155

Nemet, G. F. (2019). *How solar energy became cheap: A model for low-carbon innovation*. Routledge.

Newell, R. G., & Raimi, D. (2018). *The new climate math: Energy addition, subtraction, and transition*. October. http://www.rff.org/files/document/file/RFF-IssueBrief-NewClimateMath-final.pdf

Ng, C., Zhao, F., Watari, M., & Thubert, P. (2007). *Network mobility route optimization solution space analysis*. Network Working Group. https://doi.org/10.17487/rfc4889

Nordhaus, W. D., & Yohe, G. W. (1983). Future paths of energy and carbon dioxide emissions. In *Changing Climate: Report of the Carbon Dioxide Assessment Committee*. National Academy Press. https://doi.org/10.17226/18714

Ockwell, D. G., & Mallett, A. (2012). *Low-carbon technology transfer*. Routledge.

Odenweller, A., Ueckerdt, F., Nemet, G. F., Jensterle, M., & Luderer, G. (2022). Probabilistic feasibility space of scaling up green hydrogen supply. *Nature Energy*, *1–12*, 854–865. https://doi.org/10.1038/s41560-022-01097-4

O'Neill, B. C., Carter, T. R., Ebi, K., Harrison, P. A., Kemp-Benedict, E., Kok, K., Kriegler, E., Preston, B. L., Riahi, K., Sillmann, J., Van Ruijven, B. J., Van Vuuren, D., Carlisle, D., Conde, C., Fuglestvedt, J., Green, C., Hasegawa, T., Leininger, J., Monteith, S., & Pichs-Madruga, R. (2020). Achievements and needs for the climate change scenario framework. *Nature Climate Change*, *10*(12), 1074–1084. https://doi.org/10.1038/s41558-020-00952-0

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., Van Ruijven, B. J., Van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, *42*(Rev. Environ. Econ. Policy 7 2013), 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., Mathur, R., & van Vuuren, D. P. (2014). A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Climatic Change*, *122*(3), 387–400. https://doi.org/10.1007/s10584-013-0905-2

Ou, Y., Iyer, G., Clarke, L., Edmonds, J., Fawcett, A. A., Hultman, N., McFarland, J. R., Binsted, M., Cui, R., Fyson, C., Geiges, A., Gonzales-Zuñiga, S., Gidden, M. J., Höhne, N., Jeffery, L., Kuramochi, T., Lewis, J., Meinshausen, M., Nicholls, Z., … McJeon, H. (2021). Can updated climate pledges limit warming well below 2°C? *Science*, *374*(6568), 693–695. https://doi.org/10.1126/science.abl8976

Pathak, M., Slade, R., Shukla, P. R., Skea, J., Pichs-Madruga, R., & Ürge-Vorsatz, D. (2022). Technical summary. In P. R. Shukla, J. Skea, R. Slade, A. A. Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157926.002

Pielke, R., Burgess, M., & Ritchie, J. (2021). *Most plausible 2005–2040 emission scenarios project less than 2.5°C of warming by 2100*. https://osf.io/preprints/socarxiv/m4fdu

Pielke, R., Burgess, M. G., & Ritchie, J. (2022). Plausible 2005–2050 emissions scenarios project between 2°C and 3°C of warming by 2100. *Environmental Research Letters*, *17*(2), 024027. https://doi.org/10.1088/1748-9326/ac4ebf

Pielke, R., Wigley, T., & Green, C. (2008). Dangerous assumptions. *Nature*, *452*(7187), 531–532. https://doi.org/10.1038/452531a

Pye, S., Welsby, D., McDowall, W., Reinauer, T., Dessens, O., Winning, M., Calzadilla, A., & Bataille, C. (2022). Regional uptake of direct reduction iron production using hydrogen under climate policy. *Energy and Climate Change*, *3*, 100087. https://doi.org/10.1016/j.egycc.2022.100087

Redelmeier, D. A., Koehler, D. J., Liberman, V., & Tversky, A. (1995). Probability judgement in medicine: Discounting unspecified possibilities. *The Psychology of Decision Making*, *1995*, 227–230.

Reusswig, F., Braun, F., Heger, I., Ludewig, T., Eichenauer, E., & Lass, W. (2016). Against the wind: Local opposition to the German Energiewende. *Utilities Policy*, *41*, 214–227. https://doi.org/10.1016/j.jup.2016.02.006

Riahi, K., Bertram, C., Huppmann, D., Rogelj, J., Bosetti, V., Cabardos, A.-M., Deppermann, A., Drouet, L., Frank, S., Fricko, O., Fujimori, S., Harmsen, M., Hasegawa, T., Krey, V., Luderer, G., Paroussos, L., Schaeffer, R., Weitzel, M., van der Zwaan, B., … Zakeri, B. (2021). Cost and attainability of meeting stringent climate targets without overshoot. *Nature Climate Change*, *1–7*, 1063–1069. https://doi.org/10.1038/s41558-021-01215-2

Riahi, K., Dentener, F., Gielen, D., Grubler, A., Jewell, J., Klimont, Z., Krey, V., McCollum, D., Pachauri, S., Rao, S., Van Ruijven, B., Vuuren, D. P. V., & Wilson, C. (2012). Chapter 17. Energy pathways for sustainable development. In *Global energy assessment: Toward a more sustainable futures* (Vol. 17, pp. 1203–1306). Cambridge University Press. http://pure.iiasa.ac.at/10065/1/GEA

Riahi, K., Dentener, F., Gielen, D., Grubler, A., Jewell, J., Klimont, Z., Krey, V., McCollum, D., Pachauri, S., Rao, S., Van Ruijven, B. J., Van Vuuren, D., & Wilson, C. (2013). Energy pathways for sustainable development. *Global Energy Assessment*.

Riahi, K., Kriegler, E., Johnson, N., Bertram, C., Den Elzen, M., Eom, J., Schaeffer, M., Edmonds, J., Isaac, M., Krey, V., Longden, T., Luderer, G., Méjean, A., McCollum, D. L., Mima, S., Turton, H., Van Vuuren, D. P., Wada, K., Bosetti, V., … Edenhofer, O. (2015).

Locked into Copenhagen pledges—Implications of short-term emission targets for the cost and feasibility of long-term climate goals. *Technological Forecasting and Social Change*, *90*, 8–23. https://doi.org/10.1016/j.techfore.2013.09.016

Riahi, K., Schaeffer, R., Arango, J., Calvin, K., Guivarch, C., Hasegawa, T., Jiang, K., Kriegler, E., Matthews, R., Peters, G., Rao, A., Robertson, S., Sebbit, A. M., Steinberger, J., Tavoni, M., & Van Vuuren, D. (2022). Mitigation pathways compatible with long-term goals—Chapter 3. In P. R. Shukla, J. Skea, R. Slade, A. A. Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate Change 2022: Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157926.005

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., … Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, *42*-((Global Environ. Change 33 2015)), 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Roddis, P., Carver, S., Dallimer, M., Norman, P., & Ziv, G. (2018). The role of community acceptance in planning outcomes for onshore wind and solar farms: An energy justice analysis. *Applied Energy*, *226*, 353–364. https://doi.org/10.1016/j.apenergy.2018.05.087

Roe, S., Streck, C., Beach, R., Busch, J., Chapman, M., Daioglou, V., Deppermann, A., Doelman, J., Emmet-Booth, J., Engelmann, J., Fricko, O., Frischmann, C., Funk, J., Grassi, G., Griscom, B., Havlik, P., Hanssen, S., Humpenöder, F., Landholm, D., … Lawrence, D. (2021). Land-based measures to mitigate climate change: Potential and feasibility by country. *Global Change Biology*, *27*, 6025–6058. https://doi.org/10.1111/gcb.15873

Roelfsema, M., Van Soest, H. L., Harmsen, M., Van Vuuren, D. P., Bertram, C., Den Elzen, M., Höhne, N., Iacobuta, G., Krey, V., Kriegler, E., Luderer, G., Riahi, K., Ueckerdt, F., Després, J., Drouet, L., Emmerling, J., Frank, S., Fricko, O., Gidden, M., … Vishwanathan, S. S. (2020). Taking stock of national climate policies to evaluate implementation of the Paris Agreement. *Nature Communications*, *11*(1), 2096. https://doi.org/10.1038/s41467-020-15414-6

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Séférian, R., & Vilarino, M. V. (2018). Mitigation pathways compatible with 1.5°C in the context of sustainable development. *Special Report on Global Warming of 1.5°C (SR15)*. http://www.ipcc.ch/report/sr15/

Schneider, S. H. (2001). What is "dangerous" climate change? *Nature*, *411*(6833), 17–19. https://doi.org/10.1038/35075167

Seidel, S., & Keyes, D. (1983). *Can we delay a greenhouse warming? The effectiveness and feasibility of options to slow a build-up of carbon dioxide in the atmosphere*. Office of Policy and Resource Management.

Semieniuk, G. (2022). Inconsistent definitions of GDP: Implications for estimates of decoupling. *Working Paper*, Number 563. https://peri.umass.edu/component/k2/item/1648-inconsistent-definitions-of-gdp-implications-for-estimates-of-decoupling

Semieniuk, G., Taylor, L., Rezai, A., & Foley, D. K. (2021). Plausible energy demand patterns in a growing global economy with climate policy. *Nature Climate Change*, *1–6*, 313–318. https://doi.org/10.1038/s41558-020-00975-7

SHAPE-project. (2020). *FAQ—SHAPE*. https://shape-project.org/stakeholder-dialogue/faq#_Toc48921646

Singh, C., Ford, J., Ley, D., Bazaz, A., & Revi, A. (2020). Assessing the feasibility of adaptation options: Methodological advancements and directions for climate adaptation research and practice. *Climatic Change*, *162*(2), 255–277. https://doi.org/10.1007/s10584-020-02762-x

Skea, J., Van Diemen, R., Portugal-Pereira, J., & Khourdajie, A. A. (2021). Outlooks, explorations and normative scenarios: Approaches to global energy futures compared. *Technological Forecasting and Social Change*, *168*, 120736. https://doi.org/10.1016/j.techfore.2021.120736

Slovic, P., Fischhoff, B., & Lichtenstein, S. (1977). Cognitive processes and societal risk taking. In H. Jungermann & G. de Zeeuw (Eds.), *Decision making and change in human affairs*. D. Reidel Publishing Company.

Smil, V. (2010). *Energy transitions: History, requirements, prospects*. Praeger.

Smil, V. (2016). Examining energy transitions: A dozen insights based on performance. *Energy Research & Social Science*, *22*, 194–197. https://doi.org/10.1016/j.erss.2016.08.017

Sognnaes, I. (2022). What can we learn from probabilistic feasibility assessments? *Joule*, *6*(11), 2450–2452. https://doi.org/10.1016/j.joule.2022.10.018

Sognnaes, I., Gambhir, A., Van De Ven, D.-J., Nikas, A., Anger-Kraavi, A., Bui, H., Campagnolo, L., Delpiazzo, E., Doukas, H., Giarola, S., Grant, N., Hawkes, A., Köberle, A. C., Kolpakov, A., Mittal, S., Moreno, J., Perdana, S., Rogelj, J., Vielle, M., & Peters, G. P. (2021). A multi-model analysis of long-term emissions and warming implications of current mitigation efforts. *Nature Climate Change*, *11*(12), 1055–1062. https://doi.org/10.1038/s41558-021-01206-3

Solecki, W., Cartwright, A., Cramer, W., Ford, J., Jiang, K., Pereira, J. P., Rogelj, J., Steg, L., & Waisman, H. (2018). In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Cross-Chapter Box 3. Framing Feasibility: Key Concepts and Conditions for Limiting Global Temperature Increases to 1.5°C* (pp. 71–72). Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/02/SR15_Chapter1_Low_Res.pdf

Sorrell, S. (2018). Explaining sociotechnical transitions: A critical realist perspective. *Research Policy*, *47*(7), 1267–1282. https://doi.org/10.1016/j.respol.2018.04.008

Stammer, D., Engels, A., Marotzke, J., Gresse, E., Hedemann, C., & Petzold, J. (Eds.). (2021). *Hamburg climate futures outlook 2021. Assessing the plausibility of deep decarbonization by 2050* (p. 25). Cluster of Excellence Climate, Climate Change, and Society (CLICCS).

Steckel, J. C., Brecha, R. J., Jakob, M., Strefler, J., & Luderer, G. (2013). Development without energy? Assessing future scenarios of energy consumption in developing countries. *Ecological Economics*, *90*, 53–67. https://doi.org/10.1016/j.ecolecon.2013.02.006

Steg, L., Veldstra, J., de Kleijne, K., Kılkış, Ş., Lucena, A. F. P., Nilsson, L. J., Sugiyama, M., Smith, P., Tavoni, M., de Coninck, H., van Diemen, R., Renforth, P., Mirasgedis, S., Nemet, G., Görsch, R., Muri, H., Bertoldi, P., Cabeza, L. F., Mata, É., … Vérez, D. (2022). A method to identify barriers to and enablers of implementing climate change mitigation options. *One Earth*, *5*(11), 1216–1227. https://doi.org/10.1016/j.oneear.2022.10.007

Stern, P. C., Dietz, T., Nielsen, K. S., Peng, W., & Vandenbergh, M. P. (2022). Feasible climate mitigation. *Nature Climate Change*, *1–3*, 6–8. https://doi.org/10.1038/s41558-022-01563-7

Sterner, T., & Robinson, E. J. Z. (2018). Chapter 6. Selection and design of environmental policy instruments. *Handbook of environmental economics*, *4*, 231–284. https://doi.org/10.1016/bs.hesenv.2018.08.002.

Stoddard, I., Anderson, K., Capstick, S., Carton, W., Depledge, J., Facer, K., Gough, C., Hache, F., Hoolohan, C., Hultman, M., Hällström, N., Kartha, S., Klinsky, S., Kuchler, M., Lövbrand, E., Nasiritousi, N., Newell, P., Peters, G. P., Sokona, Y., … Williams, M. (2021). Three decades of climate mitigation: Why haven't we bent the global emissions curve? *Annual Review of Environment and Resources*, *46*(1), 1–37. https://doi.org/10.1146/annurev-environ-012220-011104

Thoni, T., Beck, S., Borchers, M., Förster, J., Görl, K., Hahn, A., Mengis, N., Stevenson, A., & Thrän, D. (2020). Deployment of negative emissions technologies at the national level: A need for holistic feasibility assessments. *Frontiers in Climate*, *2*, 590305. https://doi.org/10.3389/fclim.2020.590305

Trutnevyte, E., Hirt, L. F., Bauer, N., Cherp, A., Hawkes, A., Edelenbosch, O. Y., Pedde, S., & Van Vuuren, D. P. (2019). Societal transformations in models for energy and climate policy: The ambitious next step. *One Earth*, *1*(4), 423–433. https://doi.org/10.1016/j.oneear.2019.12.002

Tversky, A., & Kahneman, D. (1983). Extensional versus intuitive reasoning: The conjunction fallacy in probability judgment. *Psychological Review*, *90*(4), 293–315. https://doi.org/10.1037/0033-295x.90.4.293

van Beek, L., Hajer, M., Pelzer, P., Van Vuuren, D., & Cassen, C. (2020). Anticipating futures through models: The rise of integrated assessment modelling in the climate science-policy interface since 1970. *Global Environmental Change*, *65*, 102191. https://doi.org/10.1016/j.gloenvcha.2020.102191

van Beek, L., Oomen, J., Hajer, M., Pelzer, P., & Van Vuuren, D. (2022). Navigating the political: An analysis of political calibration of integrated assessment modelling in light of the 1.5°C goal. *Environmental Science & Policy*, *133*, 193–202. https://doi.org/10.1016/j.envsci.2022.03.024

van Benthem, A. A. (2015). Energy Leapfrogging. *Journal of the Association of Environmental and Resource Economists*, *2*(1), 93–132. https://doi.org/10.1086/680317

van der Zwaan, B. C. C., Rösler, H., Kober, T., Aboumahboub, T., Calvin, K., Gernaat, D., Marangoni, G., & McCollum, D. (2013). A cross-model comparison of global long-term technology diffusion under a 2°C climate change control target. *Climate Change Economics*, *4*(4), 1340013. https://doi.org/10.1142/s2010007813400137

van Dorsser, C., Walker, W. E., Taneja, P., & Marchau, V. A. W. J. (2018). Improving the link between the futures field and policymaking. *Futures*, *104*, 75–84. https://doi.org/10.1016/j.futures.2018.05.004

van Ewijk, S., & McDowall, W. (2020). Diffusion of flue gas desulfurization reveals barriers and opportunities for carbon capture and storage. *Nature Communications*, *11*(1), 4298. https://doi.org/10.1038/s41467-020-18107-2

van Sluisveld, M. A. E., Harmsen, J. H. M., Bauer, N., McCollum, D. L., Riahi, K., Tavoni, M., Van Vuuren, D. P., Wilson, C., & van der Zwaan, B. (2015). Comparing future patterns of energy system change in 2°C scenarios with historically observed rates of change. *Global Environmental Change*, *35*(Energy Econ. 31 2009), 436–449. https://doi.org/10.1016/j.gloenvcha.2015.09.019

Victoria, M., Haegel, N., Peters, I. M., Sinton, R., Jäger-Waldau, A., Del Cañizo, C., Breyer, C., Stocks, M., Blakers, A., Kaizuka, I., Komoto, K., & Smets, A. (2021). Solar photovoltaics is ready to power a sustainable future. *Joule*, *5*, 1041–1056. https://doi.org/10.1016/j.joule.2021.03.005

Vinichenko, V., Cherp, A., & Jewell, J. (2021). Historical precedents and feasibility of rapid coal and gas decline required for the 1.5°C target. *One Earth*, *4*(10), 1477–1490. https://doi.org/10.1016/j.oneear.2021.09.012

Vinichenko, V., Vetier, M., Jewell, J., Nacke, L., & Cherp, A. (2023). Phasing out coal for 2°C target requires worldwide replication of most ambitious national plans despite security and fairness concerns. *Environmental Research Letters*, *18*(1), 014031. https://doi.org/10.1088/1748-9326/acadf6

Voros, J. (2003). A generic foresight process framework. *Foresight*, *5*(3), 10–21. https://doi.org/10.1108/14636680310698379

Wack, P. (1985). Uncharted waters. *Harvard Business Review*, *1*(2), 136–137.

Warszawski, L., Kriegler, E., Lenton, T. M., Gaffney, O., Jacob, D., Klingenfeld, D., Koide, R., Costa, M. M., Messner, D., Nakicenovic, N., Schellnhuber, H. J., Schlosser, P., Takeuchi, K., Leeuw, S. V. D., Whiteman, G., & Rockström, J. (2021). All options, not silver bullets, needed to limit global warming to 1.5°C: A scenario appraisal. *Environmental Research Letters*, *16*(6), 064037. https://doi.org/10.1088/1748-9326/abfeec

Wiek, A., Keeler, L. W., Schweizer, V., & Lang, D. J. (2013). Plausibility indications in future scenarios. *International Journal of Foresight and Innovation Policy*, *9*(2/3/4), 133. https://doi.org/10.1504/ijfip.2013.058611

Williams, P. A., Simpson, N. P., Totin, E., North, M. A., & Trisos, C. H. (2021). Feasibility assessment of climate change adaptation options across Africa: An evidence-based review. *Environmental Research Letters*, *16*(7), 073004. https://doi.org/10.1088/1748-9326/ac092d

Wilson, C., Grubler, A., Bauer, N., Krey, V., & Riahi, K. (2013). Future capacity growth of energy technologies: Are scenarios consistent with historical evidence? *Climatic Change*, *118*(2), 381–395. https://doi.org/10.1007/s10584-012-0618-y

Wilson, C., Grubler, A., Bento, N., Healey, S., Stercke, S. D., & Zimm, C. (2020). Granular technologies to accelerate decarbonization. *Science*, *368*(6486), 36–39.

Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, *35*(5), 2683–2691. https://doi.org/10.1016/j.enpol.2006.12.001

Wynes, S., & Nicholas, K. A. (2017). The climate mitigation gap: Education and government recommendations miss the most effective individual actions. *Environmental Research Letters*, *12*(7), 074024. https://doi.org/10.1088/1748-9326/aa7541

Wynne, B. (1984). The institutional context of science, models, and policy: The IIASA energy study. *Policy Sciences*, *17*(3), 277–320. https://doi.org/10.1007/bf00138709

Xu, S., & Rahmat-Samii, Y. (2007). Boundary conditions in particle swarm optimization revisited. *IEEE Transactions on Antennas and Propagation*, *55*(3), 760–765. https://doi.org/10.1109/tap.2007.891562

Yang, M.-S., & Liu, M.-C. (1998). On possibility analysis of fuzzy data. *Fuzzy Sets and Systems*, *94*(2), 171–183. https://doi.org/10.1016/s0165-0114(96)00259-x

Yian-Kui, L., & Baoding, L. (2002). Random fuzzy programming with chance measures defined by fuzzy integrals. *Mathematical and Computer Modelling*, *36*(4–5), 509–524. https://doi.org/10.1016/s0895-7177(02)00180-2

How to cite this article: Jewell, J., & Cherp, A. (2023). The feasibility of climate action: Bridging the inside and the outside view through feasibility spaces. *WIREs Climate Change*, e838. https://doi.org/10.1002/wcc.838