

Article

## Exploring Global Climate Policy Futures and Their Representation in Integrated Assessment Models

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### Abstract

The Paris Agreement, adopted in 2015, paved the way for a new hybrid global climate governance architecture with both bottom-up and top-down elements. While governments can choose individual climate goals and actions, a global stocktake and a ratcheting-up mechanism have been put in place with the overall aim to ensure that collective efforts will prevent increasing adverse impacts of climate change. Integrated assessment models show that current combined climate commitments and policies of national governments fall short of keeping global warming to 1.5 °C or 2 °C above preindustrial levels. Although major greenhouse gas emitters, such as China, the European Union, India, the United States under the Biden administration, and several other countries, have made new pledges to take more ambitious climate action, it is highly uncertain where global climate policy is heading. Scenarios in line with long-term temperature targets typically assume a simplistic and hardly realistic level of harmonization of climate policies across countries. Against this backdrop, this article develops four archetypes for the further evolution of the global climate governance architecture and matches them with existing sets of scenarios developed by integrated assessment models. By these means, the article identifies knowledge gaps in the current scenario literature and discusses possible research avenues to explore the pre-conditions for successful coordination of national policies towards achieving the long-term target stipulated in the Paris Agreement.

### Keywords

climate action; climate policy; global climate governance architecture; integrated assessment models; Paris Agreement; scenario analysis

### Issue

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### 1. Introduction

After almost three decades of international climate negotiations, national governments have still not yet adopted effective means of implementation to cope with the problem of climate change. While the Covid-19 pan-

demic led to a temporary decline in global greenhouse gas (GHG) emissions (Bertram, Luderer, et al., 2021; Le Quéré et al., 2021), current collective efforts to mitigate global warming remain insufficient for the overall ambition stipulated in the Paris Agreement to keep global warming “well below 2 °C above preindustrial levels

and pursuing efforts to limit the temperature increase to 1.5 °C” (United Nations Framework Convention on Climate Change [UNFCCC], 2015, Article 2).

Although major GHG emitters, such as China, the European Union, India, the United States under the Biden administration, and several other countries, have recently made new pledges to take more ambitious climate action, it is highly uncertain where global climate policy is heading within the next decade. An official analysis of all revised plans for nationally determined contributions (NDCs) found only a small effect on GHG emission trajectories until 2030 (UNFCCC, 2021). Whilst a further analysis of updated pledges done in preparation for the 26th Conference of the Parties (COP26) in Glasgow tentatively suggests a stronger foundation for achieving the long-term goals of the Paris Agreement (Ou et al., 2021), deep GHG emission cuts would still be required to keep the door open to limiting peak warming to 1.5 °C (Intergovernmental Panel on Climate Change [IPCC], 2018).

The adoption of the Paris Agreement in 2015 marked a watershed moment in the overall global climate governance architecture. The Paris Agreement established a new legal framework that for the first time entailed responsibilities for virtually all countries to introduce measures to mitigate climate change (Streck et al., 2016). Moreover, in contrast to the Kyoto Protocol which involved a top-down governance approach with quantified GHG emission reduction targets for a certain set of industrialized countries, the Paris Agreement is based on bottom-up pledges by national governments combined with common principles for accounting, transparency, a periodic global stocktake, and a ratcheting-up mechanism to ensure that combined national efforts avoid increasing adverse impacts of climate change. The Paris Agreement is based on a “pledge and review” logic and its success depends on the continuous strengthening of national ambitions to reduce GHG emissions and attain carbon neutrality (Falkner, 2016).

While a couple of recent exceptions exist (e.g., Bauer et al., 2020; Bosetti et al., 2013; Deetman et al., 2015; van Soest et al., 2021), most mitigation scenarios used in integrated assessment models (IAMs) focus on so-called cost-optimal reduction pathways. This means that they start from the notion that climate action will accelerate over time and consensus will emerge among national governments about how to share efforts to mitigate climate change. Moreover, most IAM scenarios suppose that climate policies can be implemented in all regions and sectors irrespective of national and local circumstances (Rogelj et al., 2018). In addition, they often apply uniform carbon prices across world regions with different socio-political conditions (Bauer et al., 2020). This assumption is still far from reality and the prospect of the further evolution of the global climate governance architecture is ambiguous. While IAM scenarios are primarily meant to identify possible cost-optimal strategies (and thus do not really represent an assumption of a realistic

policy environment), we argue that it is crucial to draw upon plausible assumptions regarding future trajectories of global climate cooperation in order to build the next generation of policy-relevant climate scenarios.

In this article, we adopt a forward-looking perspective on the possible futures of global climate governance architectures. In particular, we develop four global climate governance archetypes that differ according to their degree of coordination. They are: (a) a revitalized top-down approach, (b) a hybrid approach with a strong joint commitment by national governments, (c) a hybrid approach with a weak joint commitment by national governments, and (d) a breakdown of global cooperation on climate change. We match these governance archetypes with existing sets of scenarios from IAMs to illustrate to what extent existing models depict these possible governance futures. By these means, we seek to identify knowledge gaps in the current scenario literature and point to possible research avenues to explore the pre-conditions for successful coordination of national policies towards achieving the targets stipulated in the Paris Agreement. Thus, this article nurtures the debate about which type of global climate governance architecture is most conducive to reaching the 1.5 °C target.

The article is structured as follows. In Section 2, we clarify the concept of governance architecture and describe crucial changes in the global climate governance architecture over the past three decades. In Section 3, we explain the development of possible futures of the global climate governance architecture and how we matched them with existing IAM scenarios. In Section 4, we develop and elaborate on the four governance archetypes which form the basis for the following analysis. In Section 5, we assess the scenario literature and explore to what extent existing sets of IAM scenarios cover the different governance archetypes. In Section 6, we discuss identified knowledge gaps and point to options for closing them, before we draw our conclusions in Section 7.

## 2. The Changing Global Climate Governance Architecture

The term “governance architecture” refers to the metaphor of buildings that comprise “copious rooms, lavish apartments, winding staircases and meandering corridors, [that are] all part of one interrelated system while keeping independent roles and spaces” (Biermann & Kim, 2020, pp. 7–8). Over the past few years, the concept of governance architectures has received increasing attention among scholars concerned with global policymaking (e.g., Biermann & Kim, 2020; Biermann et al., 2010; van Asselt & Zelli, 2014; Zelli, 2011). It is used as an umbrella term to denote the evolving institutional structure in a given policy domain composed of public and private entities operating at different governmental levels and scales.

While authors previously concentrated their analysis primarily on single institutions and their dyadic

interactions (e.g., the international climate regime and interactions with for instance the World Trade Organization), the concept of governance architecture takes a holistic perspective and looks at the vast multiplicity and overarching framework of actors and institutions in a certain policy domain. In the following paragraphs, we sketch the evolution of the global governance architecture in the field of climate change.

After mounting scientific evidence in the late 1980s that the earth was warming as a result of increasing atmospheric GHG concentrations, national governments adopted the UNFCCC at the Earth Summit in 1992 (United Nations, 1992). This Convention did not contain any binding targets for nation-states to reduce their GHGs but laid the foundation for the negotiation of the Kyoto Protocol which was agreed upon in 1997.

The Kyoto Protocol introduced obligations for a certain set of industrialized countries to limit their GHG emissions (UNFCCC, 1997), but it did not foresee any mitigation obligations for developing countries which at that time accounted only for a smaller share of overall GHG emissions. After intense negotiations about a rulebook and procedures for a market-based instrument, the Kyoto Protocol came into force in 2005. This top-down governance approach (Hare et al., 2010) was largely modeled on the success story of the Montreal Protocol, which effectively scaled down the global production and consumption of chlorofluorocarbons and other ozone-depleting substances (e.g., Oberthür, 2001; Parson, 2003).

However, in the years following the Kyoto Protocol's entry into force, there was little progress, with many key industrialized countries either not meeting their individual Kyoto targets or not ratifying the protocol in the first place. At the same time, GHG emissions increased substantially in developing countries, especially in Asia (Lamb et al., 2021). As a result, multilateral treaty-making as the means to tackle climate change came under intense scrutiny (Bernstein et al., 2010). Some scholars even questioned whether international climate negotiations were still necessary for addressing the problem of climate change (e.g., Hoffmann, 2011; Rayner, 2010; Victor, 2011). This frustration came to a peak following the failure of the international community to agree on a new international treaty at the Copenhagen Climate Summit in late 2009. Despite extensive preparations and the participation of more than 120 heads of state or government, the meeting was not successful in establishing a legally binding replacement for the Kyoto Protocol as anticipated, not least by thousands of civil society activists in and around the conference venue (Bodansky, 2010).

After several years of uncertainty and further rounds of negotiations, national delegates led by a coalition of committed governments and backed by the United Nations, with the support of the UNFCCC Secretariat and numerous non-governmental organizations, adopted the widely celebrated Paris Agreement in 2015. Its adop-

tion generated a shift away from top-down targets for nation-states towards bottom-up pledges that are combined with centralized principles for accounting, transparency, and a periodic global stocktake, hence representing a new type of hybrid global climate governance (Dubash, 2020). The bottom-up nature ensured a new governance framework that envisages obligations for almost all countries to take action against climate change (Streck et al., 2016). The Paris Agreement also foresees a key role for non-state actors to take part in the review of ambition levels, implementation, and compliance by national governments (e.g., Bäckstrand et al., 2017; van Asselt, 2016).

While the latest rounds of international climate negotiations under the UNFCCC in Glasgow in November 2021 have shown some progress, there is no clear road towards meeting the long-term temperature targets as stipulated in the Paris Agreement. Countries announced new commitments to curb methane emissions, phase-down coal-fired power plants, and halt continued deforestation (United Nations, 2021; see also Masood & Tollefson, 2021). Nevertheless, collective commitments still fall far short of the required steps needed to effectively tackle climate change. Recent projections and databases show an increasing GHG emissions gap between aggregate pledged near-term trajectories and what is needed to keep global warming to 1.5 °C or 2 °C (Roelfsema et al., 2020; United Nations Environment Programme, 2018; Vrontisi et al., 2018).

Furthermore, many countries with ambitious mitigation targets for 2030 currently lack progressive climate policies to ensure target achievement, exhibiting a clear lack of implementation (den Elzen et al., 2019). In response to the Paris Agreement's invitation to submit long-term strategies and the 2018 special report of the IPCC with its emphasis on carbon neutrality, we witnessed a "wave of net-zero emission targets" (Höhne et al., 2021, p. 820) by countries. This suggests that so far it is easier for countries to formulate medium-to-long-term targets than to enact legislation and adopt policies that lead to corresponding near-term effects. This has been framed as a "credibility gap" (Climate Action Tracker, 2021).

At the UNFCCC COP26, the two largest GHG emitters—China and the United States—released a joint statement promising to increase cooperation on climate action ("UN chief welcomes China–US pledge," 2021). Likewise, the European Union has refined its strategy to become climate neutral by 2050 and put forward a plan to reduce its GHG emissions compared to 1990 by at least 55% until 2030 (European Union, 2021). Yet, it remains largely unclear whether these pledges will materialize and how global cooperation on climate change will develop further. Hence, this article describes possible future developments of the global climate governance architecture within the next decade and assesses how such governance futures are depicted in existing IAMs.

### 3. Methodology

The analysis in this article was undertaken in two consecutive steps. Firstly, we developed four archetypes of the evolution of the global climate governance architecture. Secondly, we conducted a mapping exercise with existing IAM scenarios. The different governance archetypes are the result of discussions which took place in a series of expert workshops combined with a review of the relevant academic literature in the field of global climate governance. The categorization of four archetypes is necessarily a simplification depicting broad future policy pathways.

The development of the four governance archetypes informed the matching of the different possible global climate policy futures with existing IAM scenarios. Building upon the categorization of the four governance archetypes, the main purpose of the matching has been to identify gaps in the scenario literature. We, therefore, aim in this article to depict a broad overview of stylized pathways and illustrative modeling exercises as opposed to discussing all IAM scenarios in detail as this would have gone beyond the scope of the article.

In sum, the matching of the four governance archetypes with IAM scenarios tries to draw a rough picture, with illustrative nuances. To further contextualize the article in the broader scenario literature, we compiled a table that summarizes the different criteria used for our matching of the four governance archetypes with existing sets of IAM scenarios. This table includes a com-

parison of our four archetypes with the representative scenarios from the IPCC *Sixth Assessment Report* (AR6; see Table S1 in the Supplementary File).

### 4. Looking Forward: Developing Four Governance Archetypes

Drawing on the literature on global climate governance, we now develop and elaborate four archetypes for different possible futures of the global climate governance architecture within the next decade. The four archetypes range from (a) a revitalized top-down approach, (b) a hybrid approach with a strong joint commitment by national governments, and (c) a hybrid approach with a weak joint commitment by national governments to (d) a breakdown of global cooperation on climate change (see Table 1 for an overview of these governance archetypes and their main features).

In our usage of the term global climate governance architecture, we focus primarily on the actions of states and the UNFCCC process. However, we recognize the importance of sub-national authorities and non-state actors in contributing to GHG emissions reduction and the role they play in global climate policy (e.g., Green et al., 2014; Hickmann, 2017; van Asselt, 2016). The role of city networks, business self-regulation, and non-governmental initiatives in supporting and demanding state-level international cooperation is incorporated in the governance archetypes as outlined below. Yet, we note that the coverage of such climate actions launched

**Table 1.** Summary of key assumptions for each of the four governance archetypes.

<p>1. Revitalized top-down approach (“return to Kyoto” approach)</p> <ul style="list-style-type: none"> <li>• Top-down approach with strong legal and mandatory institutional characteristics</li> <li>• Strong accounting, monitoring, and verification as well as sanctions in case of non-compliance</li> <li>• Strict enforcement of national policies to ensure achievement of the 1.5 °C target</li> </ul>	<p>2. Hybrid approach with strong joint commitment (Paris Agreement targets reached)</p> <ul style="list-style-type: none"> <li>• Hybrid approach with clear goal orientation and effective coordination on effort-sharing among governments</li> <li>• Based on individual national pledges and common principles leading to a joint understanding of effort-sharing</li> <li>• Idealized continuation of current global climate governance architecture, enabling near-term GHG reductions and the possibility of upscaling</li> </ul>
<p>3. Hybrid approach with weak joint commitment (Paris Agreement targets missed)</p> <ul style="list-style-type: none"> <li>• Hybrid approach without clear goal-orientation and effective coordination on effort-sharing among governments</li> <li>• Failure to strengthen national climate actions and accelerating the global mitigation ambition over time</li> <li>• Prolongation of status quo with soft coordination of national climate policies, but failure of effective ratcheting-up</li> </ul>	<p>4. Breakdown of global climate cooperation (UNFCCC process failed)</p> <ul style="list-style-type: none"> <li>• Gradual erosion of global climate policy with steady withdrawal of countries from multilateral treaties and agreements</li> <li>• A decline of national climate pledges leading to an anarchical international setting</li> <li>• All key principles, norms, rules, and decision-making procedures of global climate policy fall apart</li> </ul>

and pursued by actors other than national governments is limited in current IAM scenarios and requires further exploration.

Above all, the four governance archetypes are not meant as accurate pictures of reality but rather bold descriptions to allow for matching with different IAM scenarios and to identify knowledge gaps. At the same time, they help to systematically compare the level of global cooperation ambition needed to achieve the Paris Agreement.

#### *4.1. Governance Archetype One: Revitalized Top-Down Approach*

The first governance archetype constitutes a top-down or centralized approach with strong legal and mandatory institutional characteristics. It can be seen as the Kyoto model and envisages clear legally binding targets within a multilaterally agreed process for all national governments to reduce their GHG emissions by a certain date, including strong accounting, monitoring, and verification procedures as well as sanctions for national governments in case of non-compliance (e.g., Hare et al., 2010). In other words, this governance archetype entails strict enforcement of public policies on a global level that aim to ensure the achievement of the long-term climate stabilization target as stipulated by a new universal climate treaty.

This archetype suggests that within the next decades, impactful measures will be adopted by a large number of countries due to the growing threat of climate change. These countries not only regularly meet at the global level, but also adhere to stringently defined overarching targets and the allocation of individual GHG emission budgets based on recent academic analysis (Messner et al., 2013). This archetype assumes that all governments of major GHG-emitting countries will adopt an explicit climate change mitigation effort-sharing agreement that guides national climate actions. In line with such an agreement, countries adopt ambitious climate policies and accelerate them step by step based on scientific advice and a high and increasing carbon price (uniform across regions or differentiated based on the agreed effort-sharing principle) and similar wide-ranging instruments to reduce global GHG emissions (Weitzman, 2014).

#### *4.2. Governance Archetype Two: Hybrid Approach With a Strong Joint Commitment*

A second governance archetype constitutes a hybrid approach with a strong joint commitment by national governments leading to a “race to the top.” It entails a goal-oriented effort-sharing approach among most national governments to tackle climate change through accelerated ambitions and climate actions over time representing the idealized future of the current architecture set in place with the Paris Agreement (Falkner, 2016).

This governance archetype is based on individual pledges by nation-states and common principles for accounting and monitoring. They are developed in an open and transparent process under the auspices of the United Nations in a multilateral setting and a convergence of understanding of fair effort-sharing. Such an agreement is based on the principle of common but differentiated responsibilities enshrined in the UNFCCC (Morgan et al., 2014; Weikmans et al., 2020).

This governance archetype can be seen as flexible but productive coordination of national climate policies. Even in the absence of a clear and overarching global GHG emission cap and without strong enforcement measures, such a global climate governance architecture would be largely effective and further developed in international climate negotiations (Dimitrov et al., 2019). In this global climate policy future, international coordination through a joint transparent global stocktake, climate clubs of pioneering governments, and demonstration effects from sub-national authorities and non-state actors that GHG emission reductions can be achieved are expected to ratchet up the ambition level of climate policies within the next decade (Abbott, 2012; Nordhaus, 2015; Widerberg & Pattberg, 2015). A common understanding of key principles of fair effort-sharing ensures an acceptable degree of heterogeneity of national targets. Similarly, financial and technical assistance for developing countries is ramped up to support actions. Overall, this results in strong GHG emission cuts, keeping long-term targets of carbon neutrality by 2050 within reach.

#### *4.3. Governance Archetype Three: Hybrid Approach with a Weak Joint Commitment*

A third governance archetype constitutes a hybrid approach with a weak joint commitment by national governments. It starts from the same preconditions as the second archetype and is also based on individual pledges by nation-states to mitigate climate change in their jurisdictions (Bodansky, 2016). Yet, this governance archetype does not foresee a goal-oriented approach with effective effort-sharing. National governments would still present renewed pledges in international climate negotiations, enact laws to reduce GHG emissions, and undertake related initiatives to address climate change in their jurisdictions. These national actions would however not be guided by strong principles for accounting and monitoring that would subsequently not generate a continuous strengthening of ambitions, making it difficult to attain the goal to keep global warming below 2 °C (Climate Action Tracker, 2021).

This governance archetype resembles the prolongation of the status quo situation with only soft coordination of national climate policies that are not bolstered by a clear global GHG emission cap and strong enforcement measures. In this global climate policy future, the

ratchet-up mechanism of the Paris Agreement does not exert a meaningful impact as intended in the institutional design (Allan, 2019; Sachs, 2019; Young, 2016). While some national governments might in this global climate governance archetype seek to adopt a range of climate change mitigation policies leading to a moderate reduction of global GHG emissions, a lack of coordination and competitiveness concerns limit the pace of decarbonization, which will thus likely be too slow to meet peak warming targets.

#### 4.4. Governance Archetype Four: Breakdown of Global Climate Cooperation

A fourth governance archetype constitutes the gradual erosion of global cooperation on climate change with a steady withdrawal by national governments from multilateral agreements and a “race to the bottom.” This governance archetype is based on a deterioration of pledges by nation-states, while potentially a number of influential philanthropists propose and support technology-oriented solutions to address the most adverse effects of global warming (Held & Roger, 2018; Victor, 2011). Eventually, all key principles, norms, rules, and decision-making procedures of global climate policy would slowly fall apart, and governments would fail to reduce GHG emissions on a global scale.

This governance archetype can be seen as non-global governance. It assumes that previously adopted agreements will not be implemented due to national competition, the rise of populist parties, and lack of consensus on the right approach, among other reasons (Hale et al., 2013). Such a development is not very likely but remains a possibility. In this governance archetype, global GHG emissions will continue to rise following a business-as-usual trajectory in many countries, possibly at a certain point being countered by last-minute technological interventions for dealing with global warming conducted by countries most affected by climate change impacts, such as geoengineering (Schenuit et al., 2021).

#### 4.5. Summing Up and Contextualization

As previously stated, the four governance archetypes described above are simplified and bold descriptions of the possible future trajectories of the global climate governance architecture. The governance archetypes developed in this article are closely related to past efforts within the shared socioeconomic pathways (SSP), which strive to lay out a coherent set of narratives about future socio-economic pathways, including prospects of global cooperation (e.g., Kriegler et al., 2014; Riahi et al., 2017; van Vuuren et al., 2017). Our approach to the development of four governance archetypes and the SSP framework have similar starting points and both have the ambition to depict possible global policy futures.

However, a major difference is that the SSPs basically serve as reference scenarios without explicit assump-

tions about global or national climate policies (Kriegler et al., 2014), while the four governance archetypes specifically focus on the further evolution of the global climate governance architecture. The added value of these four governance archetypes lies in their solid foundation and development in a series of expert workshops and a review of the existing governance literature. We argue that our categorization of four governance archetypes can complement the SSP framework as well as similar studies that seek to describe broader socio-economic developments.

### 5. Matching Possible Governance Futures With Existing Integrated Assessment Model Scenarios

After developing the four archetypes of the future development of the global climate governance architecture, we now match them with existing sets of scenarios from process-oriented IAMs that are also included in the IPCC’s *Sixth Assessment Report* (IPCC, 2022). This mapping exercise serves as a first approximation between studies in global climate governance and the scenario literature to identify knowledge gaps and novel research directions for integrating possible global climate policy futures into climate models (see Table 2).

IAM scenarios are designed by different research teams around the world to inform policymakers about trajectories of global and national GHG emissions and related global mean temperature changes. In essence, these sophisticated and process-oriented models build upon various strands of knowledge to illustrate how human development and societal choices interact with and affect the natural world. Due to the focus of this article on global climate governance architectures, we here concentrate the analysis on global IAM scenarios.

While existing sets of IAM scenarios draw mainly on economic, technological, and biophysical processes that produce GHG emissions, less attention is paid to insights from political science (Shen, 2021, p. 1) although in the last few years a few scenarios with a stronger political science orientation have been published (e.g., Andrijevic et al., 2020; Brutschin et al., 2021; van Sluisveld et al., 2020). In any case, IAM scenarios play an essential role in current political debates related to the choices of GHG emission reduction strategies and policies leading to carbon neutrality, especially through the IPCC reports (Skea et al., 2021; van Beek et al., 2020). The special report of the IPCC on global warming of 1.5 °C received especially wide global media coverage and public attention (e.g., Boykoff & Pearman, 2019). It has also substantially influenced both political and scientific debates on the timing of reaching net-zero CO<sub>2</sub> emissions around 2050 (Rogelj et al., 2021). Given the high relevance of the insights from IAM scenarios for policymaking, it is important that the scenario literature takes key assumptions regarding future developments of global climate cooperation into account.

### 5.1. Scenarios Depicting a Revitalized Top-Down Approach

Scholars have for a long time developed IAM scenarios that depict the ideal situation, in which national governments agree on clear legally binding targets to reduce GHG emissions within a multilaterally agreed process. An example is the set of “optimal carbon price” scenarios which assume a uniform global price for CO<sub>2</sub> emissions to reach specific long-term climate targets with more or less perfect foresight. Similarly, recursive models project similar kinds of scenarios in which carbon prices, while not inter-temporally optimal, are uniform across regions and are adjusted by the modelers (or some heuristic or algorithm) so that specified long-term GHG emission reduction targets are attained.

A different set of scenarios departs from the uniform carbon price paradigm, allowing for regional differentiation of carbon prices to reflect alternative effort-sharing paradigms without financial transfers (van den Berg et al., 2020), or the limited use of transfers due to sovereignty or other concerns (Bauer et al., 2020). These scenarios however assume either an explicit agreement on a quantitative sharing of the remaining carbon budget among national governments (van den Berg et al., 2020) or an implicit coordination mechanism that leads to equal relative welfare losses across regions compared to a counterfactual assumption (Bauer et al., 2020).

### 5.2. Scenarios Depicting the Hybrid Archetype With Strong Joint Commitment

There are currently no comprehensive scenarios in the academic literature that explicitly represent a highly coordinated hybrid approach to global climate policy that leads to a strong joint commitment of national governments to tackle climate change. The closest approximations are often called “bridge” scenarios (e.g., Kriegler et al., 2018; van Soest et al., 2021). Within the next decade, they foresee a strengthening of climate change mitigation ambition based on good practice policies (Fekete et al., 2021; Roelfsema et al., 2018) that generate a ratcheting up of climate actions by national governments.

While some regional differentiation is assumed in these scenarios, the exact policy assumptions are not necessarily reflective of domestic political developments. Moreover, they are only loosely tied to requirements for attaining long-term goals. To achieve long-term climate change mitigation targets, these scenarios after 2030 abruptly or gradually shift back to the approach described in the previous section depicting governance archetype one. Therefore, existing “bridge” scenarios are not mirroring a successful implementation of the Paris Agreement concerning the further evolution of the global climate governance architecture.

Another set of existing scenarios, which are even less reflective of the institutional design set in place with

the Paris Agreement, but can nevertheless best be put into this category, are so-called “delayed” scenarios (e.g., Bertram, Riahi, et al., 2021; Luderer et al., 2018). They assume the continuation of either current international climate policy or existing national targets until 2030, and then also sharply shift to the policy paradigm of the “top-down governance” archetype. In comparison, they presume an even more disruptive change of policy in 2030 compared to the “bridge” scenarios, and they are thus rather far away from real developments in contemporary global climate governance, as it is unclear how such an abrupt change should come about.

A third category of existing IAM scenarios that could best be categorized in this type is “climate club” scenarios (e.g., Paroussos et al., 2019). They envisage an explicit forming of sub-global coordination and cooperation, but they do not assume the attainment of long-term climate change mitigation goals. While these scenarios show further potential for cooperation among progressive actors, they do not yet span the full solution space and do not sufficiently inform about potentially successful coordination strategies.

### 5.3. Scenarios Depicting the Hybrid Archetype With Weak Joint Commitment

While the different sets of IAM scenarios in the previously described governance archetype expect a steady acceleration of climate change mitigation ambitions and respective actions over time, there are also scenarios that portray less positive and dynamic developments. They take into account that national governments do not adjust and strengthen their commitments to tackle climate change in their jurisdictions and adopt effective policies to reduce GHG emissions over time.

The prime examples of such scenarios are the so-called NDC or NDC2100 scenarios (the most up-to-date scenarios in this category are published as part of the ENGAGE project at <https://data.ene.iiasa.ac.at/engage>; see also Bertram, Riahi, et al., 2021; Riahi et al., 2021; Roelfsema et al., 2020). They foresee the achievement of the current set of NDCs in 2030 and use different heuristics to extrapolate “comparable ambition” levels for the period from 2030 to 2100.

The two extreme types of extrapolations do not represent “comparable ambition”: Assuming automatic long-term achievement of GHG emission reduction targets like in the delayed scenarios above is clearly too optimistic, while assuming a complete reversal to a baseline without any climate policies and carbon prices is too pessimistic. In between these two extremes, there are various options that can equally qualify for categorization as “comparable ambition” but have diverging long-term results. It is for instance unclear whether GHG emissions in NDC scenarios while staying nearly stable from 2020 to 2030, start to increase, remain roughly constant, or eventually start declining after 2030. This depends on further political developments as well as population trends,

growth rates of national economies, and technology innovations required for meeting NDC targets in 2030.

This group of scenarios, therefore, comprises IAM scenarios with various assumptions about the degrees of coordination among national governments and their commitments to take action on mitigating climate change beyond 2030. Those scenarios resulting in GHG emission increases after 2030 are probably best associated with a failure of the Paris Agreement, whereas those scenarios resulting in GHG emission declines show at least a partial functioning of the current NDC process and the ratcheting up mechanism. The latter scenarios however still represent an inadequacy of the global stocktake to eventually ensure trajectories in line with the Paris Agreement’s long-term target.

#### 5.4. Scenarios Depicting a Breakdown of Global Climate Cooperation

Lastly, for risk-managing purposes, it is important for the transition scenario literature to also keep on explor-

ing climate scenarios in which global climate cooperation fully fails and collapses. Scenarios best reflective of such an extreme future of the global climate governance architecture are the so-called “no new policies” scenarios (Roelfsema et al., 2020). To more realistically assess the implications of a breakdown of global cooperation to tackle climate change, further alternatives could be explored. In particular, various scenarios of regional policy dial-back could be studied based on existing legislative progress in different countries. Models with an integrated representation of damages could be used for studies of Nash equilibria, typically used for describing the non-cooperative behavior of actors, to explore plausible pathways for self-interested climate policy for large, heavily impacted countries like China or India.

#### 6. Discussion: Knowledge Gaps and Options for Future Climate Modeling

The development of the four governance archetypes and their combination with existing sets of IAM scenarios in

**Table 2.** Matching possible global climate policy futures with existing sets of IAM scenarios.

	Possible global climate policy future	Examples of existing sets of IAM scenarios	Judgement of current representation
Governance archetype one	Top-down approach with strong legal and mandatory institutional characteristics	Optimal carbon price scenarios and differentiated carbon prices based on explicit effort-sharing or implicit coordination	Relatively well represented in existing sets of IAM scenarios
Governance archetype two	Hybrid approach with a strong joint commitment by governments	Bridge scenarios, delayed scenarios, and climate club scenarios	Not adequately represented in existing sets of IAM scenarios as existing scenarios assume a shift from archetype three to one around 2030 without clear consideration of why this shift could come about and its requirements (bridge and delayed scenarios) or foresee only limited cooperation (climate club scenarios)
Governance archetype three	Hybrid approach with a weak joint commitment by governments	NDC or NDC2100 scenarios	Relatively well represented in existing sets of IAM scenarios
Governance archetype four	Breakdown of global climate cooperation	No new policies scenarios	Not adequately represented in existing sets of IAM scenarios as existing scenarios do not reflect ongoing research into technological solutions and self-interests for mitigation efforts due to adverse climate impacts

Notes: The table gives an overview of how existing IAM scenarios depict the four governance archetypes and points to knowledge gaps in the scenario literature; a more detailed table with information on the different criteria for the matching of the four governance archetypes with existing sets of IAM scenarios and references to groupings of climate models in the most recent *Sixth Assessment Report* of the IPCC can be found in the Supplementary File.



this article point to important knowledge gaps in the representation of possible global climate policy futures in the current scenario literature. Presupposing successful global climate cooperation, many existing scenarios make a detailed exploration of the requirements for the technological transformation of the energy and land-use systems and related behavioral and institutional changes on the demand side (like modal shifts in transportation). Scenarios moreover contribute to informing national policy debates about the role of different economy-wide and sectoral policy instruments, and they lay out the effects of failed cooperation among national governments on global GHG emission trends and mid- to long-term temperature trends.

However, the relation between global climate governance and national policies is two-way: While national climate policies are required for credible commitments to mitigate climate change, some form of effective cooperation between key actors at the global level and agreements among the major GHG emitting players are needed to enable and foster more ambitious national policies (e.g., Hickmann, 2016, 2017), not least to alleviate problems of carbon leakage and free-riding (Jakob, 2021; Nordhaus, 2015). The scenario literature so far provides only little information on global climate governance pathways and the requirements for national climate change mitigation targets to be ramped up in line with long-term GHG emission reduction targets.

In the present article, we have introduced governance archetype one (a mostly top-down approach) and governance archetype four (a purely bottom-up approach) as the two extreme variants of the further evolution of global climate governance architectures. These governance archetypes are both not likely to happen, although the Covid-19 pandemic or the war in Ukraine, and an increasingly antagonistic geopolitical environment among the major world powers have shown that large-scale global changes are indeed a possibility and not unthinkable.

Nevertheless, we argue that it is crucial to focus on the differences between the hybrid governance archetypes two (with a strong joint commitment by governments) and three (with a weak joint commitment by governments). While they at first glance seem to be quite similar, the two different global climate policy futures would imply very different outcomes with regard to the overall goal of climate stabilization. Thus, based on our analysis in this article, we urge global climate governance scholars and the IAM scenario community to put particular efforts into investigating the different pathways and crucial differences between effective and ineffective global climate cooperation.

To build a new generation of scenario modeling aligned with the hybrid governance architecture put in place through the adoption of the Paris Agreement in 2015, climate modelers could explore different ways of defining regular strengthening of climate change mitigation ambition. They could be based on criteria that are

directly measurable, like for instance a per capita gross domestic product (GDP; many modeling studies employ concepts that are hard to measure, such as welfare reductions compared to a counterfactual scenario).

A first option could be to run models recursively with periodically adjusted near-term climate change mitigation ambition levels, taking into account countries' past performances of GHG emission trajectories, both domestically, but potentially also with feedback from the performance of other countries. For instance, the pledges of national governments could be assumed to require strengthening if the GHG emissions of countries have not yet started to decrease for countries above a certain development threshold measured on the basis of GDP. While these interaction effects are difficult to incorporate into models, the political science literature highlights the importance of diffusion across countries (Jordan & Huitema, 2014) and governmental levels (Fuhr et al., 2018).

A second option that could be relatively easily included in models, while not fully aligned with the current developments of the UNFCCC negotiations, would be to implement generalizable, but also differentiating rules of a minimum carbon price based on countries' GDP and emission track records. In contrast to scenarios with differentiated carbon prices discussed in the previous section (Bauer et al., 2020; van den Berg et al., 2020), these carbon prices would however not emerge from an intertemporal perspective, but only develop recursively based on past GDP and GHG emission trends. Such new scenarios would thus be ex-ante determined (so that the same mechanism could be directly operationalized into national policies as part of the global stock-take), in contrast to existing target-meeting scenarios that feature perfect foresight, or some other form of policy definition that only works in the model setup.

The heuristics for adjustment could then be implemented in a very strict form, ensuring the achievement of an overall emission budget by meandering around an optimal global GHG emissions curve, which however would require very strong reactions of carbon prices. This would make such an approach challenging. More lenient heuristics of adjustment would in turn not ensure the achievement of a certain budget or a precise year for reaching net-zero GHG emissions globally but could nevertheless be enough to achieve ambitious climate change mitigation targets, at least under a subset of assumptions regarding overall socio-economic and technology development.

A third option could also be to define sectoral decarbonization roadmaps to which countries (differentiated by income group) need to gradually adhere if the Paris Agreement's goals should be achieved. This could also be combined with perspectives on activities by non-state actors, like industry groups, setting their own targets and thus contributing to GHG emission reductions that can go beyond national commitments (Hsu et al., 2018). The good-practice scenarios could serve as the starting

point for a hybrid model combining both carbon pricing and sectoral elements if they are enriched with a stronger dynamic evolution of global climate policy coordination.

Other scenario designs that balance the requirements for national bottom-up determinations (based on the sovereignty principle) and the overall global cap on cumulative GHG emissions needed to achieve climate change mitigation targets could include different forms of climate clubs (Hovi et al., 2016; Nordhaus, 2015).

## 7. Conclusions

The future of global climate policy is uncertain and not sufficiently represented in current IAM scenarios that display various pathways towards decarbonization. In this article, we sought to rectify this by firstly developing four governance archetypes and identifying how they are depicted by existing sets of IAM scenarios. The four governance archetypes include: (a) a revitalized top-down approach, (b) a hybrid approach with strong joint commitment, (c) a hybrid approach with weak joint commitment, and (d) a breakdown of global climate cooperation. We have shown that, while governance archetype one and archetype three are well covered within the scenario literature, archetype two and archetype four are not adequately portrayed.

Considering recent developments in global climate policy, the hybrid governance approach with a strong joint commitment is likely the most feasible and desired evolution of the overall global climate governance architecture. Yet, it is currently far from certain that we are heading in this direction. A continuation along the path of a hybrid governance approach with a weak joint commitment and ineffective coordination among the major GHG emitters is equally on the cards. Given the current multilateral crisis and lack of trust between many countries, even a complete deterioration of cooperation should not be entirely ruled out. Hence, a solid analysis of implications in terms of GHG emission trajectories and global mean temperature increases is important from a risk management perspective. Thus, this article underscores the urgency to improve climate modelling efforts to better depict varying global climate policy futures.

Model-based scenario work can provide a more solid foundation for policymakers aiming to enhance goal orientation in the current global stocktake and ratcheting up processes through innovative studies that go beyond the stylized scenario design in the existing scenario literature. Stronger and deeper consideration of the political framework for combating climate change at the global level and its key regulatory elements established by the Paris Agreement is needed for the next generation of IAM scenarios.

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## Conflict of Interests

The authors declare no conflict of interests.

## Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

## References

- Abbott, K. W. (2012). The transnational regime complex for climate change. *Environment and Planning C: Government and Policy*, 30(4), 571–590.
- Allan, J. I. (2019). Dangerous incrementalism of the Paris Agreement. *Global Environmental Politics*, 19(1), 4–11.
- Andrijevic, M., Cuaresma, J. C., Muttarak, R., & Schleussner, C.-F. (2020). Governance in socioeconomic pathways and its role for future adaptive capacity. *Nature Sustainability*, 3(1), 35–41.
- Bäckstrand, K., Kuyper, J. W., Linnér, B. O., & Lövbrand, E. (2017). Non-state actors in global climate governance: From Copenhagen to Paris and beyond. *Environmental Politics*, 26(4), 561–579.
- Bauer, N., Bertram, C., Schultes, A., Klein, D., Luderer, G., Kriegler, E., Popp, A., & Edenhofer, O. (2020). Quantification of an efficiency–sovereignty trade-off in climate policy. *Nature*, 588(7837), 261–266. <https://doi.org/10.1038/s41586-020-2982-5>
- Bernstein, S., Betsill, M., Hoffmann, M., & Paterson, M. (2010). A tale of two Copenhagens: Carbon markets and climate governance. *Millennium Journal of International Studies*, 39(1), 161–173.
- Bertram, C., Luderer, G., Creutzig, F., Bauer, N., Ueckerdt, F., Malik, A., & Edenhofer, O. (2021). Covid-19-induced low power demand and market forces starkly reduce CO<sub>2</sub> emissions. *Nature Climate Change*, 11(3), 193–196.
- Bertram, C., Riahi, K., Hilaire, J., Bosetti, V., Drouet, L., Fricko, O., Malik, A., Nogueira, L. P., van der Zwaan, B., van Ruijven, B., van Vuuren, D., Weitzel, M., Longa, F. D., de Boer, H.-S., Emmerling, J., Fosse, F., Fragkiadakis, K., Harmsen, M., Keramidas, K., . . . Luderer, G. (2021). Energy system developments and investments in the decisive decade for the Paris Agreement goals. *Environmental Research Letters*, 16(7), Article 074020. <https://doi.org/10.1088/1748-9326/ac09ae>
- Biermann, F., & Kim, R. E. (Eds.). (2020). *Architectures of earth system governance: Institutional complexity and structural transformation*. Cambridge University Press.

- Biermann, F., Zelli, F., Pattberg, P., & van Asselt, H. (2010). The architecture of global climate governance. In F. Biermann, P. Pattberg, & F. Zelli (Eds.), *Global climate governance beyond 2012: Architecture, agency and adaptation* (pp. 15–24). Cambridge University Press.
- Bodansky, D. (2010). Copenhagen climate change conference: A postmortem. *American Journal of International Law*, 104(2), 230–240.
- Bodansky, D. (2016). The Paris Climate Change Agreement: A new hope? *American Journal of International Law*, 110(2), 288–319.
- Bosetti, V., Carraro, C., De Cian, E., Massetti, E., & Tavoni, M. (2013). Incentives and stability of international climate coalitions: An integrated assessment. *Energy Policy*, 55, 44–56.
- Boykoff, M., & Pearman, O. (2019). Now or never: How media coverage of the IPCC special report on 1.5 °C shaped climate-action deadlines. *One Earth*, 1(3), 285–288.
- Brutschin, E., Pianta, S., Tavoni, M., Riahi, K., Bosetti, V., Marangoni, G., & van Ruijven, B. (2021). A multidimensional feasibility evaluation of low-carbon scenarios. *Environmental Research Letters*, 16, Article 064069.
- Climate Action Tracker. (2021). *Glasgow's 2030 credibility gap: Net zero's lip service to climate action. Wave of net zero emission goals not matched by action on the ground.* [https://climateactiontracker.org/documents/997/CAT\\_2021-11-09\\_Briefing\\_Global-Update\\_Glasgow2030CredibilityGap.pdf](https://climateactiontracker.org/documents/997/CAT_2021-11-09_Briefing_Global-Update_Glasgow2030CredibilityGap.pdf)
- Deetman, S., Hof, A. F., & van Vuuren, D. (2015). Deep CO<sub>2</sub> emission reductions in a global bottom-up model approach. *Climate Policy*, 15(2), 253–271.
- den Elzen, M., Kuramochi, T., Höhne, N., Cantzler, J., Esmeijer, K., Fekete, H., Fransen, T., Keramidas, K., Roelfsema, M., Sha, F., van Soest, H., & Vandyck, T. (2019). Are the G20 economies making enough progress to meet their NDC targets? *Energy Policy*, 126, 238–250. <https://doi.org/10.1016/j.enpol.2018.11.027>
- Dimitrov, R., Hovi, J., Sprinz, D. F., Sælen, H., & Underdal, A. (2019). Institutional and environmental effectiveness: Will the Paris Agreement work? *Wiley Interdisciplinary Reviews: Climate Change*, 10(4), Article e583.
- Dubash, N. K. (2020). Revisiting climate ambition: The case for prioritizing current action over future intent. *Wiley Interdisciplinary Reviews: Climate Change*, 11(1), Article e622.
- European Union. (2021). *European Green Deal.* [https://ec.europa.eu/clima/policies/eu-climate-action\\_en](https://ec.europa.eu/clima/policies/eu-climate-action_en)
- Falkner, R. (2016). The Paris Agreement and the new logic of international climate politics. *International Affairs*, 92(5), 1107–1125.
- Fekete, H., Kuramochi, T., Roelfsema, M., den Elzen, M., Forsell, N., Höhne, N., Luna, L., Hans, F., Sterl, S., Olivier, J., van Soest, H., Frank, S., & Gusti, M. (2021). A review of successful climate change mitigation policies in major emitting economies and the potential of global replication. *Renewable and Sustainable Energy Reviews*, 137, Article 110602. <https://doi.org/10.1016/j.rser.2020.110602>
- Fuhr, H., Hickmann, T., & Kern, K. (2018). The role of cities in multi-level climate governance: Local climate policies and the 1.5 °C target. *Current Opinion in Environmental Sustainability*, 30, 1–6.
- Green, J. F., Sterner, T., & Wagner, G. (2014). A balance of bottom-up and top-down in linking climate policies. *Nature Climate Change*, 4(12), 1064–1067.
- Hale, T., Held, D., & Young, K. (2013). *Gridlock: Why global cooperation is failing when we need it most.* Polity.
- Hare, W., Stockwell, C., Flachsland, C., & Oberthür, S. (2010). The architecture of the global climate regime: A top-down perspective. *Climate Policy*, 10(6), 600–614.
- Held, D., & Roger, C. (2018). Three models of global climate governance: From Kyoto to Paris and beyond. *Global Policy*, 9(4), 527–537.
- Hickmann, T. (2016). *Rethinking authority in global climate governance: How transnational climate initiatives relate to the international climate regime.* Routledge.
- Hickmann, T. (2017). The reconfiguration of authority in global climate governance. *International Studies Review*, 19(3), 430–451.
- Hoffmann, M. (2011). *Climate governance at the crossroads: Experimenting with a global response after Kyoto.* Oxford University Press.
- Höhne, N., Gidden, M. J., den Elzen, M., Hans, F., Fyson, C., Geiges, A., Jeffery, M. L., Gonzales-Zuñiga, S., Mooldijk, S., Hare, W., & Rogelj, J. (2021). Wave of net zero emission targets opens window to meeting the Paris Agreement. *Nature Climate Change*, 11, 820–822. <https://doi.org/10.1038/s41558-021-01142-2>
- Hovi, J., Sprinz, D. F., Sælen, H., & Underdal, A. (2016). Climate change mitigation: A role for climate clubs? *Palgrave Communications*, 2(1), Article 16020.
- Hsu, A., Höhne, N., Kuramochi, T., Roelfsema, M., Weinfurter, A., Xie, Y., Lütkehermöller, K., Chan, S., Corfee-Morlot, J., Drost, P., Faria, P., Gardiner, A., Gordon, D. J., Hale, T., Hultman, N. E., Moorhead, J., Reuvers, S., Setzer, J., Singh, N., . . . Widerberg, O. (2018). A research roadmap for quantifying non-state and subnational climate mitigation action. *Nature Climate Change*, 9(1), 11–17. <https://doi.org/10.1038/s41558-018-0338-z>
- Intergovernmental Panel on Climate Change. (2018). *Global warming of 1.5 °C: 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, sustainable development, and efforts to eradicate poverty.* Cambridge University Press.

- Intergovernmental Panel on Climate Change. (2022). *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.
- Jakob, M. (2021). Why carbon leakage matters and what can be done against it. *One Earth*, 4(5), 609–614.
- Jordan, A., & Huitema, D. (2014). Innovations in climate policy: The politics of invention, diffusion, and evaluation. *Environmental Politics*, 23(5), 715–734.
- Kriegler, E., Bertram, C., Kuramochi, T., Jakob, M., Pehl, M., Stevanović, M., Höhne, N., Luderer, G., Minx, J. C., Fekete, H., Hilaire, J., Luna, L., Popp, A., Steckel, J. C., Sterl, S., Yalew, A. W., Dietrich, J. P., & Edenhofer, O. (2018). Short term policies to keep the door open for Paris climate goals. *Environmental Research Letters*, 13(7), Article 074022. <https://doi.org/10.1088/1748-9326/aac4f1>
- Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K. L., Kram, T., Riahi, K., Winkler, H., & van Vuuren, D. (2014). A new scenario framework for climate change research: The concept of shared climate policy assumptions. *Climatic Change*, 122(3), 401–414.
- Lamb, W. F., Wiedmann, T., Pongratz, J., Andrew, R., Crippa, M., Olivier, J. G. J., Wiedenhofer, D., Mattioli, G., Khourdajie, A. A., House, J., Pachauri, S., Figueroa, M., Saheb, Y., Slade, R., Hubacek, K., Sun, L., Ribeiro, S. K., Khennas, S., de la Rue du Can, S., . . . Minx, J. (2021). A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *Environmental Research Letters*, 16(7), 073005. <https://doi.org/10.1088/1748-9326/abee4e>
- Le Quéré, C., Peters, G. P., Friedlingstein, P., Andrew, R. M., Canadell, J. G., Davis, S. J., Jackson, R. B., & Jones, M. W. (2021). Fossil CO<sub>2</sub> emissions in the post-Covid-19 era. *Nature Climate Change*, 11(3), 197–199. <https://doi.org/10.1038/s41558-021-01001-0>
- Luderer, G., Vrontisi, Z., Bertram, C., Edelenbosch, O. Y., Pietzcker, R. C., Rogelj, J., De Boer, H. S., Drouet, L., Emmerling, J., Fricko, O., Fujimori, S., Havlík, P., Iyer, G., Keramidas, K., Kitous, A., Pehl, M., Krey, V., Riahi, K., Saveyn, B., . . . Kriegler, E. (2018). Residual fossil CO<sub>2</sub> emissions in 1.5–2 °C pathways. *Nature Climate Change*, 8(7), 626–633. <https://doi.org/10.1038/s41558-018-0198-6>
- Masood, E., & Tollefson, J. (2021, November 5). COP26 climate pledges: What scientists think so far. *Nature*. <https://www.nature.com/articles/d41586-021-03034-z>
- Messner, D., Schellnhuber, J., Rahmstorf, S., & Klingensfeld, J. D. (2013). The budget approach: A framework for a global transformation towards a low carbon economy. In H.-J. Koch, D. König, J. Sanden, & R. Verheyen (Eds.), *Climate change and environmental hazards related to shipping: An international legal framework* (pp. 9–33). Brill Nijhoff.
- Morgan, J., Dagnet, Y., Höhne, N., Oberthür, S., & Li, L. (2014). *Race to the top: Driving ambition in the post-2020 international climate agreement*. World Resources Institute. <https://www.wri.org/research/race-top-driving-ambition-2015-climate-agreement>
- Nordhaus, W. (2015). Climate clubs: Overcoming free-riding in international climate policy. *American Economic Review*, 105(4), 1339–1370.
- Oberthür, S. (2001). Linkages between the Montreal and Kyoto protocols: Enhancing synergies between protecting the ozone layer and the global climate. *International Environmental Agreements*, 1(3), 357–377.
- 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>
- Paroussos, L., Mandel, A., Fragkiadakis, K., Fragkos, P., Hinkel, J., & Vrontisi, Z. (2019). Climate clubs and the macro-economic benefits of international cooperation on climate policy. *Nature Climate Change*, 9(7), 542–546.
- Parson, E. (2003). *Protecting the ozone layer: Science and strategy*. Oxford University Press.
- Rayner, S. (2010). How to eat an elephant: A bottom-up approach to climate policy. *Climate Policy*, 10(6), 615–621.
- Riahi, K., Bertram, C., Huppmann, D., Rogelj, J., Bosetti, V., Cabardos, A. M., Deppermann, A., Drouet, L., Frank, S., Fricko, O., & Fujimori, S. (2021). Cost and attainability of meeting stringent climate targets without overshoot. *Nature Climate Change*, 11(12), 1063–1069.
- Riahi, K., van Vuuren, D., Kriegler, E., Edmonds, J., O’Neill, B., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., & Lutz, W. (2017). The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, 42(1), 153–168.
- Roelfsema, M., Fekete, H., Höhne, N., den Elzen, M., Forsell, N., Kuramochi, T., de Coninck, H., & van Vuuren, D. (2018). Reducing global GHG emissions by replicating successful sector examples: The “good practice policies” scenario. *Climate Policy*, 18(9), 1103–1113.
- 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), Article 2096. <https://doi.org/10.1038/s41467-020-15414-6>
- Rogelj, J., Geden, O., Cowie, A., & Reisinger, A. (2021).

- Three ways to improve net-zero emissions targets. *Nature*, 591(7850), 365–368.
- Rogelj, J., Popp, A., Calvin, K. V., Luderer, G., Emmerling, J., Gernaat, D., Fujimori, S., Strefler, J., Hasegawa, T., Marangoni, G., Krey, V., Kriegler, E., Riahi, K., van Vuuren, D. P., Doelman, J., Drouet, L., Edmonds, J., Fricko, O., Harmsen, M., . . . Tavoni, M. (2018). Scenarios towards limiting global mean temperature increase below 1.5 °C. *Nature Climate Change*, 8(4), 325–332. <https://doi.org/10.1038/s41558-018-0091-3>
- Sachs, N. M. (2019). The Paris Agreement in the 2020s: Breakdown or breakup. *Ecology Law Quarterly*, 46(3), 865–909.
- Schenuit, F., Gilligan, J., & Viswamohan, A. (2021). A scenario of solar geoengineering governance: Vulnerable states demand, and act. *Futures*, 132, Article 102809.
- Shen, S. V. (2021). Integrating political science into climate modeling: An example of internalizing the costs of climate-induced violence in the optimal management of the climate. *Sustainability*, 13(19), Article 10587.
- Skea, J., Shukla, P., Al Khourdajie, A., & McCollum, D. (2021). Intergovernmental Panel on Climate Change: Transparency and integrated assessment modeling. *Wiley Interdisciplinary Reviews: Climate Change*, 12(5), Article e727.
- Streck, C., Keenlyside, P., & Von Unger, M. (2016). The Paris Agreement: A new beginning. *Journal for European Environmental & Planning Law*, 13(1), 3–29.
- UN chief welcomes China–US pledge to cooperate on climate action. (2021, November 10). *US News*. <https://news.un.org/en/story/2021/11/1105512>
- United Nations. (1992). *United Nations framework convention on climate change* (FCCC/INFORMAL/84). <https://unfccc.int/resource/docs/convkp/conveng.pdf>
- United Nations. (2021). *Glasgow Climate Pact* (Decision –/CP.26). [https://unfccc.int/sites/default/files/resource/cop26\\_auv\\_2f\\_cover\\_decision.pdf](https://unfccc.int/sites/default/files/resource/cop26_auv_2f_cover_decision.pdf)
- United Nations Environment Programme. (2018). *Emissions gap report 2018*.
- United Nations Framework Convention on Climate Change. (1997). *Kyoto Protocol to the United Nations Framework Convention on Climate Change* (FCCC/CP/1997/L.7/Add.1). <https://digitallibrary.un.org/record/250111?ln=en#record-files-collapse-header>
- United Nations Framework Convention on Climate Change. (2015). *Adoption of the Paris Agreement* (FCCC/CP/2015/L.9/Rev.1). <https://digitallibrary.un.org/record/831039>
- United Nations Framework Convention on Climate Change. (2021). *Nationally determined contributions under the Paris Agreement: Synthesis report by the Secretariat* (FCCC/PA/CMA/2021/8). [https://unfccc.int/sites/default/files/resource/cma2021\\_08E.pdf](https://unfccc.int/sites/default/files/resource/cma2021_08E.pdf)
- van Asselt, H. (2016). The role of non-state actors in reviewing ambition, implementation, and compliance under the Paris Agreement. *Climate Law*, 6(1/2), 91–108.
- van Asselt, H., & Zelli, F. (2014). Connect the dots: Managing the fragmentation of global climate governance. *Environmental Economics and Policy Studies*, 16(2), 137–155.
- 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, Article 102191.
- van den Berg, N. J., van Soest, H. L., Hof, A. F., den Elzen, M. G. J., van Vuuren, D. P., Chen, W., Drouet, L., Emmerling, J., Fujimori, S., Höhne, N., Köberle, A. C., McCollum, D., Schaeffer, R., Shekhar, S., Vishwanathan, S. S., Vrontisi, Z., & Blok, K. (2020). Implications of various effort-sharing approaches for national carbon budgets and emission pathways. *Climatic Change*, 162(4), 1805–1822. <https://doi.org/10.1007/s10584-019-02368-y>
- van Sluiseveld, M. A. E., Hof, A. F., Carrara, S., Geels, F. W., Nilsson, M., Rogge, K., Turnheim, B., & van Vuuren, D. P. (2020). Aligning integrated assessment modelling with socio-technical transition insights: An application to low-carbon energy scenario analysis in Europe. *Technological Forecasting and Social Change*, 151, Article 119177. <https://doi.org/10.1016/j.techfore.2017.10.024>
- van Soest, H. L., Aleluia Reis, L., Baptista, L. B., Bertram, C., Després, J., Drouet, L., den Elzen, M., Fragkos, P., Fricko, O., Fujimori, S., Grant, N., Harmsen, M., Iyer, G., Keramidas, K., Köberle, A. C., Kriegler, E., Malik, A., Mittal, S., Oshiro, K., . . . van Vuuren, D. P. (2021). Global roll-out of comprehensive policy measures may aid in bridging emissions gap. *Nature Communications*, 12(1), Article 6419. <https://doi.org/10.1038/s41467-021-26595-z>
- van Vuuren, D. P., Riahi, K., Calvin, K., Dellink, R., Emmerling, J., Fujimori, S., KC, S., Kriegler, E., & O’Neill, B. (2017). The shared socio-economic pathways: Trajectories for human development and global environmental change. *Global Environmental Change*, 42, 148–152. <https://doi.org/10.1016/j.gloenvcha.2016.10.009>
- Victor, D. G. (2011). *Global warming gridlock: Creating more effective strategies for protecting the planet*. Cambridge University Press.
- Vrontisi, Z., Luderer, G., Saveyn, B., Keramidas, K., Lara, A. R., Baumstark, L., Bertram, C., de Boer, H. S., Drouet, L., Fragkiadakis, K., Fricko, O., Fujimori, S., Guivarch, C., Kitous, A., Krey, V., Kriegler, E., Broin, E. Ó., Paroussos, L., & van Vuuren, D. (2018). Enhancing global climate policy ambition towards a 1.5 °C stabilization: A short-term multi-model assessment. *Environmental Research Letters*, 13(4), Article 044039. <https://doi.org/10.1088/1748-9326/aab53e>

Weikmans, R., Van Asselt, H., & Roberts, J. T. (2020). Transparency requirements under the Paris Agreement and their (un)likely impact on strengthening the ambition of nationally determined contributions (NDCs). *Climate Policy*, 20(4), 511–526.

Weitzman, M. L. (2014). Can negotiating a uniform carbon price help to internalize the global warming externality? *Journal of the Association of Environmental and Resource Economists*, 1(1/2), 29–49.

Widerberg, O., & Pattberg, P. (2015). International coop-

erative initiatives in global climate governance: Raising the ambition level or delegitimizing the UNFCCC? *Global Policy*, 6(1), 45–56.

Young, O. R. (2016). The Paris Agreement: Destined to succeed or doomed to fail? *Politics and Governance*, 4(3), 124–132.

Zelli, F. (2011). The fragmentation of the global climate governance architecture. *Wiley Interdisciplinary Reviews: Climate Change*, 2(2), 255–270.

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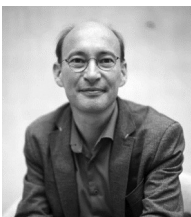
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