ELEVATE: Enabling and Leveraging Climate Action Towards Net-Zero Emissions

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D2.2 – Ex-post evaluation of climate policies and identification of barriers and milestones towards climate neutrality

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Dissemination Level		
PU	Public	√

1. Changes with respect to the description of work

The task evaluates the implementation of climate policies and NDCs to identify barriers, drivers and milestones towards carbon neutrality. With empirical analysis, the first subtask will assess the levels of ambition stated in the updated NDCs on feasibility concerns and identify the main drivers and barriers of implementing the intended policies. This framework is **expanded to evaluate the national feasibility of global scenarios** [12]. Some of the key pledges and targets within NDCs can be evaluated (e.g., renewable energy targets, afforestation goals) using this framework, using a specific set of indicators. **We will identify regions and countries with the highest mismatch between ambition and the overall mitigation capacity.** The second subtask will analyse **the recent NDC update cycle to identify which conditions and factors enable NDC ambition raising.** We expand existing work on NDC assessments [24, 25] by asking **why and how much countries have increased their ambition**. We will explore factors, including economic responsibility (e.g. fossil fuel-related jobs, economic capacity), environmental responsibility (e.g. biodiversity, land availability), social inclusiveness (energy poverty, income inequality), and ambition of the first NDC to identify key issues that can support future ambition raising. Our findings will feed into Task 2.3 and other WPs (e.g. WP6 on revised SSPs) to better consider country-specific constraints, drivers and barriers to policy implementation in scenario analyses.

Although there is no substantial change in the scope of the task, additional research was published on updated NDCs between the proposal preparation and the positive grant evaluation. Specifically, others investigated determinants of NDC ambition raising to find that countries engaging in stakeholder consultations when developing their updated NDCs are more likely to enhance their targets (Peterson et al., 2023). This research substantially overlaps with the original scope of one of the subtasks described above. Therefore, we adjusted our methods and approaches to ensure our findings are building on the existing literature. We focused on the past ambition raising cycle and on the relationship between adopted policies and the NDC targets (Section 2).

2. Dissemination and uptake

This deliverable is public and will be available at ELEVATE's website.

Some of the work prepared for this report was used in the report intended to support the scenario analysis of the EU advisory board (Byers et al., 2023).

The key findings of this task are or will be also published open-access in peer-reviewed journals.

The work on coal and gas phase-out was presented during the Integrated Assessment Modeling Consortium (IAMC) annual meeting in Venice in November 2023 in the transition-themed session The presentation was titled “Exploring more socio-politically feasible coal and gas phase-out pathways”.

The work on the sequence of policies and targets in the previous NDC ambition-raising cycle has been presented in an ELEVATE co-creation workshop in February 2024 and at COP28. The presentation at COP28 was titled “Progress implementing the Paris Agreement”.

2. Short summary of results (<250 words)

This report presents an approach for evaluating climate policies by comparing observed data with modelled projections. It highlights the discrepancies between enacted policies and their outcomes, and identifies key barriers and enablers. The observed data includes current policies, NDCs (Nationally Determined Contributions) and promised goals, as well as actual policy outcomes like emissions reductions and coal reduction trajectories. These observed data points are compared with results from Integrated Assessment Models (IAMs), both national and global, as well as other modelling approaches, i.e. in our work we combine many different lines of evidence.

We identify two major gaps: the gap between enacted policies and actual outcomes, and the gap between NDC ambition and current policies, particularly in fossil fuel-dependent countries.

The insights from different models suggest that assumptions in the models can be improved from a feasibility perspective. Recommendations include updates on solar energy, more feasible coal decline rates, and increased focus on biomass, hydrogen, CCS (Carbon Capture and Storage), and natural gas sensitivities.

Overall, our work underscores the importance of integrating observed data and modelled projections to understand the effectiveness of climate policies and identify pathways to overcome policy lock-ins and achieve more ambitious climate goals. It highlights how different lines of evidence could be used to make sure that there is a dialogue between work conducted in integrated assessment models and the policy implementation in the real world.

4. Evidence of accomplishment

See report below.

Version log

Version	Date	Released by	Nature of Change
1	20-06-2024	Elina Brutschin	First draft
2	06-07-2024	Elina Brutschin	Final version for submission, based on internal review

Table of contents

1. Introduction

In this report, we evaluate climate policies using a variety of tools to gain a better understanding of potential barriers as well as key enablers, but also to create a feedback loop between different types of tools (Where are the main disagreements across the different sources of evidence? Which sources particularly depart from the assumptions discussed in other sources?) to improve our collective knowledge. Countries are striving to achieve the climate targets of the Paris Agreement by proposing and updating Nationally Determined Contributions (NDCs), broader emission targets, and specific sectoral goals such as increasing the share of renewables or phasing out fossil fuels. Integrated Assessment Models (IAMs) have played a significant role when exploring the future by assessing the implications of current policies, the expected outcomes of pledged NDCs (Aleluia Reis & Tavoni, 2023; den Elzen et al., 2022; Roelfsema et al., 2020; van Soest et al., 2021), and more ambitious efforts aimed at achieving the 1.5°C target (Rogelj et al., 2018).

Analysing the past can help us understand the characteristics of countries with more ambitious climate targets (Lamb & Minx, 2020) and the key drivers of more ambitious coal phase-outs (Brutschin et al., 2022). Recently, past observations have also been used to benchmark scenario outputs, assessing whether certain trajectories are feasible in the real world (Jewell & Cherp, 2023; Schenuit et al., 2024).

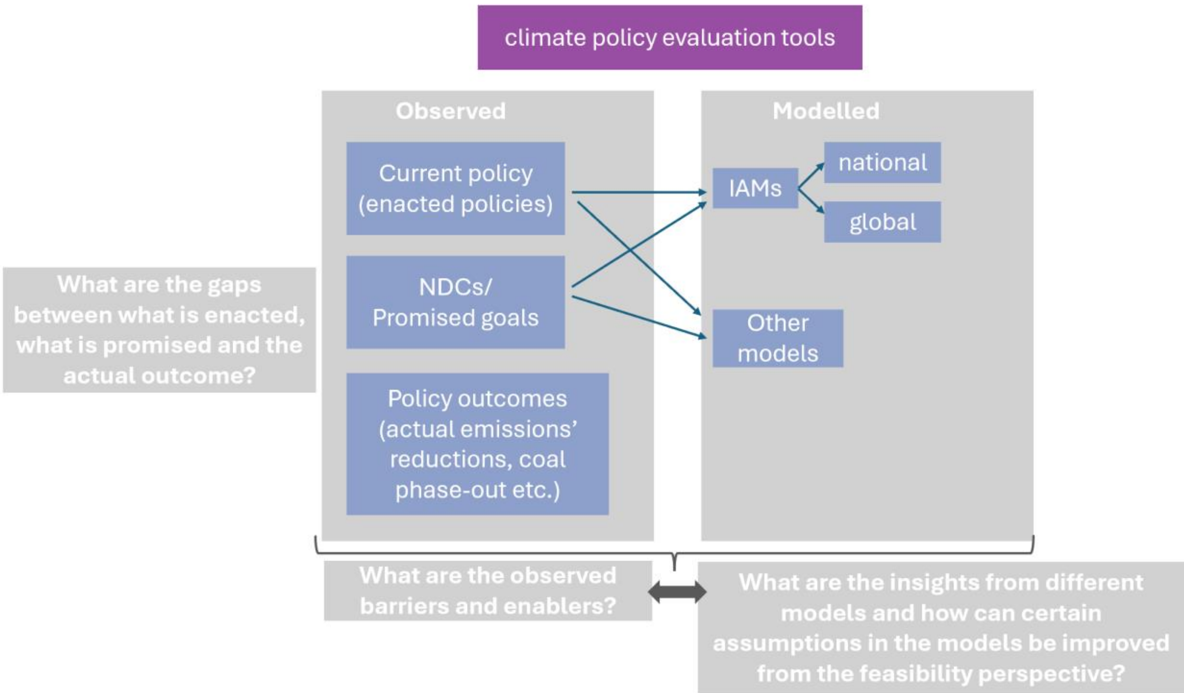

Figure 1 Overview of the tools used for evaluation of climate policies

We build on these past efforts by linking different streams and approaches to identify insights from evaluations of climate policies. Figure 1 illustrates the connections between various tools. Greenhouse gas emissions projections help quantify the emission implications of certain policies, which is particularly helpful for understanding the gap between currently enacted climate policies and the promises made in NDCs, and identifying the characteristics of countries that raise their ambition over time. This analysis is detailed in Section 2, where we find that countries heavily reliant on gas and oil exports or on coal in electricity supply are more likely to fail to increase their ambition.

In Section 3, we focus on a wider range of indicators of modelled NDCs and compare insights from different lines of evidence, such as outputs from global models, national models where possible, other types of models, and pledges indicated by countries. In this analysis, we find particularly high mismatch in the context of future solar, coal and gas trajectories, and high uncertainty in the context of CCS, hydrogen and biomass. This exercise provides an important feedback to the IAM community regarding possible improvements in the next generation of scenarios, whether exploring the implications of updated NDCs or developing more regionally differentiated narratives aimed at reaching 1.5°C or staying well below 2°C.

2. Enablers and Barriers of NDC ambition raising

Disclaimer

This text is adapted from the publications:

- Nascimento, L. et al. (2023) 'Comparing the Sequence of Climate Change Mitigation Targets and Policies in Major Emitting Economies', Journal of Comparative Policy Analysis: Research and Practice, pp. 1–18. Available at: https://doi.org/10.1080/13876988.2023.2255151.

- Nascimento, L. et al. (2024) 'Climate policy in 2023', Nature Reviews Earth & Environment, 5(4), pp. 255–257. Available at: https://doi.org/10.1038/s43017-024-00541-1.

Additional information about methods and emission scenarios is presented in detail in the main publications.

2.1. Motivation

In 2023, countries reached agreements on additional mechanisms for international cooperation, such as the Just Energy Transition Partnerships (JETPs) and the Loss and Damage Fund. Additionally, many major emitters adopted new climate policies aimed at driving future emissions reductions. However, climate policy also regressed, as demonstrated by the UK's backtracking on its climate commitments. This apparent tug-of-war—where positive developments and negative developments cancel each other out—makes halving emissions by 2030 nearly impossible, leading to slow or stagnant global progress toward the Paris Agreement.

Additional international cooperation initiatives and climate policies without substance do not necessarily reduce actual emissions and, in some cases, could hinder progress. Some initiatives, such as the Oil and Gas decarbonisation Charter, will likely prolong the use of fossil fuels when they focus on improving the efficiency of fossil fuel use instead of adopting well-established technologies and behaviours to phase them out completely. Similarly, countries that set ambitious visions without adopting corresponding policies are another example of measures that lack substance and delay global progress.

Evaluating progress at the national and international level remains fundamental to identify bottlenecks to accelerate short-term climate action.

Global analyses show that an ambition gap exists between countries' updated NDCs and adopted policies (den Elzen et al., 2022). However, country-specific analyses are better suited to inform and guide national mitigation efforts. For example, countries that are projected to meet their NDC are well positioned to increase ambition. Alternatively, countries projected to miss their targets need to adopt more stringent policies. Several studies have investigated the warming effect of updated NDCs (Höhne et al., 2021; Meinshausen et al., 2022) but no peer-reviewed, multi-country analysis to date investigated whether individual countries are expected to meet their updated NDCs under currently adopted policies. Up-to-date assessments of countries' policies and NDC targets is key to improve accountability under the Paris Agreement. Since countries' NDCs are influenced by their national circumstances (Tørstad et al., 2020). In our analysis, we evaluate if national circumstances also affect ambition raising.

In our research, we prepared and compared emission projections implied by countries' adopted policies and NDC targets. First, we developed a framework to identify countries ambition raising patterns that consider their progress towards both original and updated targets. Second, we prepared up-to-date emission projections up to 2030 under NDC targets and adopted policies. These projections show whether countries are expected to meet their NDCs and enable applying the proposed framework to identify ambition raising patterns. Finally, we analysed whether architectures of climate policy constraints (Lamb & Minx, 2020) are associated with countries' ambition raising patterns. In this process, we also reviewed recent international and national climate policy context.

2.2. Ambition raising framework

The Paris Agreement establishes an ambition raising mechanism for countries to improve their domestic mitigation efforts, which here refer to countries' NDCs and policies. The mechanism is based on the principle that more ambitious NDCs guide the adoption of more stringent national policies to reduce emissions (see below).

We identify four ambition raising patterns based on this idealized framework:

1. Ambition raising follows sufficient policy adoption: includes countries that follow the ambition raising sequence up to stage III. These countries are projected to meet their original NDCs and submitted a more ambitious updated NDC. However, adopted policies remain insufficient to meet the updated NDC. These countries have a good track record and have set updated NDCs that guide additional mitigation efforts.
2. Ambition raising without sufficient policy adoption: includes countries that submitted more ambitious updated NDCs. However, policies remain insufficient to meet the original NDC. These countries focus on the ambition raising element of their pledges but overlook or delay national policy adoption. Meeting their updated NDCs requires substantial climate policy expansion.

3. **Ambition raising with limited effect**: includes countries that are already projected to meet their updated NDCs. The updated NDCs are still expected to positively influence policy adoption, since they represent an improvement compared to original targets. However, in this case updated NDCs result in more emissions compared to policies and are not expected to guide substantial additional climate change mitigation efforts.
4. **No ambition raising**: This category includes countries that did not increased ambition of their original NDCs. For example, countries that did not submit updated NDCs or submitted updated NDCs including the same emission target. This category includes countries that missed the opportunity to raise ambition of their NDC independently on whether they are expected to meet their original NDCs.

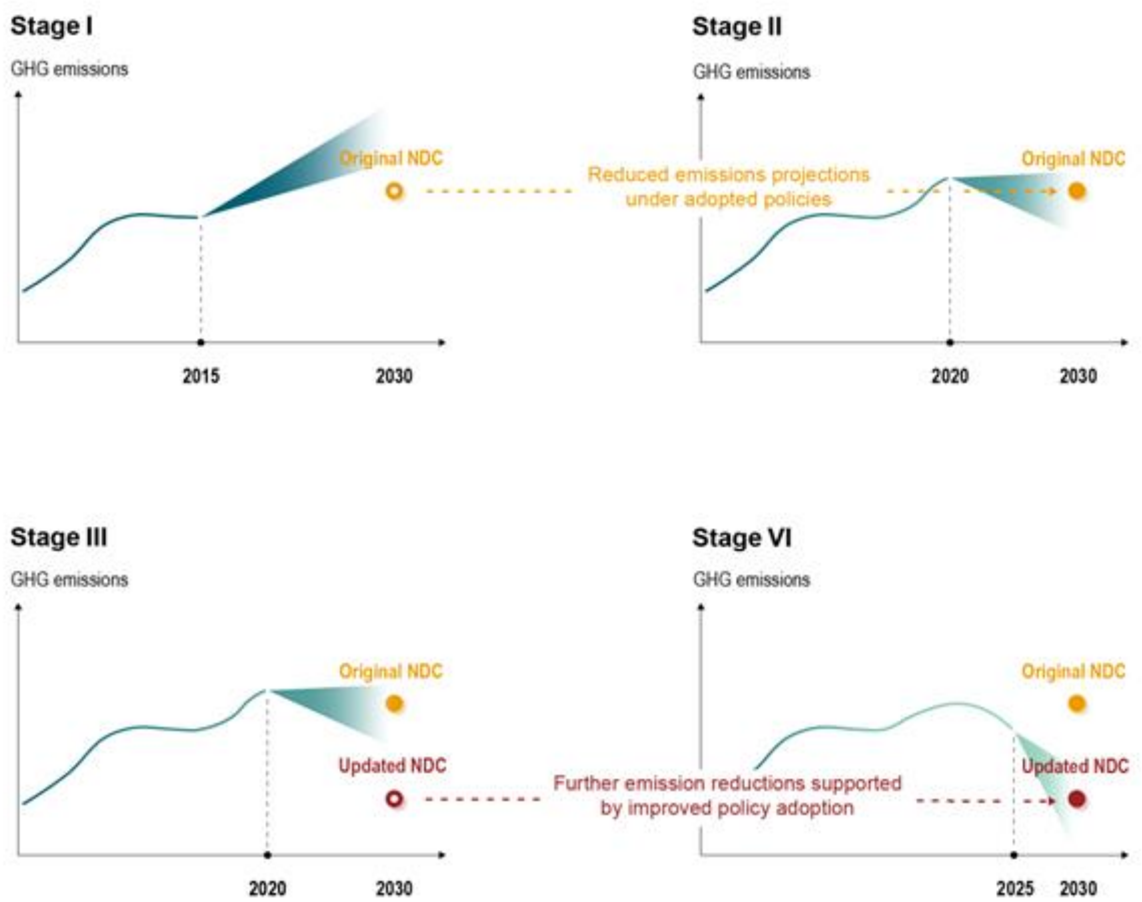

Figure 2: Sequencing ambition raising and policy adoption reduces emissions over time.

Instead of focusing on individual constraints (or enablers), we relied on previous research that identified national architectures of climate policy constraint. These architectures are “mutually reinforcing national conditions that are stable and resistant to intervention” and affect climate policy (Lamb and Minx, 2020).

2.3. Results

Over one-quarter of the countries analyzed fall into the ‘ambition raising follows sufficient policy adoption’ category (Figure 3). These countries are projected to meet their original NDCs but fall short to meet the updated one. Australia, Argentina, the European Union, Japan, the United Arab Emirates, the United Kingdom and South Africa have all used the latest NDC update to submit targets that take them beyond current mitigation efforts. The United Kingdom was still part of the European Union when the Paris Agreement was adopted and therefore has no original NDC. We considered it to have the same status of the European Union when it comes to its original NDC. Most of these countries are high-income, OECD countries with the lowest estimated level of constraints.

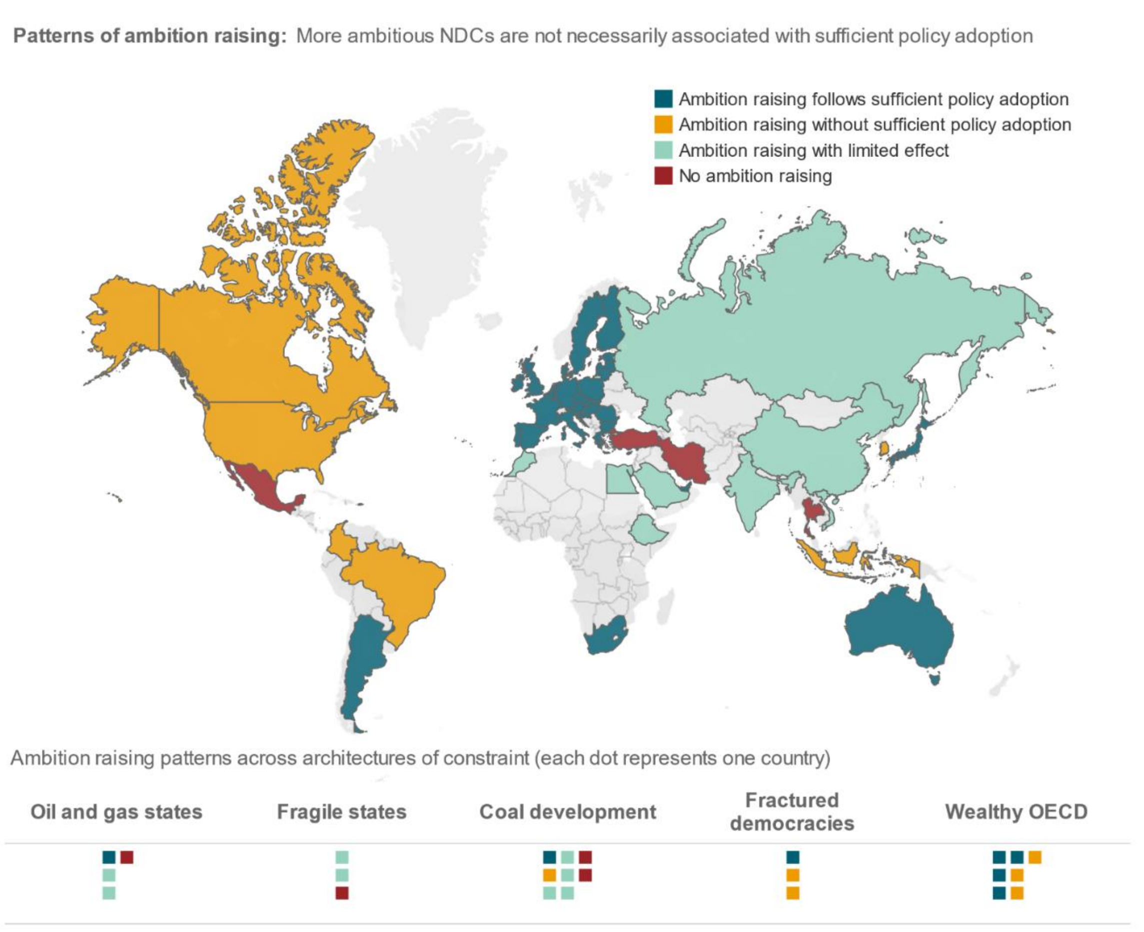

Figure 3: Patterns of ambition raising and associated architectures of climate policy constraint.

Almost one-quarter of the countries analysed fall into the 'ambition raising without sufficient policy adoption' (Figure 3). These countries adopted more ambitious updated NDCs without adopting sufficient policies to meet the original NDC. Countries that fall in this category are Brazil, Colombia, Canada, Indonesia, the United States and South Korea. Some of these countries, Brazil and Colombia, are considered fractured democracies, which usually have democratic systems combined with low trust in institutions. Our findings suggest that although this does not hinder ambition raising, it does increase barriers to implement national policy and action to meet NDCs. However, most countries in the ambition without implementation group are wealthy OECD countries. Notably, this group includes the United States, which is currently the world's second biggest emitter, and Canada, one the countries with the highest per capita emissions.

Almost one-third of the countries analysed fall into the category 'ambition raising with limited effect' (Figure 3). These countries adopted more ambitious update NDCs and are directly projected to meet them. These countries are China, Morocco, Egypt, India, Russia, Saudi Arabia, and Viet Nam. Egypt does not have an emission target in its original NDC. In our analysis, we considered that Egypt raised NDC ambition by adding emission targets. We also considered that Ethiopia increased its ambition by submitting an unconditional target. The main similarity within this country group is the reliance on fossil fuels. Several countries rely on coal to power their economic growth and improve energy access, while others strongly rely on oil and gas extraction revenues. There are varying degrees of democracy, corruption, and climate policies within this group. However, according to our findings, their substantial national constraints are associated with more conservative target setting. Although, the strategy to set unambitious targets allows these countries to meet international requirements to improve NDC ambition, these targets will probably have limited effect guiding additional emissions reductions.

Finally, some countries (Iran, Mexico, Thailand and Turkey) failed to meet the call to raise the ambition of their NDCs (Figure 3). Iran has not ratified the Paris Agreement; Turkey has but did not submit an updated NDC; Thailand and Mexico submitted updated NDCs containing the same 2030 emission target. Iran and Turkey's original NDCs have targets that result in emissions above those implied by policies, Mexico is also projected to meet its targets. Thailand has a target that requires the adoption of additional policies. This suggests that the former three countries are well suited to improve the ambition of their NDCs.

2.4. Summary of insights

The Paris Agreement relies on sequences of NDC ambition raising and adoption of national climate policies. Evaluating NDC ambition progression at the global level shows progress in the right direction but hides important patterns observable at the national level. We find that countries need to better align international and national goals for the ambition raising cycle of the Paris Agreement to work. Appropriate sequencing of ambition raising and coherent policy adoption is urgently needed to translate the Paris Agreement into action.

Most countries need to implement additional policies to meet their NDCs.

Out of the 25 countries analysed, eighteen are projected to meet their original targets and eleven are projected to meet their updated NDCs. A reduction in the number of countries projected to meet their NDCs results from NDC updates representing a progression compared to the original ones. More outstanding are the eleven countries projected to meet their updated NDCs at the time they were submitted. In this case, both original and updated NDCs still lead to emissions above current policy emissions projections in 2030. These findings suggest that several NDC updates will have a limited effect on guiding additional mitigation policies. Under this perspective, they fail in their function to bridge current national efforts to the long-term goal of the Paris Agreement, since ambitious NDCs guide short-term action and reduce pressure on post-2030 emissions reduction rates.

Climate policy coherence within and among countries remain necessary to accelerate global climate action.

A tug of war between negative developments in some countries and positive developments in others is insufficient. Only with all countries moving in the same direction will climate policy reach the pace needed to safeguard sustainable development for all.

Domestic developments are often contradictory, as demonstrated by the simultaneous expansion of coal and renewables in major emitters. Ensuring coherent climate policies within countries' borders remains fundamental to meeting the goals of the Paris Agreement.

New initiatives and mechanisms to support international cooperation, such as the Global Renewables and Energy Efficiency Pledge, help to advance national and global climate policy but they will require credible national action to back them up.

The ambition raising cycle requires additional scrutiny

Additionally, in one-quarter of the countries analysed ambition raising does not follow sufficient policy adoption. Several countries have not yet adopted policies to meet their original NDCs, which were set over seven years ago. For the Paris Agreement ambition raising mechanism to work, countries need to adopt policies to meet their targets. Increasing the ambition of targets alone widens the credibility gap between international targets and national action and undermines the Paris Agreement. Our results indicate that many countries would need to substantially expand climate policy to meet their own NDCs.

Constraints to national climate policy probably also hinder international ambition raising.

Finally, we also investigated the relationship between these patterns of ambition raising and national constraints to climate policy.

We found that countries with more national constraints are less likely to sequence ambition raising and policy adoption. Oil and gas producing states and countries that currently rely on fossil fuels to support economic growth tend to raise ambition with limited effect (NDC above current policies) or not raise the ambition of their NDC at all. This provides empirical evidence supporting the linkages between international and national climate politics and invites better coordination of these processes to ensure NDC ambition is followed by national policy adoption.

3. Regional and National Feasibility Evaluations

3.1. Conceptual Framework

Understanding what might be feasible in medium to long-term climate policies is challenging. Integrated Assessment Models (IAMs) have been key tools in exploring the necessary changes and transformations in the energy system to meet specific climate targets, such as for example by systematically assessing the implication of the announced pledges in terms of reaching specific climate targets (Roelfsema et al., 2020; van Soest et al., 2021). However, in recent years, IAM outputs have faced substantial criticism from various perspectives, leading to calls for a more systematic evaluation of which IAM pathways might be difficult to implement in the real world or which assumptions and elements of the transformations depicted in the IAMs, especially in certain specific sectors, might be politically not feasible (Brutschin, Pianta, et al., 2021; Jewell & Cherp, 2023).

At the same time, countries and regions set their targets and signal these through national goals, reports on climate mitigation strategies, mentions in Nationally Determined Contributions (NDCs) or Long Term Strategies (LTS). Some of these goals, such as the hydrogen scale-up by 2030 in the EU indicated in the reports by the European Commission, might be quite ambitious and challenging to achieve as is shown in studies that put this goal in the context of the observed rates of upscale in other technologies (Odenweller et al., 2022).

By applying a feasibility framework that combines different lines of evidence, we can assess where major feasibility concerns may arise, either from what is reported in IAMs or what is announced and pledged by certain countries and regions, and determine whether these ambitions are realistic or fall short, or whether the level of uncertainty is too high and would require additional research.

Feasibility is a complex concept, and operationalizing it is challenging. The feasibility evaluation of IAMs is limited by the type of variables the models report, and each scenario is based on a set of stylized, internally consistent assumptions. To address these challenges, Brutschin et al. (2021) developed a multidimensional approach for ex-post scenario evaluation, focusing on geophysical, technological, economic, socio-cultural, and institutional dimensions to identify potential feasibility concerns and trade-offs. This framework's main strength is its flexibility; it provides general guidance on which dimensions to examine and which indicators to include, while leaving the choice of specific thresholds and benchmarks open. This allows for the application and combination of various methods and the inclusion or exclusion of indicators based on specific research interests. The framework's initial application evaluated global 1.5°C scenarios as a proof of concept (Brutschin et al. 2021) and has since been applied to post-Glasgow scenarios (van de Ven et al., 2022), scenarios incorporating Direct Air Capture and Storage technology (Gidden et al., 2023) and report developed for the EU Advisory Board (Byers et al., 2023).

Given that in this analysis we focus on major regions and countries, we have reduced the number of indicators explored compared to the original framework developed by Brutschin et al. (2021). Instead of 24 indicators, we focus on seven, selected based on their political relevance and usage in national or related policy documents and strategies. For deriving thresholds, we extended our analysis to include various lines of evidence by comparing insights from different models, strategic documents, and historical observations.

3.2. Scenarios, models, and indicators

To evaluate scenarios, we utilized various sources and types of models. The primary source of data was the AR6 scenario database (Byers et al., 2022), which includes both global and national Integrated Assessment Models (IAMs). We concentrated on scenarios that include the implications of Nationally Determined Contributions (NDC), noting that these NDCs were only updated up to the AR6 and do not distinguish between conditional and unconditional NDCs.

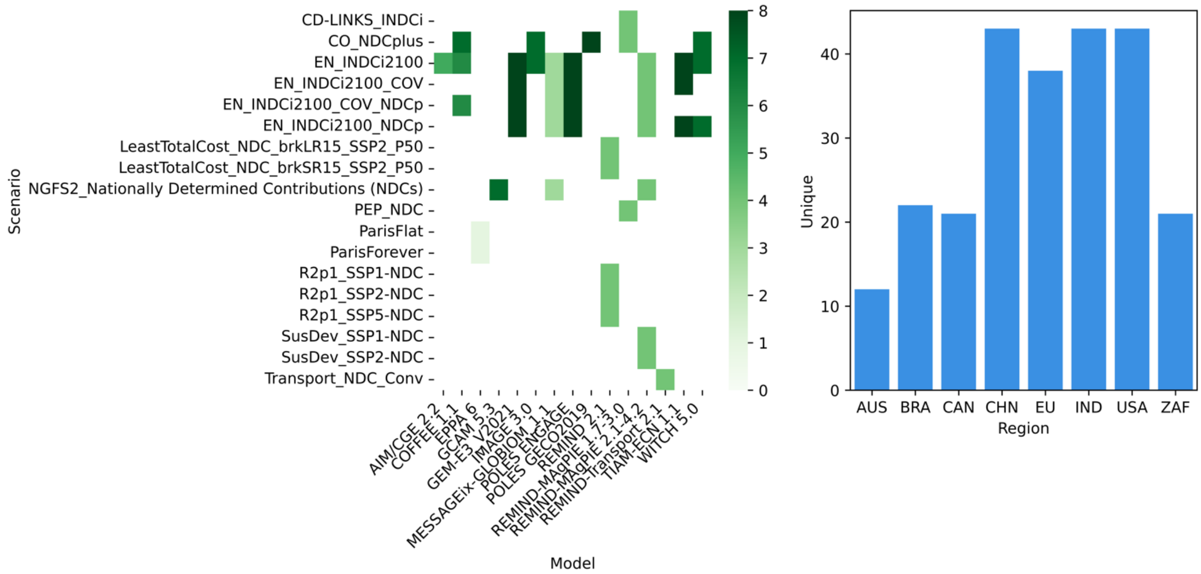

Figure 4. Overview of policy scenarios and global IAM models evaluated and the availability of regional data.

Global IAM scenarios were identified through a policy classification provided in the IPCC Working Group III, Annex III, Table 17. From this classification, we selected the P1c category (developed for global IAMs), which consists of scenarios without globally coordinated climate policy (no global carbon price) but includes NDCs. Initially, 160 scenarios passed the vetting process, and among these, 56 scenarios included climate assessments. We then used downscaled data for key regions that were reported in ISO3 AR6 database, this reduced the number of scenarios to 45 (see Table 2). Figure 4 illustrates the combinations of scenarios and models within this list and highlights the unique scenario country/region coverage. The AR6 scenario database ISO3 does not show policy classifications for national IAM scenarios, so we selected them by searching for 'NDC' as a substring. The national models were identified based on the information provided in the IPCC Working Group III (see Table 1). It is important to note that no national scenarios were available for Canada, and no NDC scenarios were available for South Africa.

Table 1. Overview of the national IAM models and scenarios.

Country or Region	National models	# national scenarios
AUS	TIMES-Australia 20.73	1
BRA	BLUES-Brazil 1.0, BLUES-Brazil 2.0	5
CAN	None	0
CHN	AIM/Hub-China 2.2, TIMES-China 2.0	21
EU	PRIMES 1.0, PRIMES_V1	2
IND	AIM/Enduse India 3.1, AIM/Hub-India 2.2	11
USA	GCAM-USA 4.2, GCAM-USA 5.3, GCAM-USA_CDLINKS	4
ZAF	None	0

Table 2. Regional coverage of global IAM scenarios.

Model	AUS	BRA	CAN	CHN	EU	IND	USA	ZAF
REMIND-MAgPIE 2.1-4.2				7	7	7	7	
REMIND 2.1				5	5	5	5	
GCAM 5.3		1	1	1	1	1	1	1
MESSAGEix-GLOBIOM_1.1				5		5	5	
POLES ENGAGE	4	4	4	4	4	4	4	4
WITCH 5.0		3	3	3	3	3	3	3
REMIND-Transport 2.1				1	1	1	1	
GEM-E3_V2021	4	4	4	4	4	4	4	4
EPPA 6					2			
COFFEE 1.1		3	3	3	1	3	3	3
AIM/CGE 2.2		1		1	1	1	1	
TIAM-ECN 1.1	3	3	3	3	3	3	3	3
REMIND-MAgPIE 1.7-3.0				3	3	3	3	
IMAGE 3.0		2	2	2	2	2	2	2
POLES GECO2019	1	1	1	1	1	1	1	1
Total number of scenarios	12	22	21	43	38	43	43	21

We provide an overview of indicators used in this analysis in Table 3. As mentioned above, this is a reduced set compared to the global level analysis in Brutschin et al. (2021) and includes geophysical indicators such as biomass potential, technological indicators such as solar, wind, hydrogen, and carbon sequestration capacity expansion, economic indicators such as coal- and gas-fired electricity phase-out. The reduced set was selected to make to sure to include key policy indicators for which many different lines of evidence are available. For most technologies, we focus on exploring near-term assumptions around the year 2030. However, for biomass and CCS, we extend our focus to the year 2050 due to their critical role as negative emissions technologies and their later uptake in most scenarios.

Table 3. Indicators evaluated in this analysis.

Indicator	Variable in the AR6 database	Year	Unit
Biomass potential	Primary Energy|Biomass	2050	EJ
Solar capacity expansion	Capacity|Electricity|Solar	2030	GW
Wind capacity expansion	Capacity|Electricity|Wind	2030	GW
Hydrogen capacity expansion	Secondary Energy|Hydrogen	2030	EJ
Carbon sequestration capacity expansion	Carbon Sequestration|CCS	2050	Mt
Coal-fired electricity	Secondary Energy|Electricity|Coal	2030	% in electricity
Gas-fired electricity	Secondary Energy|Electricity|Gas	2030	% in electricity

We use several lines of evidence to evaluate the feasibility and uncertainty of national and regional sector-level transitions (Table 4). The types of evidence can be separated into targets and scenarios, which indicate different levels of commitment. Within targets, sector-level NDC targets are assumed to be the strongest commitments, followed by Long Term Strategy (LTS), and region strategies led or endorsed by government ministries. Within other scenarios, we consider global outlooks developed by international institutions (e.g., International Energy Agency (IEA), Asia-Pacific Economic Cooperation (APEC)), domestic outlooks developed by domestic institutions (e.g., the US Energy Information Administration (EIA)), and other literature.

Table 4 Overview of other types of evidence considered in the evaluation.

Name	Description	Target	Scenario
NDC	signals towards the international community, more commitment (most don't have sectoral commitments)	Yes	No
LTS	signals towards the international community	Yes	No
regional strategies	regional (sometimes sectoral) proposals led or endorsed by government ministries (e.g., EU Commission Hydrogen Strategy)	Yes	No
global outlook	scenarios developed by international institutions (e.g., IEA World Energy Outlook, APEC Energy Demand and Supply Outlook)	No	Yes
domestic outlook	scenarios developed by domestic institutions (e.g., US EIA Annual Energy Outlook) or other consultancies	No	Yes
literature	other scenarios, especially national sectoral analysis	No	Yes

The global outlooks do not provide full coverage of the eight countries and regions in our analysis. The APEC Outlook 2022 covers Australia, Canada, China, and the United States. The IEA World Energy Outlook 2023 Dataset (free version) includes Brazil, China, European Union, India, and United States. The IRENA RE map 2016 scenarios provides information for all countries except the European Union.

In Section 3.3 will evaluate each indicator individually and discuss different regional thresholds separately. We then summarize the main insights in section 3.5.

3.3. Analysis of insights from different lines of evidence

In the following sections, we qualitatively analyse and compare the insights from different lines of evidences in terms of uncertainty (major differences across different lines of evidence) and from a feasibility perspective. The specific feasibility considerations and sources of feasibility thresholds are described in each specific section.

3.3.1. Geophysical perspective

The primary goal of evaluating scenarios from a geophysical standpoint is to determine if they are approaching the limits of geophysical resources. Assessments of 1.5°C scenarios (Brutschin, Pianta, et al., 2021) indicate that these scenarios do not approach concerning levels based on the projected wind and solar energy consumption by the end of the century. Current geophysical concerns in scientific discussions about scenarios focus on biomass (Creutzig et al., 2021; Fuss et al., 2018), particularly the insufficient land available to produce the biomass levels indicated in some scenarios.

Here we extend past efforts and explore assumptions pertaining to biomass levels in 2050 (EJ/year) at the regional level across different lines of evidence. We then also benchmark those to the ranges indicated in Table 5.

Table 5 Overview of technical total biomass potentials estimates in 2050 in EJ/year (Haberl et al., 2010). Please note that the data is aggregated to the IAM regional resolution, making it only partially useful for identifying the concerning levels in Table 6.

region	low	high
North America	21	42
Western Europe	13	21
Pacific OECD	7	13
Central and Eastern Europe	3	6
Former Soviet Union	9	17
Centrally planned Asia, China	23	34
South Asia	18	20
Other Pacific Asia	9	15
Middle East and North Africa	6	8
Latin America and the Caribbean	34	58
Sub-Saharan Africa	20	34

Table 6 Overview of Biomass in 2050 (EJ/year) across different lines of evidence. Red indicates very concerning levels (above the high potential estimate), while orange indicates medium level of concern (between low and high potential estimates) if the results are compared to the overlapping regions from 5. We report the source of the data and the maximum value reported in the given scenario ensemble.

›n	National max	AR6 P1c max	EIA max	IRENA max	WEO2022 max
Australia	0.57	0.25			
Brazil	6.93	10.05			
Canada		1.37			
China	77.05	16.50			19.71
European Union		18.23			
India	48.59	13.43			12.59
South Africa		0.56		0.03	
United States	16.80	13.35	5.48		

While there have been major efforts to update and constrain global levels of biomass production to be below sustainability thresholds identified in the literature (Creutzig et al., 2021), less attention has been paid to whether regional results from IAMs align with other calculations that focus more on sustainability concerns. For example, in the context of the EU, a recent analysis has found that some of the scenarios are assuming extremely high levels of biomass consumption (Byers et al., 2023). By comparing data from different sources, we observe particularly significant variations in assumptions for China and India, with some scenarios from national models reporting much higher values compared to bottom-up estimates (Haberl et al., 2010). Certain scenarios from global IAMs approach the upper bounds proposed for the European Union, similarly to the finding in Byers et al. (2023).

In

Figure 5, we then can trace the overall spread within different sources. Here we find a major overlap of assumed biomass levels in China region in global IAMs but a large difference compared to scenarios from national models. We also find quite a variation of assumed biomass levels in the European Union region, with a few scenarios being close to the upper bound for Western Europe, which Haberl et al. (2010) identified to be around 21 EJ/year (see also similar ranges in Byers et al. 2023).

Given the clear disagreement identified across different lines of evidence and some reported results being substantially higher than calculations from other sources, our overall recommendation is to update the regional biomass constraints in the global IAMs to ensure they do not exceed the upper bounds identified in the literature.

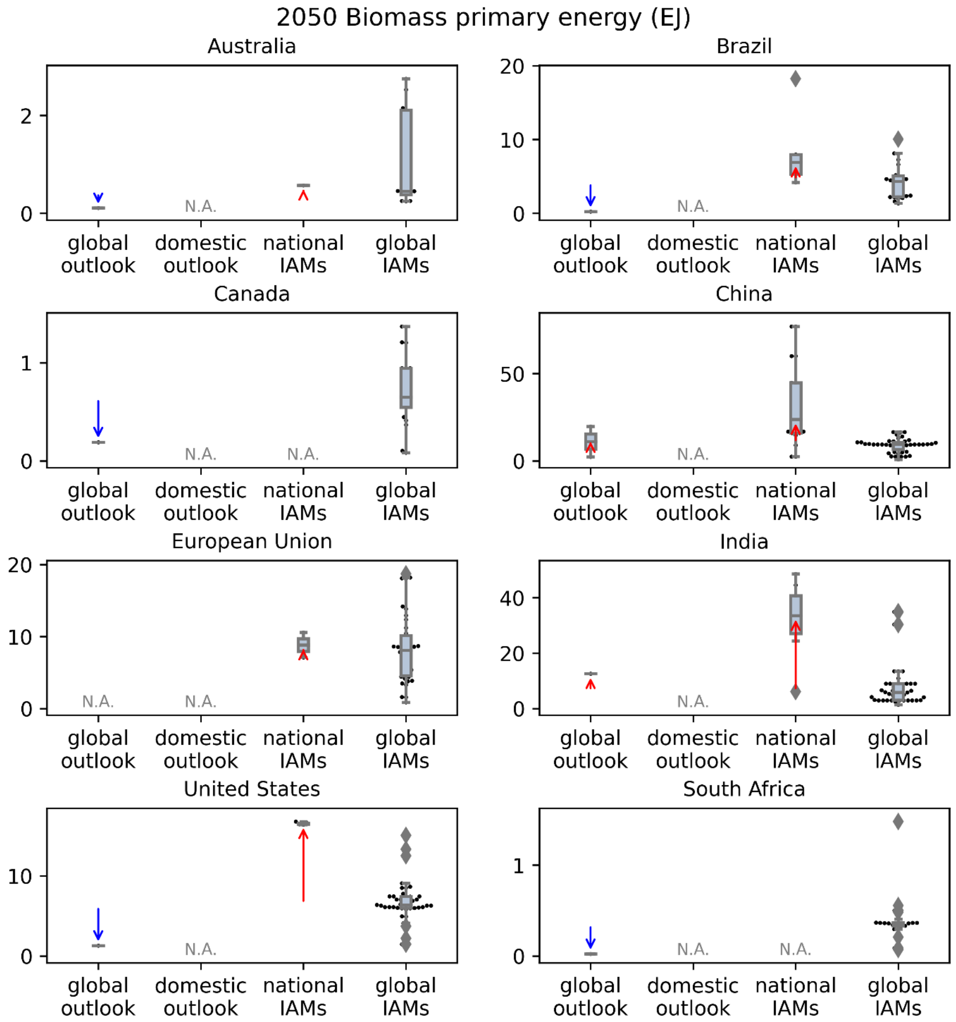

Figure 5 Overview assumed biomass levels in 2050 (EJ/year) across different lines of evidence. The arrows represent the mean difference between each line of evidence versus global IAM results. The dashed horizontal lines represent regional strategies or policies.

3.3.2. Technological perspective (solar, wind, hydrogen, and carbon sequestration)

Extensive literature has examined the speed of technology diffusion (Grubler, 1991; Sovacool, 2016; Wilson et al., 2020). There is a general consensus that diffusion follows an S-curve, and the growth rates during the scale-up phase depend on technology and national characteristics. More granular and less complex technologies typically exhibit higher growth rates and greater scale-up potential (Wilson et al., 2020) but might also be limited in national contexts where key infrastructure is lacking. Empirical studies indicate that not all countries possess the same capacity to scale up technologies and that there is substantial variation (Brutschin, Cherp, et al., 2021; Cherp et al., 2021). However, some technologies, particularly granular ones, may thrive even in countries with lower capacities when costs are low, conditional on some existing infrastructure. Assessing the feasibility of technology scale-up requires understanding the interaction between global and national trajectories for a specific technology, considering its characteristics and maturity along the S-curve, as well as the characteristics of countries adopting it.

Following past work that was applied in the context of global scenarios (ENGAGE, Deliverable for Task 3.3), we propose technology benchmarks as summarized in Figure 6. For example, there is a relatively robust finding in the literature that no matter which technology is being looked at, it often originates within countries that have high levels of state capacity, either through high GDP or other military or institutional capabilities (Bento et al., 2018; Brutschin, Cherp, et al., 2021; Vinichenko, Jewell, et al., 2023).

The overall global trajectory of technology adoption largely depends on the characteristics of the technology and the number of countries for which it is particularly suitable. For instance, many high-capacity countries (OECD) could achieve rapid scale-up rates of nuclear technology due to large unit sizes. However, nuclear technology has not diffused globally, and the number of countries that have reached those levels remains relatively low (Brutschin, Cherp, et al., 2021). Technologies that require substantial upfront investments, stable regulations, and political stability might be limited to a few countries or specific regions, resulting in relatively low global diffusion. However, one could argue that intermittent renewable energy sources are also capital-intensive but face less uncertainty regarding the evolution of overnight investment costs.

A more significant development in recent years has been the growth of wind and solar energy, the two main sources of low-carbon energy on which many mitigation scenarios rely. Wind reached 1% of global electricity generation in 2008, and solar achieved this milestone in 2014. Both technologies are currently exhibiting exponential growth at the global level, with many countries achieving yearly growth rates of at least 20% or higher. As shown in Figure 7, for example, China has sustained an annual growth rate of 30% over the past ten years. Even more remarkable upscaling occurred in China between 2022 and 2024, with installed capacity reaching 393 GW in 2022 (IRENA, 2023) and the latest estimates reporting solar capacity at 660 GW in the first quarter of 2024[1]. Our calculations indicate that the US and Australia could sustain annual growth rates of about 20% percent. At the same time, Vinichenko, Jewell, et al.(2023) show that the capacity to deploy technology varies substantially by country. For benchmarking solar capacity from a feasibility perspective, we propose the following classifications: yearly growth rates below 20% are not concerning, rates between 20% and 30% represent a medium level of concern, and rates above 30% indicate a high level of concern. For wind energy, we propose slightly lower benchmarks, as past studies have found the diffusion of wind to be slower compared to solar (Wilson et al., 2020). As we show in our more detailed analysis of wind in

[1] https://www.pv-tech.org/chinas-installed-solar-capacity-660gw/.

Section 3.3.2.2, many countries and regions are exhibiting lower yearly growth rates of wind as compared to solar energy. We then apply similar benchmarking rules for hydrogen and CCS upscale but note that with those technologies the level of uncertainty is very high.

country characteristic = state capacity to scale-up technologies

Technology characteristic	high capacity	intermediate capacity	low capacity
	Growth rates at the country level		
Granular (Solar PV)	20-30% yearly growth during periods of demand growth		
Intermediate (Wind, DAC)	Deployment earlier than in other regions/countries and then around 10%-15% yearly growth	After the global share has reached 1% and costs are brought down, around 10%-15% yearly growth	
Lumpy/complex (Nuclear, BECCS, DACCS, fossil CCS, hydrogen)	Deployment earlier than in other regions/countries and then around 10%-15% yearly growth	After the global share has reached 1% and costs are brought down, around 10%-15% yearly growth	Might not get access to some of more complex technologies

Figure 6 Proposed ranges for key technologies from a feasibility perspective. Taken from the report for the ENGAGE project (Task 3.3). On state capacity to scale up technologies see also (Pianta & Brutschin, 2022).

3.3.2.1 Solar capacity

We first compare the 20-30% yearly growth range to historical solar capacity expansion rates in each of the regions (Figure 7). Brazil is at an early stage of expansion; thus, its historical growth rate is much higher compared to other countries. Canada, the European Union, and South Africa have historically expanded their solar capacities at a rate slower than the annual 20%. Australia and the United States have expanded solar capacity within the 20-30% range, while China and India have achieved growth rates of around 30% over the past ten years.

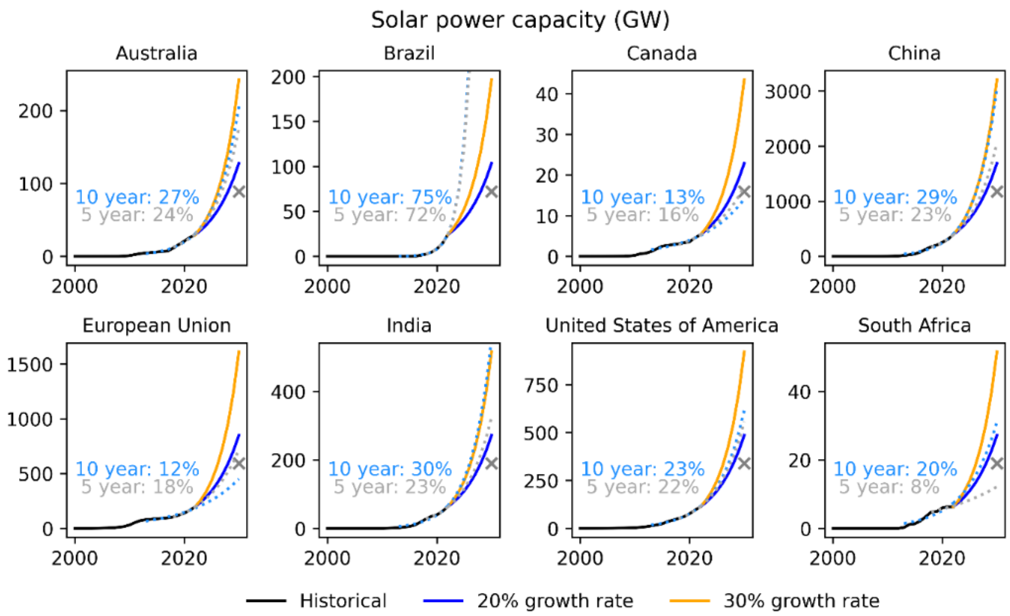

Figure 7. Historical and projected rate of solar capacity expansion. The Dotted curves represent the projected capacity expansion using annual growth rates calculated from the past 5 or 10 years of data. The solid curves represent project capacity expansion using 20% or 30% annual growth rate. The grey x marks represent solar capacity tripling from 2022. Historical data (2000-2022) from IRENA (2023).

Overall, solar capacity expansion in global Integrated Assessment Models (IAMs) could explore much more ambitious futures (Figure 8). The projected capacity expansions in global IAMs are lower than historical trends or annual growth projected feasibility constraints in Australia, Brazil, China, and South Africa. The global IAM results for Brazil and South Africa align with targets from sector-level policies (see dashed lines in Figure 8). In China and India, national IAM results are even less ambitious than those in global IAMs, despite evidence suggesting they can achieve closer to a 30% yearly growth rate (orange zone/medium level of feasibility). The high outlier values in global IAMs for Canada originate from the WITCH 5.0 model, indicating high feasibility concerns. In the United States, global outlooks, domestic outlooks, and national IAMs all predict higher solar growth than global IAMs. In the context of the EU, there are many scenarios that are below EU's target and the observed trends from the last five years (yearly growth rate of around 18%).

Our exploration thus highlights the importance of updating global IAMs to reflect the most recent developments in solar upscaling, particularly for China given its size and significance in global mitigation efforts.

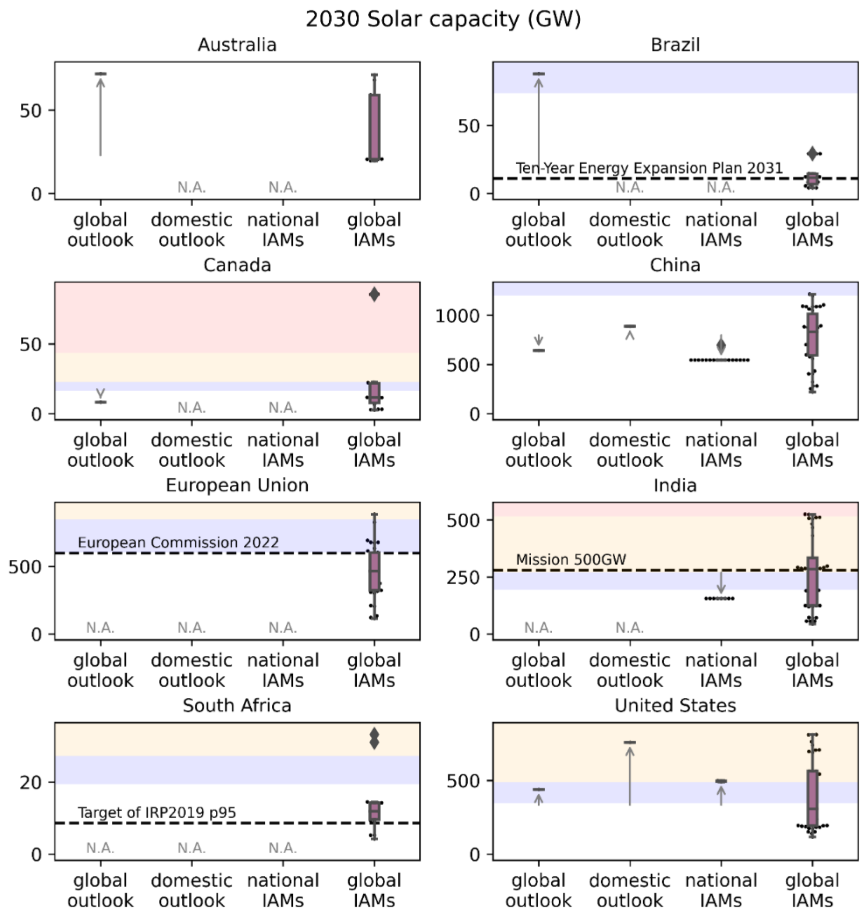

Figure 8. Overview of solar capacity expansion using different lines of evidence. The blue shaded regions represent 20-25% yearly growth from 2022; the orange shaded regions represent 25-30% yearly growth; the red shaded regions represent yearly growth above 30%. The arrows represent the mean difference between each line of evidence versus global IAM results. The dashed horizontal lines represent regional strategies or policies.

3.3.2.2 Wind capacity

We conduct similar analysis to compare yearly growth rates between 10-15% and historical wind capacity expansion (Figure 9). Australia, Brazil, China, and South Africa have shown some evidence of faster expansion than the 15% yearly growth. Canada, the European Union, and India may require additional efforts to reach the 10% yearly growth, while the United States is relatively aligned with this range.

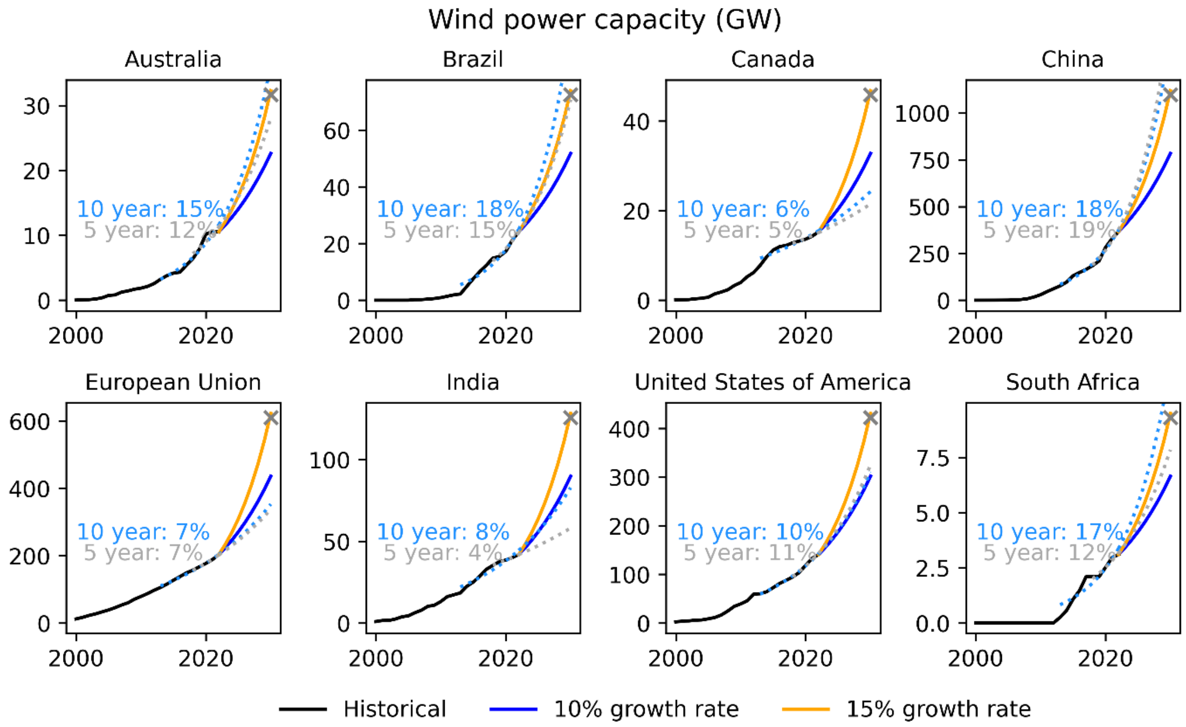

Figure 9. Historical and projected wind capacity expansion. The dotted curves represent the projected capacity expansion using annual growth rates calculated from the past 5 or 10 years of data. The solid curves represent project capacity expansion using 10% or 15% annual growth rate. The grey x marks represent wind capacity tripling from 2022. Historical data (2000-2022) from IRENA (2023).

Based on various lines of evidence, we observe that in some regions or countries, global models may assume a slightly faster upscaling of wind energy in electricity generation. For example, Australia and China are already deploying wind energy at the upper bound of the proposed feasibility range, while global IAMs assume much lower rates of upscaling in these regions. This disparity is even more pronounced in China when considering national models. In India, the stated policy ambition of reaching 500 GW by 2030 falls within the more ambitious feasibility range, but past efforts have so far resulted in lower annual growth rates of 4-8%. In the context of the EU, many global models report regional wind capacity that is below the EU's announced plans and on a less ambitious side compared to historical trends.

Similarly to the analysis of the results with solar capacity we thus recommend an update of assumptions in the global IAMs pertaining to the wind capacity, especially for regions such as the EU, Brazil, Australia and China.

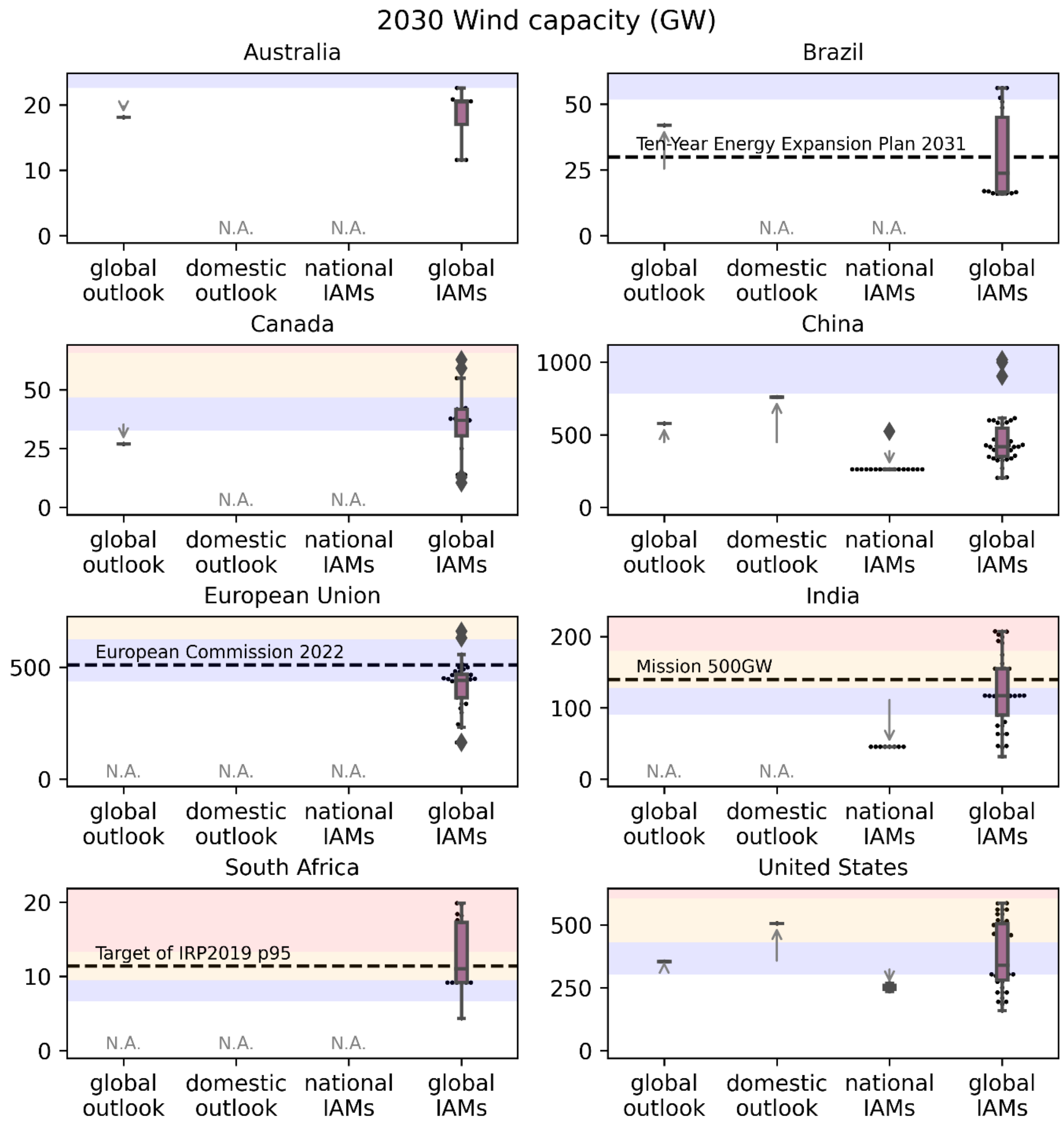

Figure 10. Overview of wind capacity expansion using different lines of evidence. The blue shaded regions represent 10-15% yearly growth from 2022; the orange shaded regions represent 15-20% yearly growth; the red shaded regions represent yearly growth above 20%. The arrows represent the mean difference between each line of evidence versus global IAM results. The dashed horizontal lines represent regional strategies or policies.

3.3.2.3. Hydrogen capacity

The International Energy Agency (IEA) provides data on hydrogen production projects through its Hydrogen Production and Infrastructure Projects Database[2], last updated on January 23, 2024. This dataset includes information on projects producing

[2] https://www.iea.org/data-and-statistics/data-product/hydrogen-production-and-infrastructure-projects-database.

hydrogen as their primary product. It categorizes projects that are currently operational, those under final investment decisions, and those in the construction phase, with the start year of each project reported. We use this dataset to explore possible trajectories of hydrogen scale-up using different growth rates (Figure 11) but note that these results have a high level of uncertainty given that the technology is still in its formative phase. Green hydrogen is gaining increased political interest, with a growing number of governments worldwide adopting hydrogen strategies. For instance, the EU recently updated its hydrogen goal in the REPowerEU strategy to produce 10 million tonnes and import an additional 10 million tonnes by 2030. Nearly all EU members now include green hydrogen strategies in their national energy plans. Currently, hydrogen is primarily used in oil refining, but it is expected to play a greater role in various industries, particularly in decarbonizing iron and steel production, as well as in the transport and chemical sectors. However, we can trace that the actual deployment of hydrogen remains limited so far, and achieving the intended levels might prove extremely challenging (Odenweller et al., 2022).

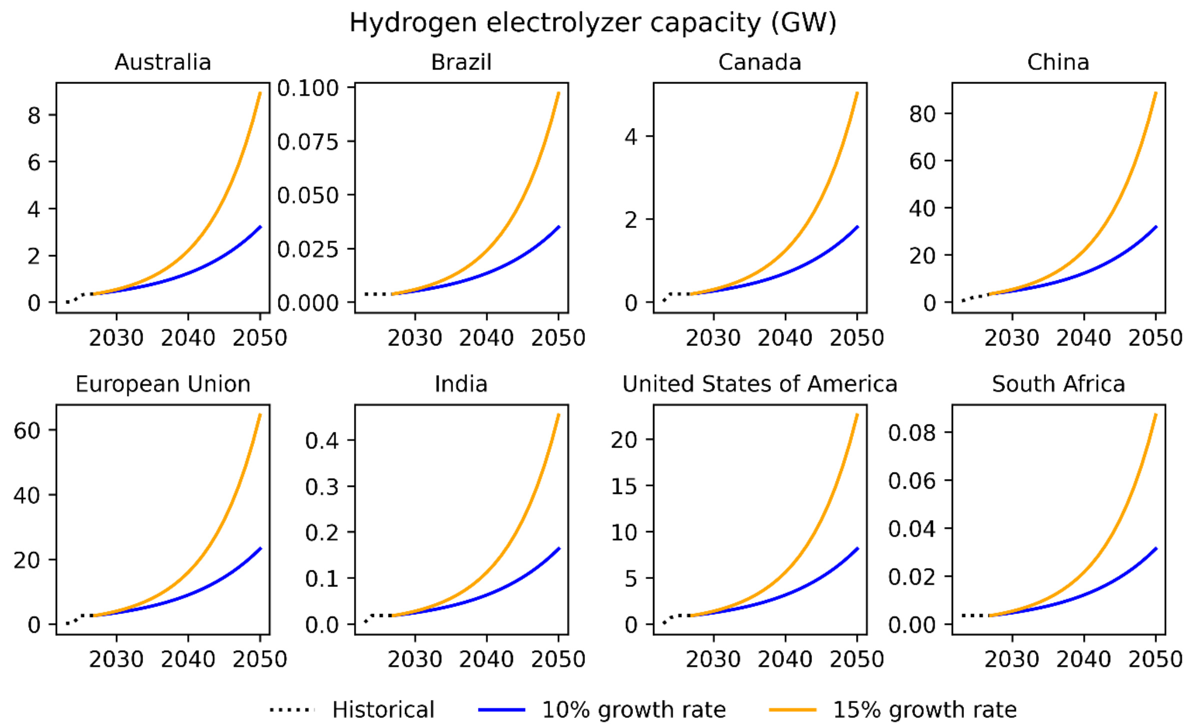

Figure 11. Historical and projected hydrogen electrolyzer capacity. The historical values include the capacity in operation and the planned capacity in final investment decisions and under construction using the scheduled start year. The projected values are calculated at 10% and 20% exponential growth rates from 2027 (please note the high level of uncertainty given that hydrogen is a technology in its formative stage). Historical data from IEA Hydrogen production projects dataset 2024.

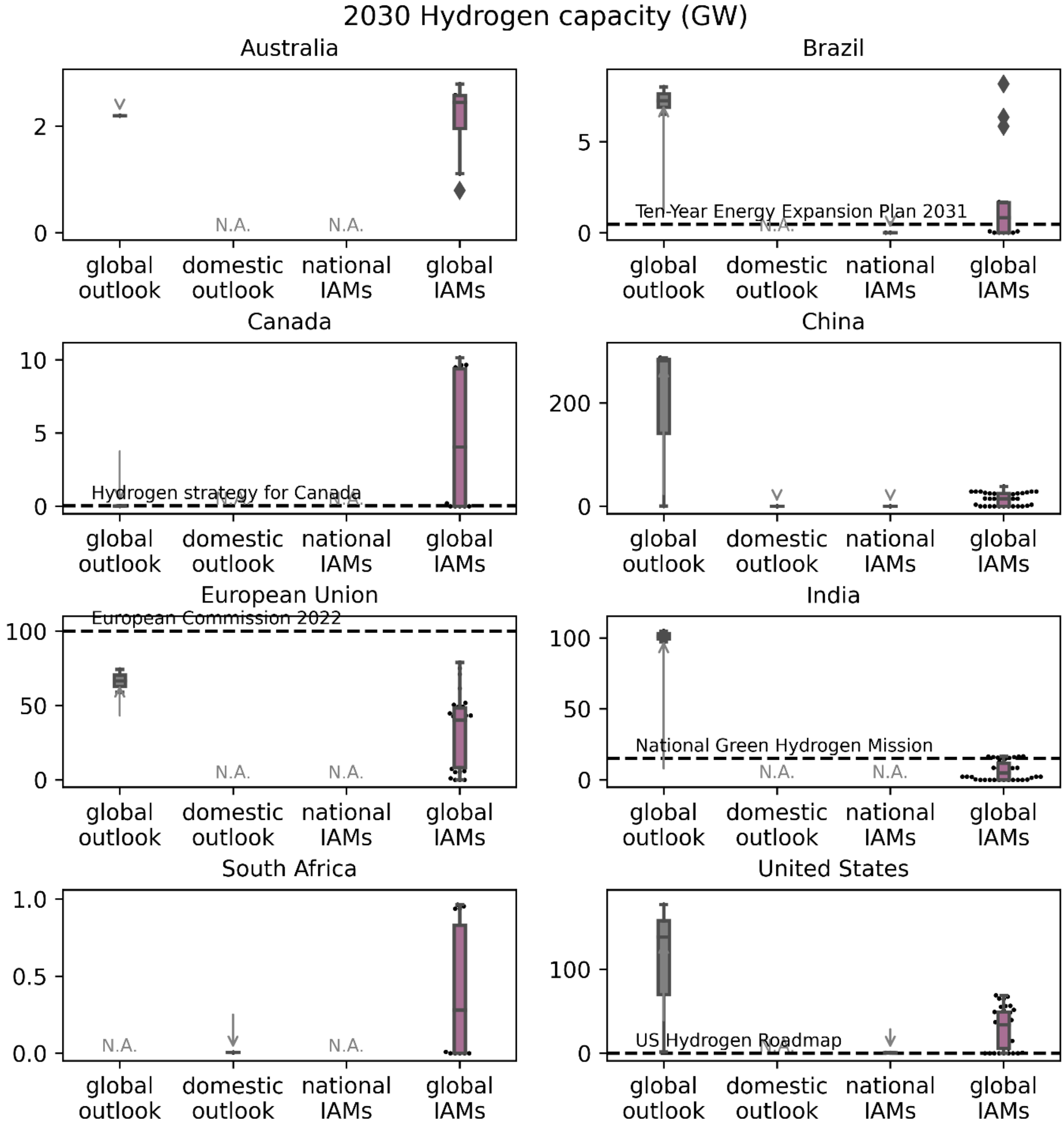

Figure 12 Overview of hydrogen capacity in GW in 2030 across different lines of evidence. .

Similarly to past analyses, we find that hydrogen currently has a limited role and representation in global IAMs (Figure 12). Brazil's plans are more or less aligned with what is reported in the global IAMs. The only country where there is a noticeable mismatch is the United States, where global IAMs assume higher rates of hydrogen deployment compared to the national plans. In the EU context, the mismatch goes in the other direction, the current plans indicated in the EU Commission's reports are much more ambitious than what is assumed in the global IAMs. Overall, there is significant uncertainty in the context of hydrogen, and more systematic research and exploration of sensitivities in the models would be essential.

3.3.2.4. Carbon Sequestration and Storage

There is also a high level of uncertainty regarding the possible scale-up of carbon storage technologies. The national IAMs for Australia, Canada, India and South Africa do not report the variable we have proposed for assessing assumed carbon storage. To benchmark the insights from different lines of evidence from a feasibility perspective, we have relied on the bounds identified by Grant et al. (2022). From the overview in Figure 13, we can observe that many global IAMs are relatively conservative in most regions regarding the assumed scale of CCS, with a few outliers. For example, the assumed levels in the US in some global IAM scenarios exceed the maximum storage capacity based on the analysis of historical injection rates of 1128 Mt/year proposed by Grant et al. (2022). Similarly, a few global IAMs are at the upper bound for CCS in China, the EU, and, to a certain extent, Brazil. National models for China and India assume a much larger CCS deployment compared to the results from the global IAMs.

Overall, similar to our recommendation in the context of hydrogen, future global IAM scenarios could focus on exploring more systematically various assumptions pertaining to CCS storage, particularly focusing on the uncertainty at the regional level.

Table 7 Overview of the reported carbon sequestration and storage level in Mt/year across AR6 P1c scenarios. Red indicates very concerning levels, while orange indicates medium level of concern if the results are compared to the overlapping regions from Grant et al. (2022). We report the maximum value reported.

Regions	**AR6 P1c (max)**
Australia	8.17
Brazil	752.87
Canada	139.95
China	853.45
European Union	859.53
India	44.91
South Africa	66.62
United States	1353.81

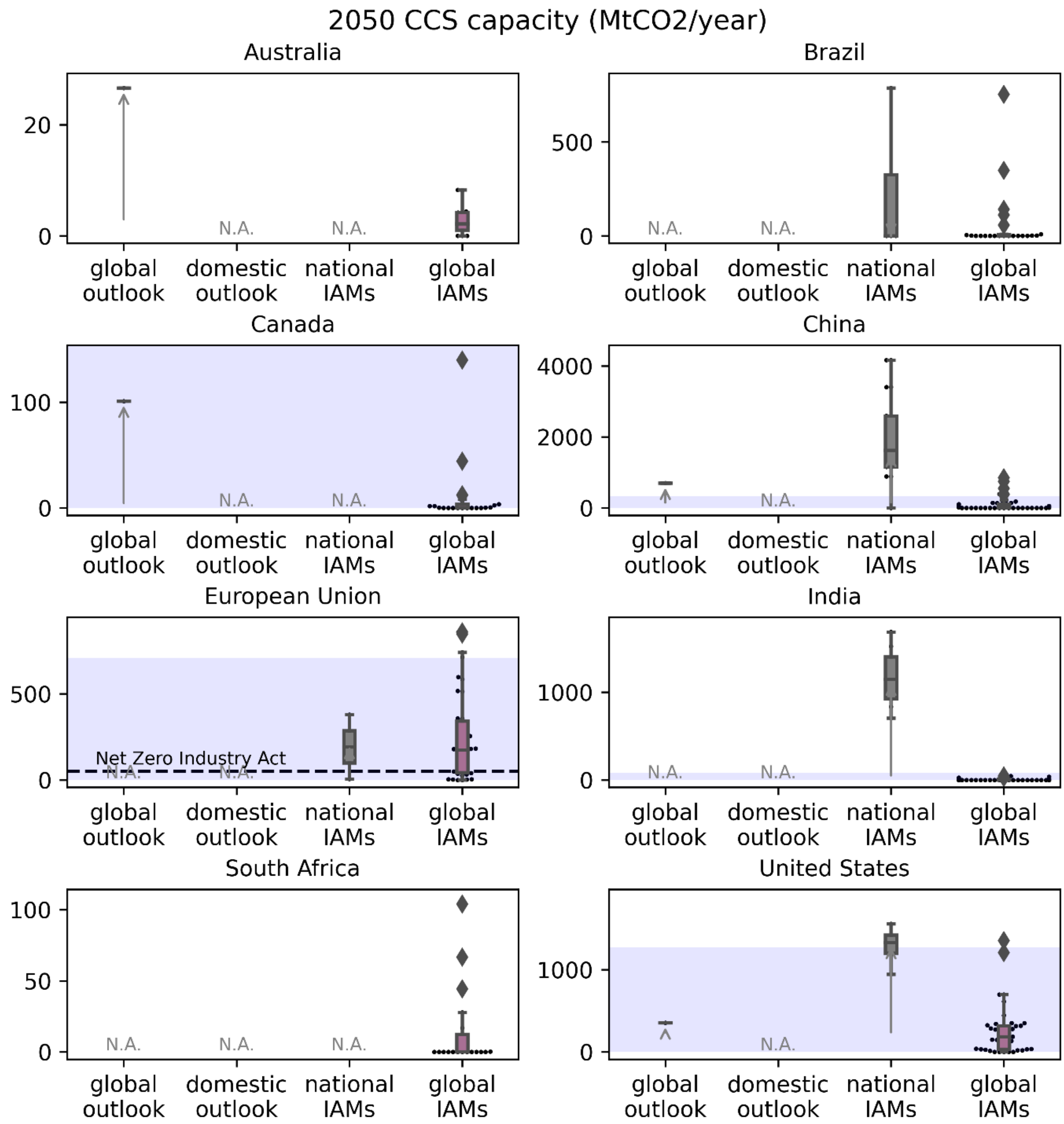

Figure 13 Overview of assumed carbon sequestration and storage level in Mt/year across different lines of evidence and benchmarked to the upper capacity bounds proposed by Grant et al. (2022).

3.3.3. Coal and gas trajectories

Using the share of coal in power generation, we calculate historical rates of decline from the past 5 or 10 years and compare the historical data to projected levels of decline (Vinichenko, Vetier, et al., 2023). Brazil and Canada are already using well less than 10% coal, while other countries (except India) are already on track for some levels of decline. Based on historical values, China, the European Union, India, and

South Africa may require additional efforts to reduce coal share by 1.3% annually. There is evidence for Australia and the United States to achieve 1.3-2% reduction.

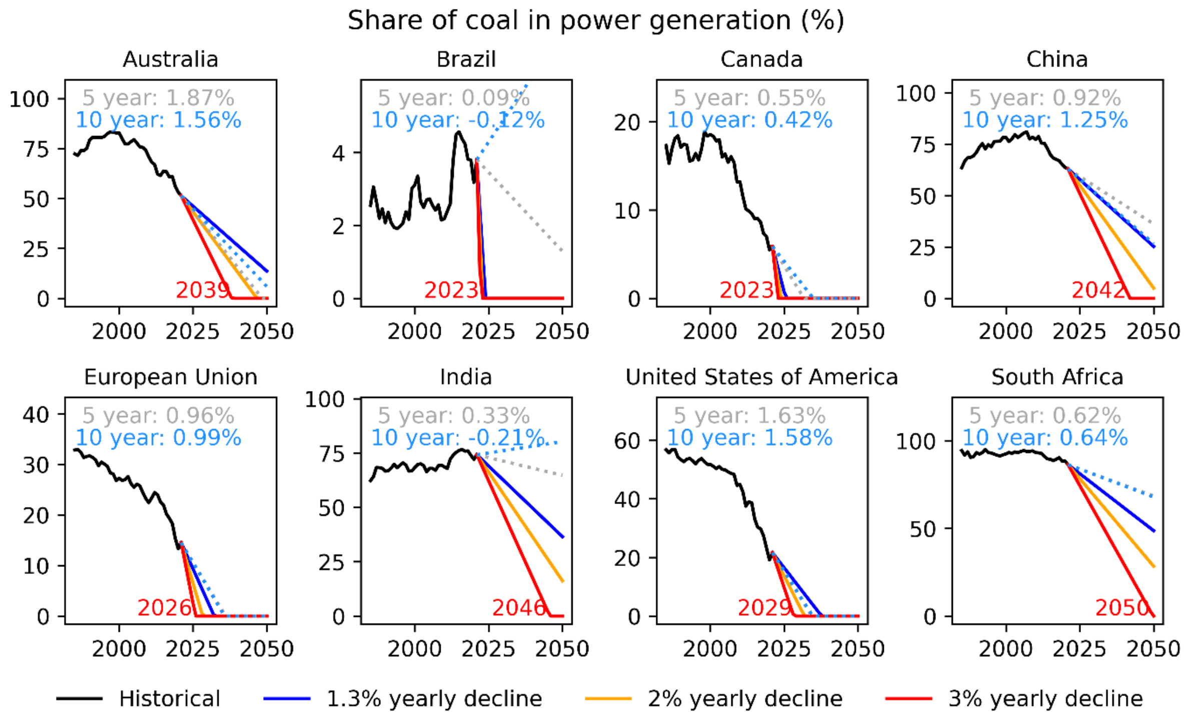

Figure 14. Historical and projected shares of coal in power generation. The dotted curves represent the projected capacity expansion using annual decline rates calculated from the past 5 or 10 years of data. The solid curves represent project capacity expansion using 13%, 20%, 30% decadal decline rates (Vinichenko et al. 2023). Years in red text represent the year each country or region will phase out coal power generation if they reduce coal generation from 2021 by 3% yearly. Historical data (1985-2021) from Our World in Data.

Global IAMs indicate that the proposed coal phase-out for Australia and South Africa is extremely ambitious, raising significant concerns about feasibility. In contrast, China and India are considered to have a medium level of feasibility concern regarding their coal phase-out efforts. Brazil and Canada, which already have minimal coal usage, should be accurately represented in most models. However, some model results still predict an increase in coal usage in these countries, despite Canada having a coal phase-out target set for 2030. Additionally, many national models, including those for Brazil, China, the EU, and the US, are not very ambitious in their coal phase-out plans.

Overall, we observe two patterns: (1) global IAMs need to further develop regionally differentiated coal phase-out trajectories, as many assumed rates exceed the historically observed best-performing decline rate of around 3% per year; and (2) many countries and regions need to intensify their efforts to phase out coal. This is particularly notable in the European Union, where the current decline rates are only around 1%, suggesting that a faster coal phase-out could be feasible.

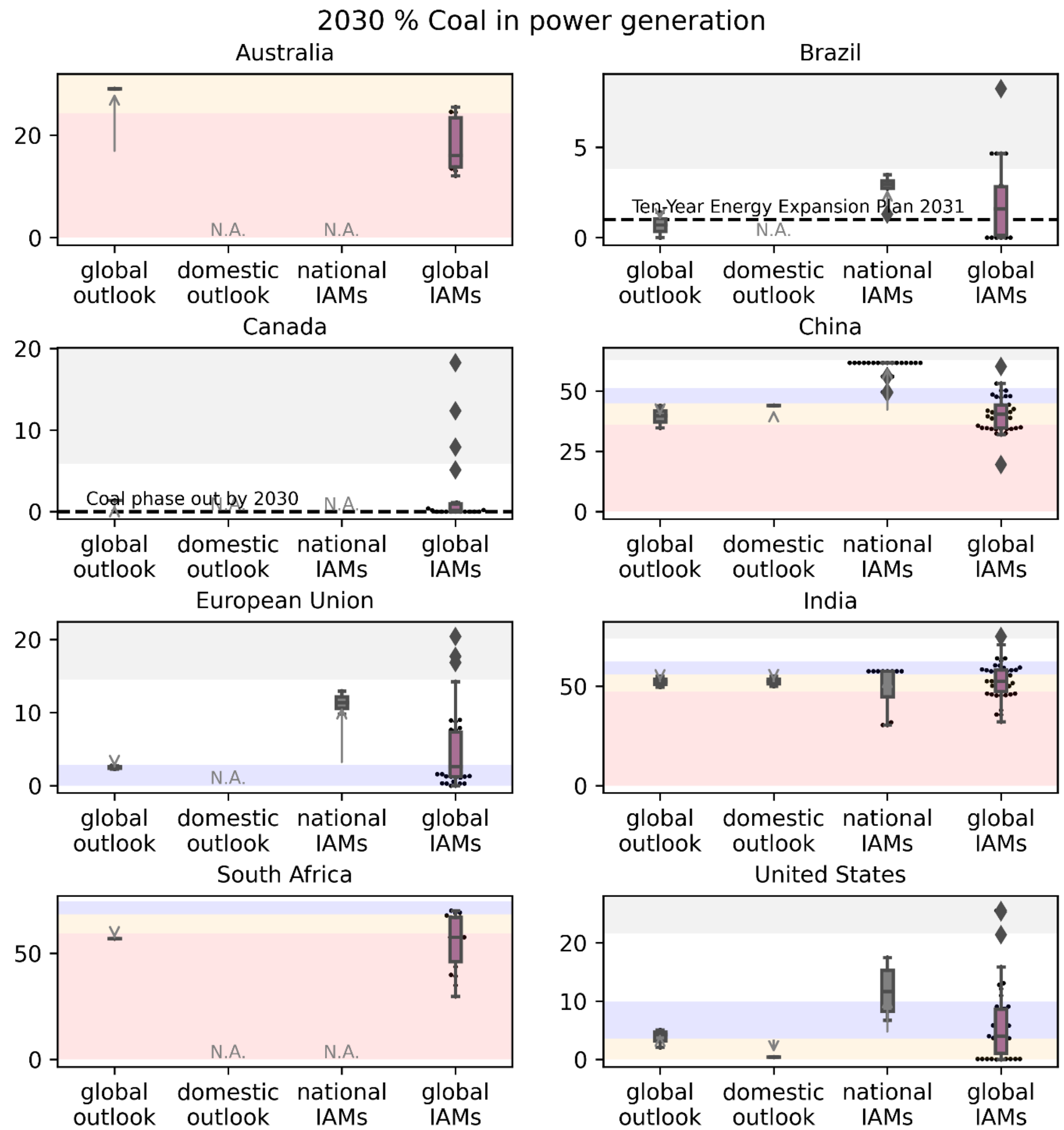

Figure 15. Overview of 2030 share of coal in power generation (without CCS) using different lines of evidence. The blue shaded regions represent 1.3-2% yearly decline from 2021; the orange shaded regions represent 2-3% yearly decline; the red shaded regions represent yearly decline above 3%; the grey shaded regions represent increases from the shares of coal in power generation in 2021. The arrows represent the mean difference between each line of evidence versus global IAM results. The dashed horizontal lines represent regional strategies or policies.

We also explore gas trajectories and identify a major discrepancy between national scenarios and assumptions in global IAMs. It is important to highlight that the AR6 scenarios were generated before the outbreak of the war in Ukraine and thus do not account for the recent geopolitical shifts in natural gas strategies. Notably, global IAMs expect gas to grow significantly in regions such as Australia, China, India, and South Africa. There is considerable variation across global IAM models, with some assuming a more prominent role for natural gas in decarbonization and others predicting a decline and phase-out in key regions.

Specific outlier values include:

- Canada in the COFFEE 1.1 model (scenario CO_NDCplus)
- Brazil in the TIAM-ECN 1.1 model (scenario EN_INDCi2100_NDCp)
- India in the GCAM 5.3 model (scenario NGFS2_Nationally Determined Contributions (NDCs))

To better understand the role of natural gas in decarbonization, it is crucial to gain a deeper insight into regional capacities and priorities. Our recommendation in this context is also to explore more systematically in the context of global IAMs different natural gas trajectories.

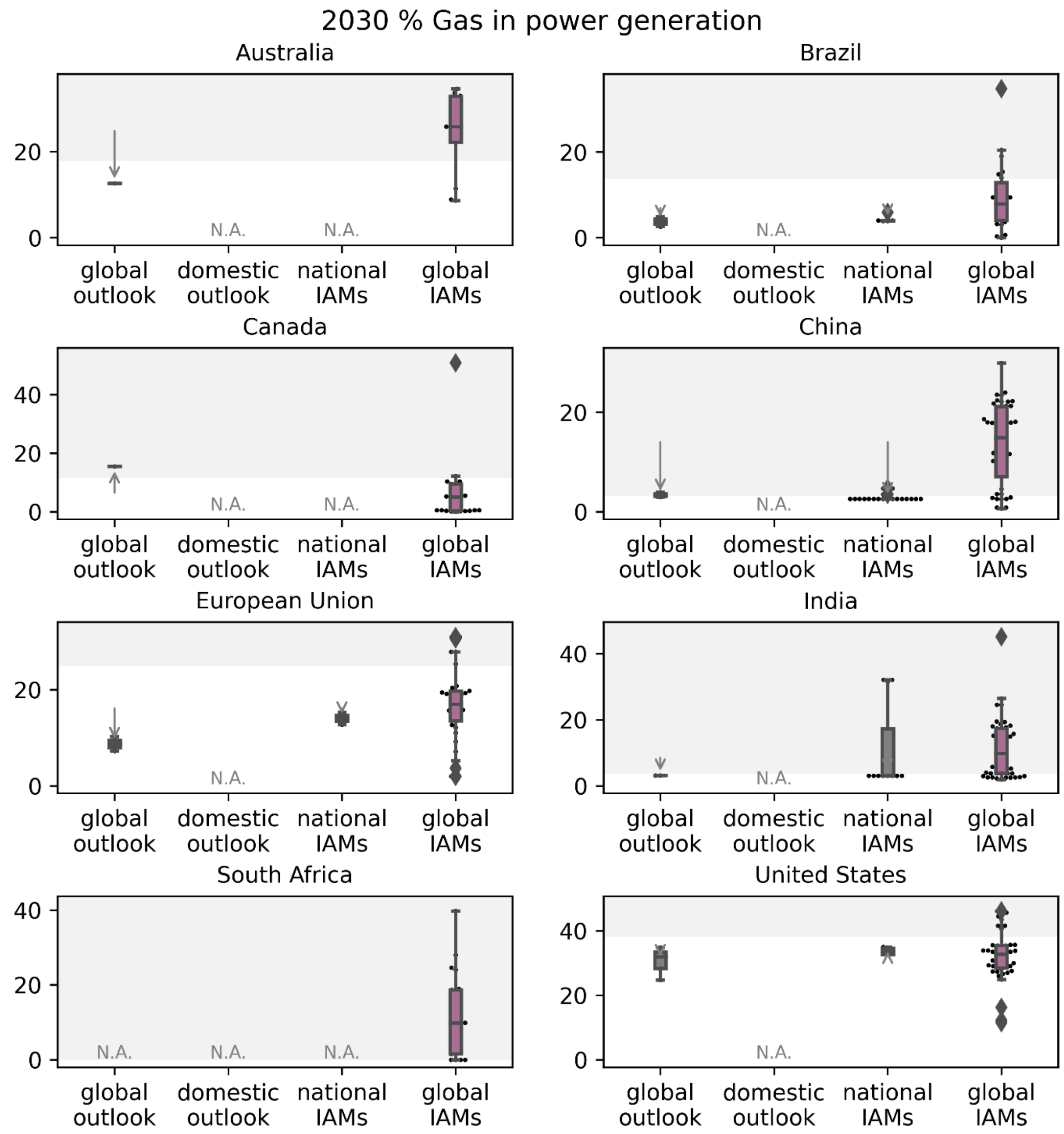

Figure 16. Overview of 2030 share of gas in power generation using different lines of evidence. The grey shaded regions represent increases from the shares of gas in power generation in 2021. The arrows represent the mean difference between each line of evidence versus global IAM results.

3.4. Drivers of coal and gas phase-out ambition

Disclaimer

The following text is adapted from ELEVATE policy brief and from a work that is being prepared for a journal submission:

- Xie, J., Brutschin, E., Rogelj, J., & Staffell, I. (2024). *Past Socio-Political Transitions Away from Coal and Gas Show Challenges and Opportunities Ahead* (SSRN Scholarly Paper 4788002). https://doi.org/10.2139/ssrn.4788002

Given the importance of fossil fuel dependence as a key barrier to more ambitious NDCs (Section 2) and the wide uncertainty we find across models in the coal and gas sectors (Section 3.3.3), we focus more extensively on this sector in this section. We provide a more robust analysis of the possible drivers of coal and gas phase-out to better understand how certain policy lock-ins can be overcome.

In addition to the feasibility constraints, current coal phase-out IAM pathways to reach Paris Agreement targets have raised justice concerns, especially in the context of China and India. Considering more feasible coal phase-out in developing countries, much more ambitious natural gas decline would be required in developed countries to compensate (Muttitt et al., 2023). While some developing countries are on track to reduce coal in power generation, some retired coal power plants have been transformed into gas power plants (Figure 17). The process of fuel switching from coal to gas can involve replacing the unit with a new natural gas plant or converting the boiler to operate with natural gas[3]. This process has been popular in the eastern United States, western Europe, and eastern China. Given the need to also reduce natural gas power generation, such substitution strategy may result in stranded assets. The underestimated climate impacts and geopolitical fuel trade uncertainties can also lead to future challenges around natural gas (Kemfert et al., 2022).

[3] https://www.eia.gov/todayinenergy/detail.php?id=44636

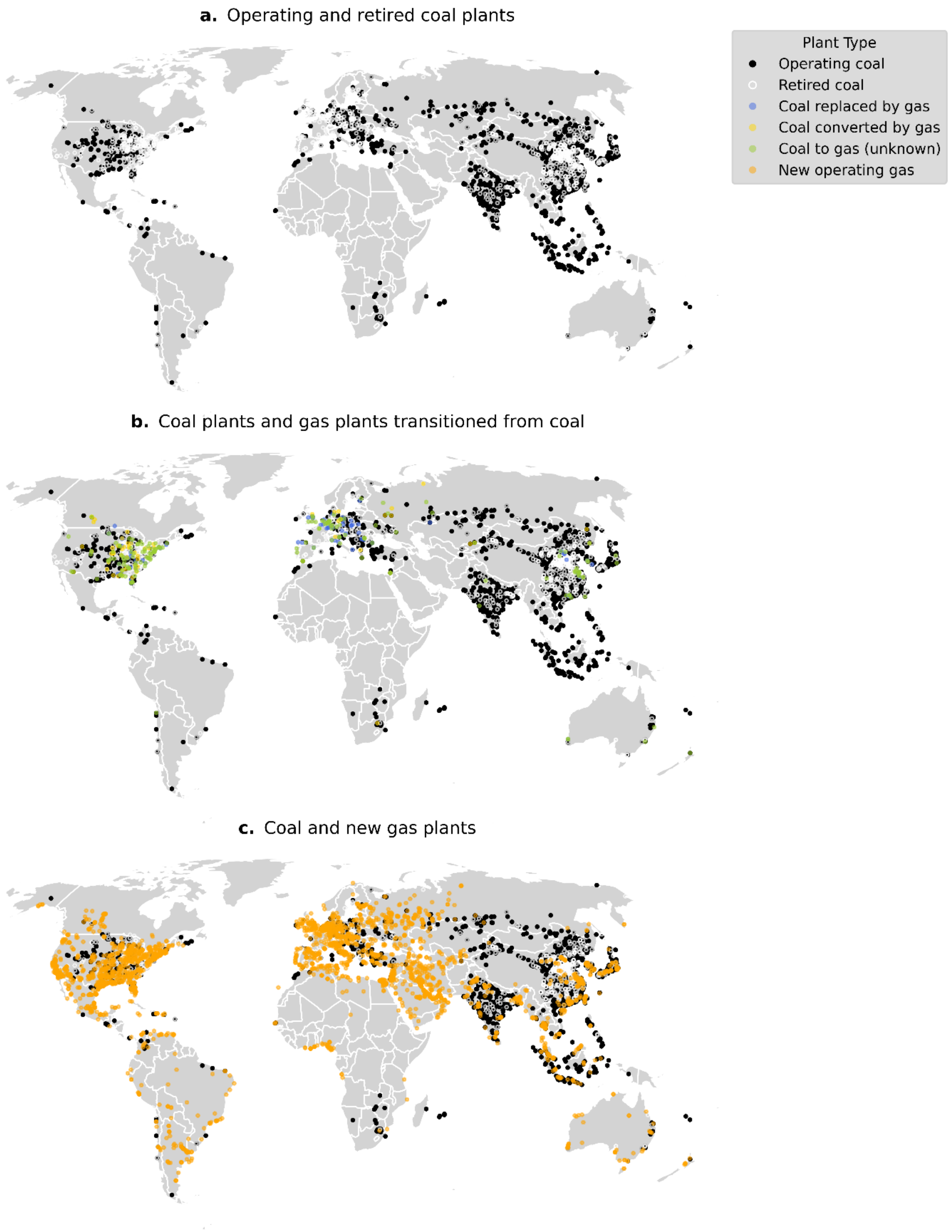

Figure 17. Coal and gas plants around the world. Data from Global Energy Monitor 2023.

Empirical analysis shows that expanding renewable energy technologies such as solar and wind coincides with historical coal and gas declines. The rapid cost reduction of renewable energy has led to some early evidence of natural gas power plant shutdowns in the United States. Localized policy efforts to reach tripling renewable capacity by 2030 target agreed on the First Global Stocktake could provide additional incentives for a transition away from fossil fuels.

Countries with a larger percentage of workforce employed in mining are less likely to phase out coal-fired power generation. Countries with natural gas production contributing to a larger portion of Gross Domestic Product (GDP) are less likely to reduce natural gas-fired power generation. Policies aimed at more ambitious fossil fuel phase-out should incorporate compensatory packages for affected communities. Engaging with local stakeholders in this transition can also improve the political buy-in and justice implications (Bolet et al., 2023). International cooperation and support[4] are especially crucial for countries reliant on fossil fuel resources and lacking economic capacities.

The difficulty in transitioning away from fossil fuels is linked with power market structure and design. Market reform across various mechanisms was found to positively correlate with more ambitious coal and gas phase-out. Notable mechanisms include the choice of electricity supplier, privatization, and the availability of wholesale markets. Countries that currently have reformed power markets are also those with higher GDP and a larger portion of the population that believe human activities are the main contributor for climate change. These countries are also more likely to enact climate policies in the energy supply sectors to address economic or regulatory barriers of fossil fuel phase-out. The combined effects of economic capacity, consumer willingness, and liberalized market could enable more ambitious actions.

Most countries with climate progress have experienced periods of fossil fuel reliance. For those only starting the transition now, there are many policy opportunities to overcome lock-in. Special attention should be paid to natural gas reliant countries which were much more stagnant in the transition.

3.5. Summary of the insights

region	biomass	solar	wind	hydrogen	ccs	coal	gas
Australia	✓	↑	↑	▲	▲	✗	●
Brazil	✓	↑	✓	✓	▲	▲	●
Canada	✓	↑	✓	▲	▼	▲	●
China	✗	↑	↑	▲	▼	✗	✗
European Union	!	↑	✓	▲	▲	▲	●
India	✗	↑	✓	▲	▲	✗	✗
South Africa	✓	↑	✓	▲	▲	✗	●
United States	✓	↑	✓	✓	▼	▲	●

[4] https://www.equityreview.org/extraction-equity-2023

Table 9 Summary of the insights for policy makers.

uses an icon system to indicate the alignment of IAM results with real-world developments, as well as other lines of evidence, and the areas where we identified that certain improvements in the current IAM assumptions would be desirable.

For biomass in 2050, Australia, Brazil, Canada, South Africa and US values reported by the global IAMs, are generally well-aligned with other lines of evidence. In contrast, China and India are not so well aligned and there is also a high level of uncertainty. For the EU some models assume higher biomass ranges that would be above upper bounds calculated in bottom-up studies.

In terms of solar energy for 2030, the results for all considered regions indicate that IAMs are lagging behind real-world developments. This suggests that the models are not keeping pace with the rapid advancements in solar energy deployment, and that assumptions about the cost reductions, or other key assumptions driving the deployment of technologies in the models need to be updated. Similarly, for wind energy in 2030, the IAM results for Australia and China are behind real-world developments, indicating a need for model updates.

Regarding hydrogen in 2030, for most regions, IAMs assume relatively low levels of deployment, which stands in contrast with the certain policy pledges and the general attention that hydrogen is given by policy-makers (see also Section 3.3.2.3). In this context, it would be great to explore the role of hydrogen in IAMs in more depth and with additional sensitivities.

Similarly, we observe a high level of uncertainty regarding CCS, coupled with relatively optimistic assumptions regarding its annual deployment by 2050 in China, the EU, and the US. Finally, we find that greater attention should be given to regional trajectories in the context of coal phase-out. Here, models either lag behind specific regional plans and commitments (such that certain scenarios report much higher coal in electricity levels in the EU as would be expected based on policy goals), or make overly optimistic assumptions, which may prove challenging to achieve (especially in China, India and South Africa). With respect to natural gas, we also find a very rapid upscale assumed in some of the countries such as China and India, with major variation in other regions. This generally indicates that future scenarios should focus on updating and exploring sensitivities to different technologies, with a particular attention to regional differences.

*Table 8 Summary of the insights for global IAM developers. Here we try to highlight areas where there is a major mismatch compared to other lines of evidence or a high level of uncertainty. *

region	biomass	solar	wind	hydrogen	ccs	coal	gas
Australia	✓	↑	↑	▲	▲	✗	●
Brazil	✓	↑	✓	✓	▲	▲	●
Canada	✓	↑	✓	▲	▼	▲	●
China	✗	↑	↑	▲	▼	✗	✗
European Union	!	↑	✓	▲	▲	▲	●
India	✗	↑	✓	▲	▲	✗	✗
South Africa	✓	↑	✓	▲	▲	✗	●
United States	✓	↑	✓	✓	▼	▲	●

Table 9 Summary of the insights for policy makers.

region	solar	wind	hydrogen	ccs	coal
Australia	✓	✓	▲	▲	✗
Brazil	✓	✓	▲	▲	✗
Canada	✗	✗	▲	▲	✗
China	✓	✓	▲	▲	✗
European Union	✗	✗	▲	▲	✗
India	✓	✗	▲	▲	✗
South Africa	✓	✗	▲	▲	✗
United States	✓	✓	▲	▲	✗

Besides generating insights for the development of global and national IAMs, we can also summarize key findings targeted towards policymakers (Table 9). We are confident in highlighting that current trends in observed data and implications of current policies to phase out coal are not aligned with most NDCs, and particularly fall short of achieving more ambitious climate targets. Additionally, we observe that the scaling up of solar and wind technologies in developed regions is relatively slow compared to trends in leading countries. This suggests an opportunity for developed nations to increase their ambition further. Additionally, there is a wide gap between what is envisioned in policy goals and what is reported in the models in the context of hydrogen and ccs. Here a more systematic exchange between policy makers, practitioners and integrated assessment modelers would be beneficial for a better understanding which specific technologies can be implemented in the real world.

4. Discussion and Conclusion

In this report, we have evaluated climate policies using a variety of tools to gain a comprehensive understanding of potential barriers and key enablers (

Figure 18). Our goal was also to create a feedback loop between different types of tools to enhance our collective knowledge. Countries are striving to achieve the climate targets of the Paris Agreement by proposing and updating Nationally Determined Contributions (NDCs), broader emission targets, and specific sectoral goals such as increasing the share of renewables or phasing out fossil fuels.

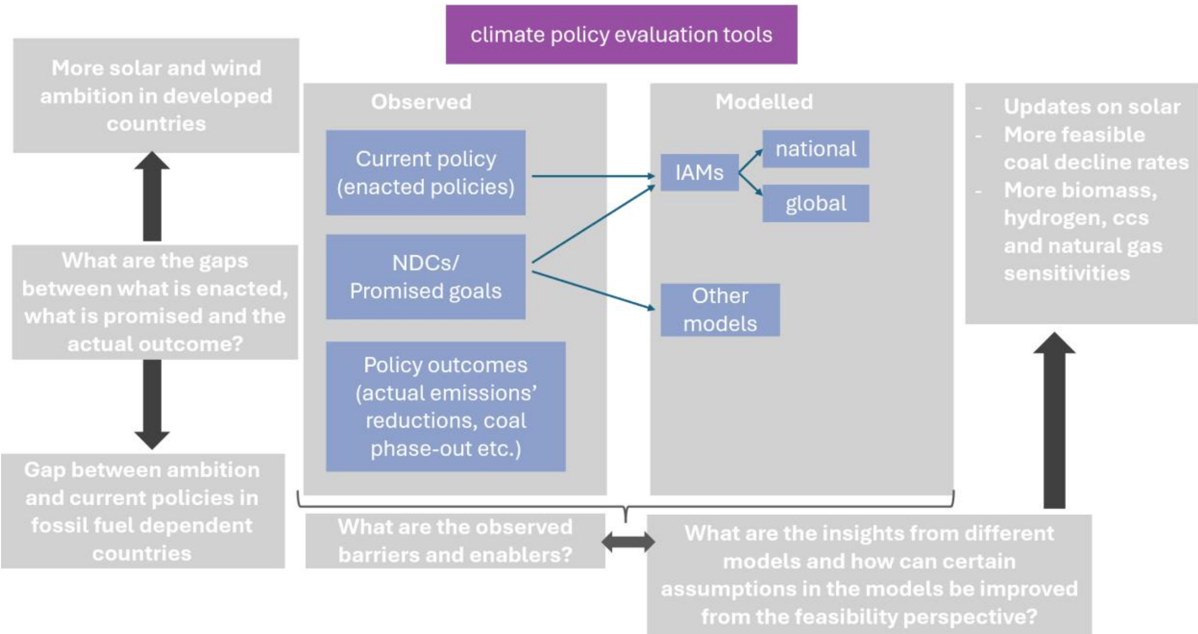

Figure 18 Summary of the main insights across the different tools and methods used.

Integrated Assessment Models (IAMs) have played a significant role in exploring future scenarios by assessing the implications of current policies, the expected outcomes of pledged NDCs, and more ambitious efforts aimed at achieving the 1.5°C target. Analyzing past data has helped us understand the characteristics of countries with more ambitious climate targets and the key drivers behind significant coal phase-outs. Recent studies have used past observations to benchmark scenario outputs, evaluating the feasibility of certain trajectories in the real world.

Building on these past efforts, we linked different streams and approaches to identify insights from evaluations of climate policies. Our analysis revealed that greenhouse gas emissions projections are crucial for quantifying the emission implications of certain policies. This is particularly helpful for understanding the gap between currently enacted climate policies and the promises made in NDCs, as well as identifying the characteristics of countries that increase their ambition over time. We found that countries heavily reliant on gas and oil exports or on coal in electricity supply are more likely to fail to increase their ambition.

Furthermore, we examined a wider range of indicators of modeled NDCs and compared insights from different lines of evidence, including outputs from global models, national models where possible, other types of models, and pledges indicated by countries. Our analysis highlighted particularly high mismatch in the context of future solar and coal trajectories, and high uncertainty in the context of natural gas, biomass, CCS and hydrogen. This exercise provided important feedback to the IAM community regarding possible improvements in the next generation of scenarios, whether exploring the implications of updated NDCs or developing more regionally differentiated narratives aimed at reaching 1.5°C or staying well below 2°C.

In conclusion, our comprehensive evaluation of climate policies using a diverse set of tools has not only identified critical insights and potential barriers but also highlighted the importance of continuous feedback and improvement in modeling efforts. By linking various approaches and integrating different types of evidence, we can better support countries in achieving their climate targets and contribute to the global effort to mitigate climate change.

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