Enabling future climate policy

An analysis of policy gaps and progress under the Paris Agreement

Leonardo Nascimento

2024

Propositions

1. The Paris Agreement requires more robust accountability mechanisms for national actions to reduce greenhouse gas emissions.
   (this thesis)

2. Increasing climate policies' strength is not the only way to improve national climate action.
   (this thesis)

3. International cooperation takes time but remains fundamental to alleviate global problems.

4. Data and knowledge are now so deeply interlinked that data science will become a basic scientific expertise.

5. The pursuit of ideal solutions delays long-term societal progress.

6. Determination is more important than optimism in addressing complex issues.

Propositions belonging to the thesis of Leonardo Nascimento

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Thesis

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Contents of this thesis

1 Introduction

Climate change and the urgency to reduce greenhouse gas emissions

Climate change is one of the major issues facing humanity in this century. The changes in Earth's climate system are unprecedented over potentially thousands of years and result in diverse impacts, such as increases in the frequency and intensity of heat haves, heavy precipitations and droughts (IPCC, 2021). This impacts ecosystems and humans, which already experience loss and damages (IPCC, 2022). The evidence is unequivocal and shows that climate change is caused by human activities and the associated emission of greenhouse gases, especially those resulting from the combustion of fossil fuels (IPCC, 2021). These activities increase the atmospheric concentrations of greenhouse gases and results in increasingly warmer global average temperatures. Human-induced global average temperature increased 1.07°C between 1850 and 2019 (IPCC, 2021). Keeping temperature increase to 1.5°C will limit the increasingly worse impacts of climate change (IPCC, 2018b).

Curbing the impacts of climate change requires reducing the emission of greenhouse gases. Future emission scenarios compatible with limiting the global temperature increase to 1.5°C assume immediate action to peak and decline greenhouse gas emissions. This is needed to reduce emissions by 49% below the 2019 level by 2030 (IPCC, 2022). Any further delay on cutting emissions increases the efforts necessary to do so, since climate change is driven by cumulative greenhouse-gas emissions. Had global emission decline started in 2010, the world would have needed to reduce emissions by approximately 2% per year on average up to 2030 to limit temperature increase to 2°C (Höhne et al., 2020). However, emissions increased between 2010 and 2020. Therefore, current global emission level requires faster emission decline of approximately 3% per year to limit temperature increase to 2°C and 7% to limit it to 1.5°C (Höhne et al., 2020).

Although climate change is a global and international issue, emission reductions mostly result from national actions. Therefore, countries must coordinate their efforts to reduce greenhouse-gas emissions if they all intend to curb average global temperature increase. To that end, 198 Parties (i.e., countries) ratified the United Nations Framework Convention on Climate Change (UNFCCC) where they agreed to stabilise "greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UN, 1992). The UNFCCC sets the stage for enhanced communication and coordination on historical emission inventories, measures to reduce future emissions, international cooperation, among others. The UNFCCC established the institutional framework for climate action but the actual commitments to address climate change are set in its subsequent international treaties, the latest of which is the Paris Agreement (Kuyper et al., 2018).

The Paris Agreement and the Global Stocktake

The Paris Agreement is an international treaty where almost all countries in the world agreed to reduce their greenhouse gas emissions. It was adopted in 2015 during the United Nations 21st Climate Change Conference (COP21) in Paris, France, and is currently the main international mechanism governing climate change issues. The treaty has three main objectives (UNFCCC, 2015b). First, Parties agreed to mitigate greenhouse gas emissions in line with the global goal of limiting temperature increase to 2°C and pursue efforts to keep it below 1.5°C. Second, Parties strive to adapt to climate change impacts while fostering climate resilient development and ensuring food production. Third, they commit to align domestic and international finance flows with the two first objectives.

The Paris Agreement invites countries to communicate their own emission-reduction pledges or Nationally Determined Contributions (NDCs) to meet its collective goals (UNFCCC, 2015b). These targets should reflect countries' highest possible ambition while acknowledging their common but differentiated responsibilities and capabilities. Parties are also expected to review and revise these pledges over time to reflect evolving national and global circumstances. The original mitigation targets included in NDCs did not add up to the collective temperature goals of the agreement (Rogelj et al., 2016). After the first review cycle, updated NDCs improved and were complemented with long-term net zero targets (Höhne et al., 2021) but remain insufficient to keep temperature increase below 1.5°C (Meinshausen et al., 2022; UNEP, 2022). Currently adopted national policies lead to even higher emissions in 2030 compared to those promised by the NDCs (den Elzen et al., 2022a). These findings indicate that countries must collectively adopt more ambitious policies and targets to meet the international mitigation goals of the Paris Agreement.

The Paris Agreement includes an ambition mechanism to support countries in strengthening their pledges in a nationally determined manner. Part of this process is the Global Stocktake, which aims to assess collective progress in meeting the goals of the Paris Agreement and inform Parties in updating and enhancing their own actions (UNFCCC, 2015b). The first Global Stocktake, which takes place between 2021 and 2023, fulfils many functions. One of them is to provide accountability and ensure public appraisal of collective progress. However, to inform Parties in enhancing their actions, the Global Stocktake must also provide guidance to spur ambitious climate action and set the pace necessary to reach the global goals of the Paris Agreement (Hermwille et al., 2019). These functions can be achieved in multiple ways, such as through providing context-specific recommendations, developing sectoral roadmaps to inform national actions or sharing successful examples to be replicated.

Knowns and unknowns: climate policy adoption and progress since the Paris Agreement

The physical basis for climate change mitigation is clear. A global agreement to coordinate efforts across countries is also in place. However, countries still fail to collectively adopt policies and targets in line with global decarbonisation. This indicates that identifying means to evaluate and improve climate change mitigation efforts remain fundamental to ensure that countries collectively succeed in limiting end-of-century's global temperature increase to 1.5°C. In the following paragraphs, I summarise existing knowledge about the implementation of the mitigation objective of the Paris Agreement and adoption of climate policies. These topics have been extensively discussed in literature, but their continuous and improved analysis remain important to accelerate and deepen national and global climate change mitigation efforts.

The Paris Agreement succeeded in getting most countries in the world to agree to limit end-of-century temperature increase and, consequently, reduce anthropogenic greenhouse-gas emissions. However, the agreement relies on a decentralised mechanism where countries submitted their NDCs, which contain greenhouse gas emission targets (Rogelj et al., 2016; UNFCCC, 2015b). These targets are not reviewed and approved in a centralised manner. They are collectively assessed through the Global Stocktake, that intends to provide guidance on whether and how targets shall be improved to reach the collective goals of the agreement (Hermwille et al., 2019). This mechanism enables broad participation but hinders accountability of countries towards their own targets. Since the official process does not assess individual countries, other stakeholders have an important role in enhancing country-level accountability. However, this task requires national information about targets and policies.

Globally, emission targets and policies improved since the adoption of the Paris Agreement, but national-level evidence of progress remains scarce. The NDC synthesis report (UNFCCC, 2021) shows that global emission levels that result from the full implementation of the NDCs, is approximately one tenth lower compared to the original NDCs. Global temperature estimates also indicate that updated NDCs improve on previous ones (Ou et al., 2021). However, targets collectively still result in emission projections way above the pathway implied by the goals of the Paris Agreement (UNEP, 2022). In addition, global analyses do not show which countries’ targets are lower and which are higher. National-level emission projections implied by the NDCs of major emitting countries are available but lack a clear and detailed comparison to adopted policies (den Elzen et al., 2022a). Some studies (e.g., Climate Action Tracker, 2022; Nascimento *et al.*, 2022) have continuously projected emissions based on currently adopted climate policies and updated NDCs. However, no peer-reviewed literature to date has analysed national-level projections across many countries or analysed their implications for the ambition raising cycle of the Paris Agreement.

Comparing national emission projections based on currently adopted policies supports assessing mitigation progress since the adoption of the Paris Agreement. However, projections based on similar methods and consistent frameworks for multiple countries remain unavailable. Some information sources exist. For example, a few countries project emissions associated with their own adopted policies (UNFCCC, 2016). These modelling exercises led by countries help to identify national-specific levers to climate change mitigation, but different methodologies and reporting requirements hinder the comparison of information across countries (Weikmans et al., 2020). Although analyses prepared by international organisations constitute additional sources of emissions projections, they are only available for a few major emitting countries or only cover a subsector of their economies (APERC, 2022; IEA, 2022). Finally, global modelling teams also develop economy-wide emission projections but often provide results based on policies adopted up to three years prior to current times for a few geographical regions (Roelfsema et al., 2020). Therefore, developing and analysing up-to-date, economy-wide emissions projections under adopted policies constitutes an important contribution to assessing climate change mitigation progress since the adoption of the Paris Agreement.

Although assessing climate change mitigation progress improves accountability, countries clearly still need to improve their policies and actions aimed at reducing emissions. Climate policies have historically helped reducing emissions (Eskander & Fankhauser, 2020). The replication of key successful climate policies can lead also to substantial future emission reductions below currently adopted policies (Baptista et al., 2022; Fekete et al., 2021). Therefore, expanding climate policies is an important tool to shape future greenhouse gas emissions.

However, the increasingly higher number of climate policies hinders direct comparisons and analyses of policies across many countries. New methods to evaluate policies adoption beyond the total number of policies in force are necessary to compare climate-policy adoption and identify policy-expansion entry points. Comparative policy analyses, for example, investigate climate policy adoption and evolution across countries. They find that climate change mitigation policies are now prevalent in most countries in the world (Mundaca & Markandya, 2016; N. M. Schmidt & Fleig, 2018). They also show that the adoption of climate policies depends on national circumstances (Lamb & Minx, 2020; Le Quéré et al., 2019). Although many of these studies quantify the effect of policies, they often do not discuss these effects in the context of the broader policy package. Further exploring the links between emission modelling and comparative policy analyses can also lead to important findings for policymakers. For example, they support identifying cross-national, evidence-based entry points to expand climate policies. This can ensure that already existing policy options cover all relevant sectors and emissions. Even if an increase in policy coverage alone does not ensure emission reductions, low policy coverage suggests that emissions can be further reduced and that a portion of global emissions remain uncovered.

Against this backdrop, I identify two broad themes to be explored in this thesis. First, existing literature invites additional and continuous research regarding progress on the mitigation component of the Paris Agreement, especially considering both NDC updates and nationally adopted policies. Such analyses can fill existing research gaps when they consider cross-national, up-to-date evidence of the emission levels implied by policies and targets and their relationship to country characteristics. Second, the surveyed literature also invites analyses that investigate climate policy adoption and identify policy expansion entry points. Developing additional methods to analyse the breadth of climate policy adoption supports synthesising existing knowledge and inform policymaking. These findings can constitute a building block to increasing policies' collective effect and, consequently, improve climate change mitigation efforts.

Aim of the thesis

The aim of this thesis is twofold. First, I evaluate climate change mitigation progress since the adoption of the Paris Agreement, focusing on greenhouse gas emissions trajectories up to 2030. In these analyses, I investigate national progress across many countries and include insights about country differences to complement existing literature, which often focuses on global progress. Second, I aim to identify policy adoption entry points that constitute means to improve national and global climate policy. In these analyses, I build methods to translate thousands of adopted climate policies into actionable information for policymakers and researchers. Combined, these objectives contribute to the Global Stocktake process by providing evidence of progress and guidance on means to improve climate policy.

Against this backdrop, this thesis investigates four research questions (RQs):

1. How effective was the ambition raising cycle of the Paris Agreement in terms of improving national emission targets?
2. How have national emissions projections under current policies changed since the adoption of the Paris Agreement?
3. What are measurable changes in the adoption of policy options to reduce greenhouse gas emissions in the past twenty years and which main policy adoption gaps remain?
4. How does policy adoption affect projected greenhouse gas emissions and what are key entry points to expand policy coverage?

I discuss each of the research questions in this thesis' chapters, each of which corresponds to a manuscript published in a peer-reviewed journal. Although the content of the manuscripts remains unchanged, the versions included in this thesis were minorly edited to fit the thesis' format. The chapters can be grouped according to three thematic foci (Table 1). The first thematic focus refers to the development of new methods and frameworks to analyse mitigation efforts. All chapters of this thesis involve some degree of methodological novelty, but chapter 3 mostly rely on well-established methods. The second thematic focus refers to building national evidence of climate change mitigation progress. It involves applying existing or developed methods to analyse progress on the implementation of the mitigation component of the Paris Agreement and on the adoption of climate policies. The third thematic focus investigates strategies to expand climate policy adoption. It supports identifying areas that remain uncovered by climate policies and, consequently, entry points to expand their adoption.

Chapter 2 investigates countries' ambition raising patterns by comparing emission projections under currently adopted policies to original and updated NDC emission targets (RQ1). Under the Paris Agreement, countries are expected to submit and update climate change mitigation targets in line with their highest possible ambition. Ideally, this process of target ambition raising is followed by the adoption of stronger policies to implement them. We empirically analyse the first NDC update cycle to investigate whether there is a sequence of ambition raising and sufficient policy adoption in selected major emitting countries. We use the emission levels implied by policies to evaluate whether countries are projected to meet their targets. This chapter evaluates the Paris Agreement mechanism using emissions projections as the main methodological tool. We clarify which countries improved their targets, what is the relationship of these targets to adopted policies and how these patterns compare to national climate policy constraints. This chapter investigates the first ambition raising cycle of the Paris Agreement and provides a critical lens through which other researchers can assess NDC updates.

Table 1: Overview of research questions and thematic focus of the distinct chapters of this thesis.

Ch	Topic	Developing methods to analyse progress	Building national-level evidence of progress	Identifying strategies to expand climate policy
2	Evaluating national ambition raising considering adopted policies and targets (RQ1)	**	**	
3	Comparing the progression of emission projections under adopted policies (RQ2)	*	**	*
4	Identifying key policy adoption gaps and changes over time (RQ3)	**	*	**
5	Exploring the variation of policy adoption across countries (RQ4)	**		**
6	Synthesis and recommendations	*	*	*

Note: two asterisks indicate that this topic is the focus on the chapter, one indicates that the topic is still considered, even though less prominently.

Chapter 3 discusses progress of adopted policies over time by projecting greenhouse gas emissions up to 2030 (RQ2). We estimate the effect of policies adopted until 2015 on emissions projections for the G20 economies, which represent most of global emissions. We repeat the exercise with policies adopted until 2021 and compare the projected emissions level in 2030 for the G20 as a group and per country. The results clarifies whether more recent projections improve on the original ones and by how much. Country-level results also support identifying potential reasons behind these changes. In this chapter we measure progress of policies since the adoption of the Paris Agreement. Using emission projections to measure this progress helps to evaluate the long-term effect of policies in force and supports the comparison of the effect of policies adopted in different periods of time. This chapter provides evidence of the impact of climate change mitigation efforts and highlights that climate change mitigation futures are influenced by ongoing climate change mitigation efforts.

Chapter 4 evaluates the change in climate policies adopted in the past two decades to assess progress over time and identify main policy adoption gaps in the G20 countries (RQ3). Climate policies increased substantially in number in the past decades. This is a positive development, but a high number of policies hinder the comparison of their adoption across countries. In this chapter, we simplify this comparison by identifying a fixed list of policy options to reduce emissions and measuring the change in their prevalence over time. This chapter presents a typology of policy options to mitigate climate change, highlights areas where more progress has been achieved in the past twenty years and identifies policy adoption gaps. This chapter identifies adoption gaps that constitute clear opportunities to improve national and global climate policy adoption.

Chapter 5 compares the number of climate policies adopted per country and benchmark policy adoption using best performing countries (RQ4). Instead of evaluating policy adoption using a list of policy options (Chapter 4), we discuss the distribution of policies adopted per sector, policy instrument types and mitigation area. We also contextualise these distributions using countries emission projections based on adopted policies. We evaluate these distributions across country groups, especially emphasising the comparison to the group with the lowest projected emission change rate up to 2030. We also evaluate whether the size of the policy portfolio is associated with lower projected emissions. This chapter clarifies whether the number of policies in force is associated with lower projected emissions and indicates potential entry points to improve climate policy adoption. This chapter highlights the importance of climate policies in reducing future greenhouse gas emissions.

Chapter 6 summarises and discusses the key findings of the thesis and provides cross-cutting recommendations based on the results of the individual research chapters. These results inform continuous efforts to evaluate progress of the Paris Agreement and subsequent adoption and implementation of policies to reduce greenhouse gas emissions. In this chapter, I also put the findings in the context of the Global Stocktake process and implications for the forthcoming ambition raising cycles of the Paris Agreement.

2 Comparing the sequence of climate change mitigation targets and policies in major emitters

Summary

The Paris Agreement requires that countries submit and update their Nationally Determined Contributions (NDCs) to mitigate global climate change. This study projected greenhouse gas emissions to evaluate the progress of 25 countries towards their original and updated NDCs. It found that almost one-quarter of the countries submitted more ambitious, updated NDCs without adopting sufficient policies to meet their original targets. Additionally, in most countries, updated NDCs lead to emissions above current policies. The findings also suggest that these patterns are influenced by national constraints, especially reliance on fossil fuels. Appropriate sequencing of ambition raising and policy adoption is urgently needed to translate the Paris Agreement into action.

Nascimento, L., den Elzen, M., Kuramochi, T., Woollands, S., Dafnomilis, I., Moisio, M., Roelfsema, M., Forsell, N., & Araujo Gutierrez, Z. (2023). Comparing the Sequence of Climate Change Mitigation Targets and Policies in Major Emitting Economies. *Journal of Comparative Policy Analysis: Research and Practice*, 1–18. https://doi.org/10.1080/13876988.2023.2255151

2.1 Introduction

The Paris Agreement sets long-term goals to strengthen the global response to climate change. It aims to hold the increase in global average temperature to well below 2°C and to pursue efforts to limit it to 1.5°C above pre-industrial levels. To achieve this goal, it recognises the need to peak global greenhouse gas (GHG) emissions as soon as possible (UNFCCC, 2015b). In this context, Parties to the agreement are invited to submit self-determined pledges, or Nationally Determined Contributions (NDCs), in line with their capabilities and responsibilities, and to implement actions to meet them. These NDCs often include 2030 emissions targets that reflect the climate change mitigation component of countries' pledges.

The full implementation of targets included in NDCs submitted in the lead-up to the Paris Agreement would be insufficient to meet its collective goals (Rogelj et al., 2016). Adopted policies in many countries are expected to lead to more emissions compared to original NDCs. Years after the Paris Agreement, half of the G20 economies were projected to miss their NDCs (den Elzen et al., 2019). Many non-G20 countries also need to adopt additional policies to meet their NDCs (Kuramochi et al., 2021). Although policy options to reduce emissions exist, many of them remain absent in major emitting countries (Nascimento, Kuramochi, Iacobuta, et al., 2022).

Countries are expected to improve their NDCs over time, closing the gap between national ambition and global goals. At least once every five years, countries should communicate updated NDCs that represent their highest possible ambition. This ambition-raising process has started; in the lead-up to the Conference of Parties in Glasgow, most countries submitted updated NDCs that would result in 2030 emissions 7% lower than original targets (den Elzen et al., 2022a). In 2021, emissions projections resulting from adopted policies are also 15% lower than estimated in 2015 for the G20 as a group (Nascimento, Kuramochi, & Höhne, 2022). This shows that both NDCs and policies improved over time. However, little national evidence connecting this round of NDC updates and adopted policies is available.

Global analyses show that an ambition gap exists between countries' updated NDCs and adopted policies (den Elzen et al., 2022a). However, country-specific analyses are better suited to inform and guide national mitigation efforts. For example, countries that are projected to meet their NDCs are well positioned to increase their ambitions. 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 has 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 are key to improving accountability under the Paris Agreement.

In our research, we prepared and compared emissions 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 emissions projections to 2030 under NDC targets and adopted policies. These projections show whether countries are expected to meet their NDCs and enable the proposed framework to identify ambition-raising patterns. Finally, we analysed whether architectures of climate policy constraints are associated with countries' ambition-raising patterns. In our research, we analysed 25 economies[1] that together represent four-fifths of global emissions (Crippa et al., 2021; FAOSTAT, 2022).

2.2 Analytical approach

This section presents important elements of our analytical approach. First, we introduce the ambition-raising framework, which is an idealised sequence of ambition raising and policy adoption leading to emissions reductions (Section 2.1). Although the pathways leading to improvements in climate change mitigation efforts are complex, a conceptual framework can assist in identifying cross-national patterns beyond determining whether a country is projected to miss or meet their NDC targets. Second, we introduce architectures of national climate policy constraints (Section 2.2), which are country characteristics that influence national climate action (Lamb & Minx, 2020). We use them to explore the national-level relationship between patterns of ambition raising and national constraints of climate policy.

2.2.1 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 (Figure 1).

Ideally, original NDCs include a 2030 target to reduce emissions below those implied by policies adopted (Figure 1: stage I). This is a fundamental component of NDC targets since they are expected to reflect the highest possible ambition (Höhne, Kuramochi, et al., 2017). Once these NDCs are adopted, they stimulate national action and positively affect the rollout of climate change mitigation technologies (Iacobuta et al., 2018; Tolliver et al., 2020), which reduce emissions projections under adopted policies (Figure 1: stage II). Some delay between the adoption of NDCs and policies is expected since NDC formulation is often disconnected from other in-country processes (Röser et al., 2020). However, policies eventually adopted should lead to emissions below the NDC.

Once a country is projected to meet its original NDC, it is well positioned to improve that target (Figure 1: stage III). Five years after the adoption of the Paris Agreement, between 2020 and 2021, several countries updated their NDCs. Since updated NDCs are often more ambitious than previous ones (den Elzen et al., 2022a), a country would be projected to miss its updated NDC shortly after it was produced. However, over time additional policy adoption is expected to reduce emissions further, so that countries also meet their updated NDCs (Figure 1: stage IV).

This framework relies on two concepts: ambition raising and policy adoption.

Operationalising ambition is challenging. Approaches to evaluating the ambition of NDCs often rely on "moral obligation" or "technical efficiency" principles (Höhne, Fekete, et al., 2017). The former compares NDCs to emissions allowances under distinct equity approaches, such as historical responsibility – i.e., those who emitted more in the past have lower emissions allowances (Robiou du Pont & Meinshausen, 2018). The latter assesses NDC ambition against technical pathways necessary to reach global decarbonisation (Aldy et al., 2016). Our analysis does not assess the level of ambition and fairness of NDCs. We consider them to be intrinsically heterogeneous and decided to focus on ambition raising.

[1] Argentina, Australia, Brazil, Canada, China, Colombia, Egypt, Ethiopia, the EU27, India, Indonesia, Iran, Japan, Mexico, Morocco, Russia, Saudi Arabia, South Africa, South Korea, Thailand, Turkey, United Arab Emirates, United Kingdom, the United States and Vietnam.

This concept captures the process of enhancing NDCs, independently of how they fare in comparison to different ambition evaluation approaches. We estimated the emissions associated with original and updated NDC targets and evaluated whether updated NDCs result in lower or higher emissions by 2030.

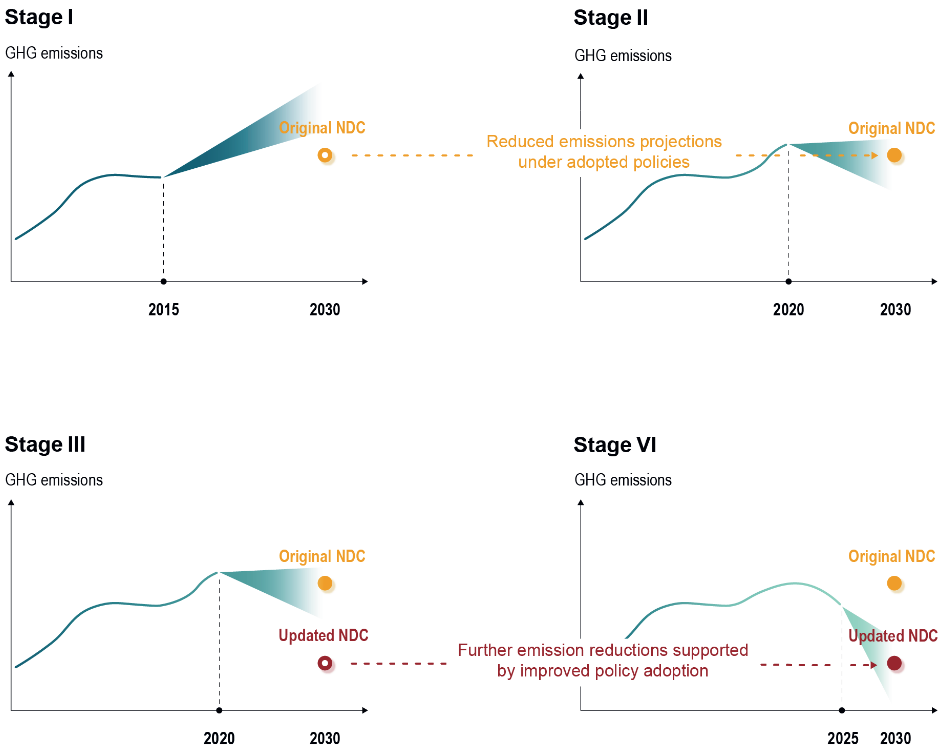

Figure 1: Sequencing ambition raising and policy adoption reduces emissions over time.

To operationalise *policy adoption*, we prepared emissions projections associated with countries' adopted policies (Roelfsema et al., 2022). Most NDCs contain emissions targets for 2030, so projecting emissions based on policies up to 2030 enables a direct comparison of countries' policies and targets. First, we identified climate policies adopted with a potential effect on GHG emissions projections. We then evaluated whether there is sufficient evidence of their implementation. For example, policies that aim at achieving a certain renewable electricity share are only included in the quantification when there are sufficient instruments supporting the uptake of renewables, such as auction schemes or subsidies, and/or whether the observed historical renewables growth is aligned with the aims of the policy. Finally, once the relevant policies were identified and analysed, we estimated their effect on emissions using different models (Section 3).

As a result of this idealized framework and our operationalisation, four groups of countries can be identified:

- **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 record and have set updated NDCs that guide additional mitigation efforts.

- **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.
- **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.
- **No ambition raising:** includes countries that did not increase the ambition of their original NDCs. For example, countries that did not submit updated NDCs or submitted updated NDCs including the same emissions target. This category includes countries that missed the opportunity to raise the ambition of their NDC independently of whether they are expected to meet their original NDCs.

2.2.2 Architectures of national climate policy constraint

Countries' NDCs are influenced by their national circumstances (Tørstad et al., 2020), including institutions, interests and ideas (Hall et al., 1997). In our analysis, we evaluate whether equivalent national circumstances also affect ambition raising.

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 & Minx, 2020). They account for combinations of, instead of individual factors, such as exposure to corruption and economic reliance on fossil fuel production and extraction. In Lamb and Minx (2020), countries are grouped into five architectures of climate policy constraints based on their similarity in distinct constraints. We analysed the prevalence of these architectures across countries to identify whether countries categorised in architectures with higher constraints to national climate policy also exhibit a lack of appropriate sequencing between ambition and policy adoption.

Here, we briefly describe the five architectures of climate policy constraints from those with the highest to the lowest level of constraint (Lamb & Minx, 2020). "Oil and gas states" heavily rely on revenues from fossil fuel extraction and production. Countries in this group face many challenges to adopting climate policies, have high levels of subsidies for fossil fuels and weaker institutions compared to other groups. They are followed by the "fragile states" group, which includes several low-income countries. Like the first, this group still has high levels of fossil fuel subsidies and few climate policies. It is responsible for an extremely low share of global emissions, and its members usually have low emissions per capita. The third group is named "coal-dependent development" and includes several fast-growing economies that often rely on high shares of coal to power their economic and energy use growth. The countries in this group are very diverse and "tend to occupy the middle-ground of political economic constraints" (Lamb & Minx, 2020). The fourth group, named "fractured democracies," includes several high-income countries that are advanced in strengthening their institutions, but have failed to substantially reduce corruption and suffer from low trust in their institutions. Finally, the fifth group with the lowest levels of constraint is "wealthy OECD" countries. This group includes several OECD countries which have substantial climate policies, stronger institutions, and high levels of climate change awareness. In our research, the 25 economies analysed[2]2 are categorised as follows:

- **Oil and gas states:** Egypt, Iran, Saudi Arabia and United Arab Emirates
- **Fragile states:** Ethiopia, Mexico and Morocco
- **Coal dependent development:** China, India, Indonesia, Russia, South Africa, Thailand, Turkey and Viet Nam.
- **Fractured democracies:** Argentina, Brazil and Colombia
- **Wealthy OECD:** Australia, Canada, the EU27, Japan, South Korea, the United Kingdom, and the United States.

2.3 Methods

To analyse ambition raising, we estimated and compared the effect of policies and NDC targets on projected emissions in 2030. We then mapped countries to categories depending on their ambition-raising patterns. Finally, we analysed the prevalence of architectures of climate policy constraint across these categories to investigate whether they are associated with countries' ambition-raising patterns.

The 25 economies analysed cover different income groups and continents. The selection covers all G20 and selected non-G20 economies with substantial emissions, such as Iran and Viet Nam. Limiting the country scope allows for sufficiently detailed analysis of countries' targets and policies. Analysing these 25 economies also supports international accountability of NDC targets covering most global emissions. We present greenhouse gas emissions in terms of 100-year global warming potentials from the IPCC Fourth Assessment report to allow for aggregation of different gases (IPCC, 2007).

Original and updated NDC scenarios

In our NDC scenarios, we calculated absolute emissions targets based on information presented in countries' NDCs (SM2 - Table 7).

We analysed progress towards countries' unconditional NDC targets, which they aim to meet without international support. In the absence of fully unconditional targets, we assessed progress towards countries' conditional targets. This is the case for Egypt and South Africa. Ethiopia only had a conditional target in its original NDC but included an unconditional one in its updated NDC. To avoid comparing different types of targets, we did not quantify Ethiopia's original target and only assess progress towards their updated unconditional target. Additionally, the United States' original NDC only covers the period up to 2025. We used emissions projections implied by the United States' policies in 2025 when assessing progress towards the original NDC. In our research, original NDCs are those submitted around the adoption of the Paris Agreement and updated NDCs include targets submitted before September 2022.

Policy scenario

We created a range for emissions based on selected policies that collectively cover all sectors of the economy. The results correspond to the middle of the range of the models. We conducted a careful

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[2] Ethiopia, the EU27 and the United Arab Emirates are not classified in Lamb and Minx (2020). Here, we classified the UAE as an oil and gas state because of its high levels of fossil fuel rents, together with Saudi Arabia and Iran. These countries also have similar values for coal share and democratic norms. Ethiopia is classified as a fragile state due to the low levels of emissions per capita and marginal progress on climate policies and fossil fuel subsidy removal. We classified the EU27 in the wealthy OECD group.

analysis to define which policies should be included in the quantification for each country. Each selected policy has a set of quantifiable indicators, such as fuel efficiency standards or a renewable target. We used these indicators to estimate the emissions associated with each policy and then subtracted that effect from a reference scenario. We combined projections prepared using multiple models[3] that use different strategies to estimate the effect of policies, thereby reducing some of the uncertainty associated with policies' quantification (Supplementary Material). The policies' selection and methods for estimating the effect of policies in each model are outlined in Nascimento et al. (2022).

In our analysis, we assume that the selected policies will be fully implemented. However, diverse factors, such as countries' economic and political circumstances, will probably affect their implementation. Policies in force may also be dismantled with administration changes (Jotzo et al., 2018a). The actual emissions of these countries in 2030 is intrinsically uncertain. However, this policy scenario constitutes our best-available estimate of the effect of policies as of June 2022. All projections are harmonised to official historical emissions based on country GHG inventories (SM2 - Table 8).

Mapping countries to ambition raising categories

All countries analysed communicated 2030 emissions targets with their NDCs[4]. We compared the absolute levels of emissions in 2030 between the policies and NDC scenarios to categorise countries into ambition-raising categories. Although our analyses result in a range of emissions in 2030 (Table S2), we assess whether a country is projected to meet its NDC based on the middle of the current policy range.

National constraints to ambition raising

Once countries were mapped to the ambition-raising categories (Section 2.2.1), we identified whether specific architectures of constraint are related to countries' ambition-raising patterns. For this purpose, we explored the prevalence of these time-invariant country characteristics across ambition-raising categories.

2.4 Results

2.4.1 Quantifying NDC targets and policies

Updated NDCs generally result in lower emissions levels compared to original NDCs, except for Brazil, Mexico and Thailand (Table 2). For Brazil and Mexico, absolute emissions associated with the updated NDC resulted in higher emissions compared to the original ones due to changes in reference emissions. Even after the 2022 update, Brazil's updated NDC emissions target remains 7% above the original. Mexico submitted an updated NDC in 2020 with the same percentage reduction target as the original NDC but increased the reference scenario. This results in 2030 emissions projections 2% higher than the original NDC. Thailand re-submitted the original emissions target in its updated NDC.

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[3] Emissions projections (excluding land use, land-use change and forestry (LULUCF)) were calculated using the integrated assessment model IMAGE (Roelfsema et al., 2022) and a bottom-up model based on spreadsheet calculations that estimate the impact of policies on country-specific reference scenarios (Nascimento et al., 2022a). The final projection represents the midpoint between both models. Additionally, the LULUCF emissions projection is calculated by the GLOBIOM land use model. For further details, see Supplementary Information.

[4] As of June 2023, Iran has not ratified the Paris Agreement, so we considered Iran's intended NDC as its NDC.

All countries projected to meet their updated NDCs are also projected to meet their original ones (Table 2). Out of the 25 countries analysed, 11 are projected to meet their updated NDCs. These 11 countries represented 43% of global emissions in 2019.

However, most countries projected to meet their targets have updated NDCs that imply a substantial increase in emissions compared to historical values. The median increase in emissions of these countries between 2019 levels and the 2030 target is 29% (range: 1%–59%). In many cases, updated NDCs also lead to emissions substantially above policy projections. This indicates that countries could increase the ambition of their targets without additional policies. Updated NDCs are at least 30% above the policies in 2030 in Viet Nam (45%), Iran (40%), Ethiopia (40%), Turkey (40%) and Mexico (30%). Russian and Indian emissions are projected to be 20% higher compared to their updated NDCs.

Table 2: Emissions (in $MtCO_2eq$) under distinct scenarios and progress towards meeting original (2014-2016) and updated. The values represent the middle-point of the projections range and are rounded to the closest ten. 'N/A' indicates that no target was available.

	2019 levels	2030 policies	Original NDC	Updated NDC
Projected to miss both original and updated NDCs (n=7)				
Brazil	1030	1770	1200	1320
Canada	740	720	520	420
Colombia	180	310	270	160
Indonesia	950	2130	2040	1950
South Korea	710	600	540	440
Thailand	370	480	440	440
USA	6570	4840	4100	3230
Projected to meet original NDC but miss updated NDC target (n=7)				
Argentina	340	390	480	350
Australia	550	400	440	350
EU	3600	2700	3390	2080
Japan	1210	1000	1080	810
South Africa	530	450	510	390
United Arab Emirates	230	250	240	210
United Kingdom	450	310	N/A	260
Projected to meet both original and updated NDCs (n=11)				
China	13400	13000	14300	13500
Egypt	350	430	N/A	510
Ethiopia	140	210	N/A	350
India	3150	3620	5010	4440
Iran	1040	1190	1960	N/A
Mexico	740	570	760	770
Morocco	90	100	140	120
Russia	2120	1720	2240	2160
Saudi Arabia	660	740	980	840
Turkey	510	570	930	N/A
Viet Nam	460	460	880	840

The 14 countries set to miss their updated NDCs represented 37% of global emissions in 2019. Seven of these countries are projected to meet their original NDCs and used this ambition-raising cycle to set more ambitious ones (Table 2). The remaining countries set more ambitious updated targets without adopting sufficient policies to meet the previous ones.

Iran, Thailand, Indonesia, Mexico, Viet Nam, Morocco, India and Ethiopia have submitted conditional targets in addition to their unconditional ones. We find that considering the conditional targets would not substantially change the results. Iran, India, Mexico and Viet Nam are projected to meet, while Thailand and Indonesia are projected to miss both NDC targets. Considering conditional NDCs would change the results for Morocco and Ethiopia. Both countries are projected to meet their unconditional targets but miss their conditional targets. Therefore, considering unconditional targets favours these two countries.

Emissions per capita vary substantially across countries (SM2 – Figure 16). Even if all countries meet their updated NDCs, per capita differences are expected to remain important in 2030.

Aggregated 2030 emissions[5] under policies for the group are projected to reach 40.9 $GtCO_2eq$ (range: 38.1-43.6 $GtCO_2eq$), and 38.8 $GtCO_2eq$ (range: 37.2-40.5 $GtCO_2eq$) under updated NDCs. Therefore, emissions associated with policies are approximately 5% above NDCs in 2030. Global analyses show current policies' emissions 14% above NDCs in 2030 (den Elzen et al., 2022a). Our percentage difference is lower because global studies use the current policy emissions level as the value for aggregation when countries have current policy projections below NDCs. Taking the same approach, we find that emissions under current policies are 15% above updated NDCs in 2030.

2.4.2 Patterns of ambition raising

Once we had quantified emissions under targets and policies, we used the framework introduced in Section 2.2 to evaluate countries' ambition-raising patterns. In most cases, identifying countries that increased their ambition is straightforward based on 2030 emissions (Table 2). However, some cases are more difficult to assess. Brazil's updated target is projected to result in higher 2030 emissions compared to the original NDC. The original target was a reduction of 43% below 2005 levels by 2030. An upward revision of the 2005 emissions inventory resulted in higher 2030 emissions. In a subsequent update, Brazil submitted a target to reduce emissions by 50% between 2005 and 2030. This percentage improvement is insufficient to offset the increase in 2005 emissions. Nonetheless, since the updated target improves the percentage reduction, we consider that Brazil increased the ambition of its NDC. We only consider that a country did not increase ambition when it did not submit an updated NDC or when it did not improve the percentage or absolute target in its updated NDC.

Over one-quarter of the countries analysed fall into the "ambition raising follows sufficient policy adoption" category (Figure 2). These countries are projected to meet their original NDCs but fall short of meeting 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 as the European Union when it comes to its original NDC. Most of these are high-income OECD countries with the lowest estimated level of constraints.

Almost one-quarter of the countries analysed fall into the "ambition raising without sufficient policy adoption" category (Figure 2). These countries adopted more ambitious updated NDCs without adopting sufficient policies to meet the original NDC. Countries in this category are Brazil, Colombia, Canada,

[5] Global values result from the combination of emissions including and excluding LULUCF, depending on the scope of the NDC.

Indonesia, the United States and South Korea. 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 implementing 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 of the countries with the highest per capita emissions.

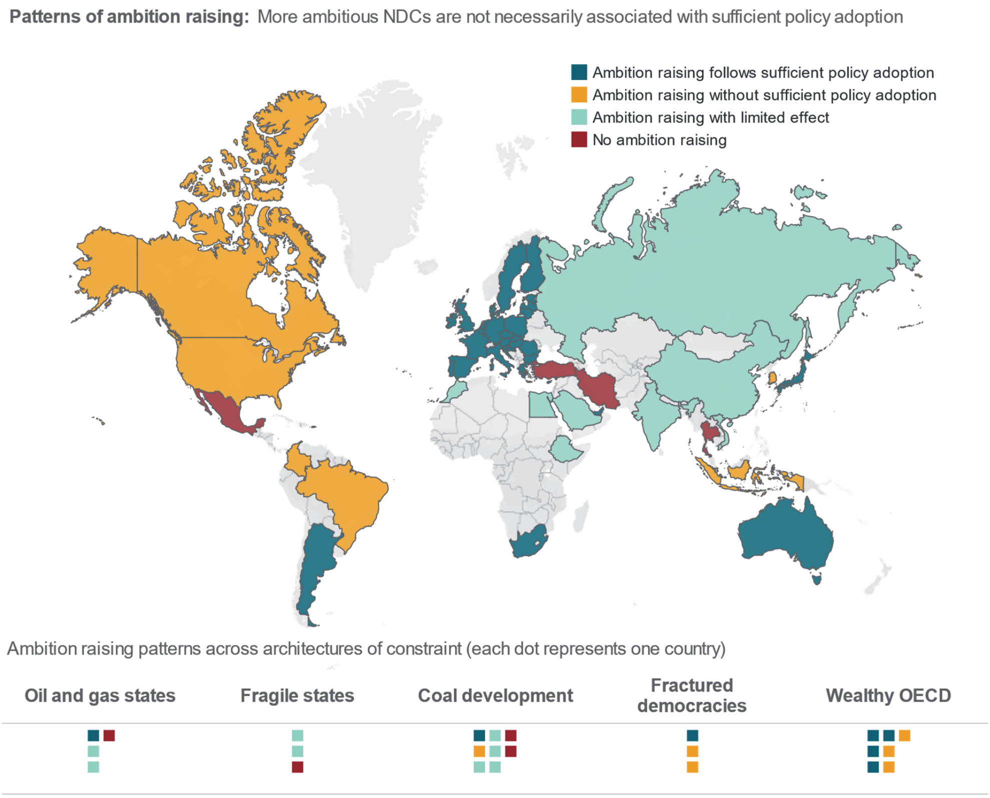


Figure 2: Patterns of ambition raising and associated architectures of climate policy constraint.

Almost one-third of the countries analysed fall into the category "ambition raising with limited effect" (Figure 2). These countries adopted more ambitious updated NDCs and are directly projected to meet them. They are China, Morocco, Egypt, India, Russia, Saudi Arabia and Viet Nam. Egypt does not have an emissions target in its original NDC. In our analysis, we considered that Egypt raised its NDC ambition by adding emissions 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 rely heavily 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 ambitions, these targets will probably have a limited effect in 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 2). 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 emissions 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.

2.5 Discussion

In our analysis, we updated historical emissions data to account for the latest governmental inventories, including those in the Biennial Update Reports and National Communications. We also included the latest policy developments in updated current policy and NDC scenarios for all countries – which is fundamental to assess progress over time. Finally, we also evaluated countries' NDC ambition raising accounting for policies and constraints. This perspective adds nuance to analysis of progress towards NDCs since a country projected to miss its updated NDC is not necessarily to blame, and vice versa. We highlight that NDCs are often not associated with policy adoption or do not imply emissions reductions beyond those resulting from policies.

More broadly, our findings have implications for the literature on the relationship between national and international climate politics. This literature recognises that these levels of climate politics are connected and influence one another (Tosun & Peters, 2020). For example, more inclusive and comprehensive NDC preparation processes raise political awareness and improve readiness to adopt and implement national climate policies (Röser et al., 2020). However, we find that NDCs are not necessarily followed by sufficient policy adoption, even though this relationship is a tenet of the Paris Agreement's ambition-raising mechanism (Dimitrov et al., 2019).

In addition, our findings suggest that similar mechanisms hinder national climate policy and explain variation in ambition raising. We build on the concept that institutions, ideas and interests influence countries' national climate policy to find that they also influence ambition-raising patterns. Countries with fewer national constraints raised the ambition of the targets once they adopted sufficient policies to meet their original targets and countries with higher constraints tend to set targets that have a limited effect on national policies or completely ignore the call to raise their ambition.

Our findings contribute to the literature analysing countries' updated NDCs but are subject to distinct limitations.

Since emission target setting is highly heterogeneous, focusing on emissions projections alone restricts the ambition-raising analysis. For example, countries being unambitious in their NDC target setting may help balance domestic priorities and lead to diverse benefits (Maor et al., 2017). This implies that unambitious NDC targets might still support climate action. However, we argue that NDC targets that do not guide countries beyond current policies are insufficient considering that the Paris Agreement calls for the "highest possible ambition" and the urgency of reducing global GHG emissions. Identifying countries that raise the ambition of NDCs with limited effect on emissions is also important to limit free riding (Bang et al., 2016). Our analysis helps to identify countries where NDCs do not guide substantial additional mitigation efforts.

Categorising countries into the "ambition raising without sufficient policy adoption" group could also be considered overly restrictive since these countries can still adopt policies to meet their NDCs. However, most countries analysed in this category are wealthy OECD countries, which have high historical responsibility for climate change and capacity to act. Our approach enables a clearer differentiation between countries that are still projected to miss their original NDCs and countries that are projected to meet their original NDCs and have raised their ambitions.

In our research, we did not discuss the long-term implications of this sequencing since we focused on the ambition-raising process up to 2022. Incremental sequencing of ambition raising and policy adoption may lead to a convex emission curve (i.e., emissions reduction rate accelerating over time). This is problematic because it increases cumulative emissions when emissions reduction increments between the sequencing stages are small and/or when countries delay ambition raising or policy adoption. Our framework contributes to this discussion. It shows in which countries emissions reduction increments of NDC updates do not lead to 2030 emissions below current policies. It also identifies countries that delay action by not submitting updated NDCs (delaying ambition raising) or by not adopting sufficient policies to meet their original NDCs (delaying policy adoption). Our framework does not address these issues but supports identifying them.

We also did not investigate the reasons why countries are projected to meet their targets. In some cases, this is influenced by factors beyond policy adoption (Nascimento, Kuramochi, & Höhne, 2022). For example, improved representation of data related to land cover substantially reduced Mexico's historical emissions levels. Since all projections are harmonised to historical data, 2030 emissions are also reduced and indicate that Mexico is projected to meet its NDC. However, these reasons do not change the estimate that countries are projected to meet (or miss) their targets. Our analysis clarifies which countries are in 2022 projected to meet their original and updated NDCs and whether this is aligned with the Paris Agreement's ambition-raising mechanism. This expands analyses that investigate progress towards NDCs.

Although the countries in this analysis represent most global emissions, the sample is small for statistical analyses. The findings of this research offer a novel perspective to evaluate ambition raising but remain insufficient to comprehensively explore the underlying mechanisms explaining different ambition-raising patterns. Replicating this analysis using national-level emission projections based on current policies for a larger sample would help identify whether the patterns observed here are maintained in a large-N analysis. Analyses focusing on specific explanatory factors, such as state capacity or role of the country in international negotiations, also support exploring how national characteristics and ambition raising are related. Our findings points to the need for additional analyses that aim to understand and leverage the process of ambition raising and the relationships between national and international climate policy.

2.6 Conclusions

In our research, we evaluated countries' progress towards their NDCs in the context of the ambition-raising mechanism of the Paris Agreement. We projected greenhouse gas emissions up to 2030 in line with countries' policies and compared the results to original and updated NDCs. We evaluated how countries' ambition raising, defined as the act of increasing the ambition of the emissions targets in NDCs, relates to the emissions implied by adopted policies using an idealised ambition-raising sequence as a conceptual framework. We also assessed the prevalence of national architectures of climate policy constraints to identify whether they are associated with different ambition-raising patterns.

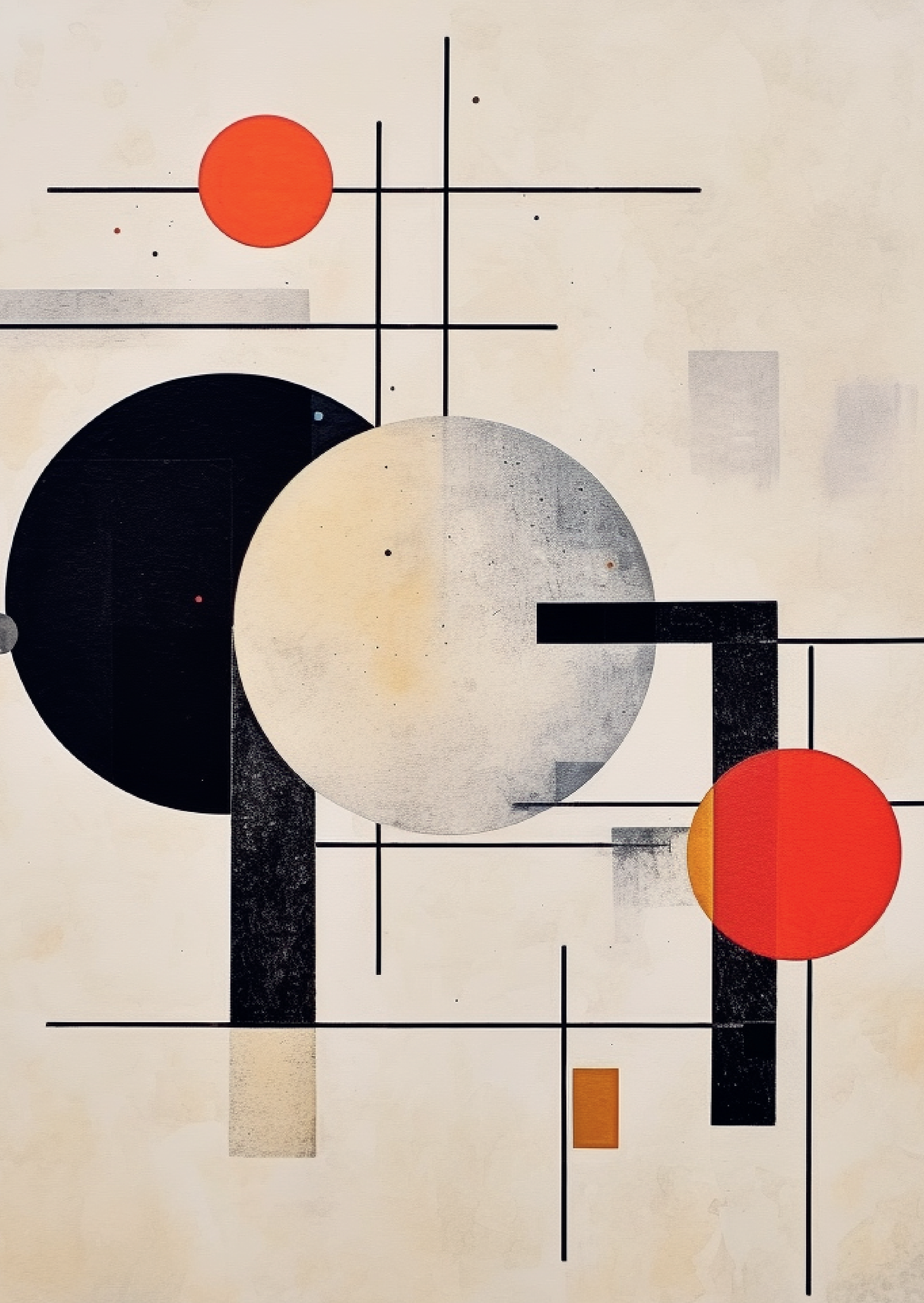
We find that most countries need to implement additional policies to meet their NDCs. Out of the 25 countries analysed, 18 are projected to meet their original targets and 11 are projected to meet their updated NDCs. A reduction in the number of countries projected to meet their NDCs results from NDC updates representing a progression compared to the original ones. More outstanding are the 11 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 meet the long-term goal of the Paris Agreement, since ambitious NDCs guide short-term action and reduce pressure on post-2030 emissions reduction rates (Höhne et al., 2020).

Additionally, in almost 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's 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.

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 ambitions with limited effect (NDC above current policies) or not raise the ambition of their NDCs 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.

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 policy adoption is urgently needed to translate the Paris Agreement into action.



3 The G20-emissions projections to 2030 improved since the Paris Agreement, but only slightly

Summary

Many years passed since the adoption of the Paris Agreement, which requires countries to determine their own contributions to climate change mitigation efforts. The Agreement does not offer a standard to measure progress but relies on a process of periodic stocktakes to inform ambition-raising cycles. To contribute to this process, we compare 2021 greenhouse gas emissions projections up to 2030 against equivalent projections prepared back in 2015. Both sets of projections were prepared using the same bottom-up modelling approach that accounts for adopted policies at the time.

We find that 2021 projections for the G20 as a group are almost 15% lower (approximately 6 $GtCO_2eq$) in 2030 than projected in 2015. Annual emissions grow 1% slower in the coming decade than projected in 2015. This slower growth mostly stems from the adoption of new policies and updated expectations on technology uptake and economic growth. However, around one-quarter of these changes are explained by the effects of the COVID-19 pandemic on short-term emissions and economic forecasts. These factors combined result in substantially lower emissions projections for India, the European Union plus the United Kingdom (EU27+UK), the United States, Russia, Saudi Arabia and South Africa. We observe a remarkable change in South Africa projections, that changed from a substantial increase to now a decline, driven in part by the planned phase-out of most of its coal-based power. Emissions in India are projected to grow slower than in 2015 and in Indonesia faster, but emissions per capita in both countries remain below 5 tCO_2eq in 2030, while those in the EU27+UK decline faster than expected in 2015 and probably cross the 5 tCO_2eq threshold before 2030. Projected emissions per capita in Australia, Canada, Saudi Arabia, and the United States are now lower than projected in 2015 but remain above 15 tCO_2eq in 2030. Although emissions projections for the G20 improved since 2015, collectively they still slightly increase until 2030 and remain insufficient to meet the Paris Agreement temperature goals. The G20 must urgently and drastically improve adopted policies and actions to limit the end-of-century warming to 1.5°C.

Nascimento, L., Kuramochi, T. and Höhne, N. (2022) 'The G20 emission projections to 2030 improved since the Paris Agreement, but only slightly', *Mitigation and Adaptation Strategies for Global Change*, 27(6), p. 39. doi:10.1007/s11027-022-10018-5

3.1 Introduction

More than two decades have passed since major emitting countries had a mandate to limit their greenhouse-gas (GHG) emissions (Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), 1997). Since then, global GHG emissions have almost doubled and the effects of climate change intensified (IPCC, 2021; Olivier & Peters, 2021; Tubiello, 2020). The long-term temperature goals also became stricter, from 2°C at the time of the 2009 Copenhagen Accord to 'well below 2°C' and 'efforts to limit the temperature increase to 1.5°C' in the 2015 Paris Agreement. The efforts necessary to reach these goals increases substantially the longer countries wait to curb their emissions (Höhne et al., 2020).

Under the Paris Agreement, countries are invited to submit Nationally Determined Contributions (NDCs), which are pledges that reflect countries' own interpretation of a fair contribution to the challenge of reducing global emissions and keeping end-of-century warming below 1.5°C (UNFCCC, 2015b). There is no common-agreed standard to measure the adequacy of each NDCs or the actual progress towards them. Instead, the UNFCCC process relies on periodic stocktakes that shall 'inform Parties in updating and enhancing, in a nationally determined manner, their actions' (UNFCCC, 2018a). To evaluate progress over time is essential to make the Paris Agreement ambition raising mechanism work.

Since the Paris Agreement was adopted, several countries updated their NDCs, which vary in content and implied absolute emission levels but collectively result in emissions lower than the original ones (Climate Action Tracker, 2021; den Elzen et al., 2022a; UNFCCC, 2021). Countries now also announce long-term pledges to reach net zero emissions (Fankhauser et al., 2022; Rogelj et al., 2021). Temperature estimates based on meeting NDCs and net zero targets show an increase in the likelihood of limiting end of century warming temperature increase to 1.5°C (Höhne et al., 2021; Keramidas et al., 2022; Meinshausen et al., 2022). Countries' pledges are not equivalent to actions and still fail to secure the global temperature goals but got a boost since the adoption of the Paris Agreement.

Several developments since 2015 affect countries' ability to meet these pledges. The adoption of each additional climate policy likely reduces national emissions intensity (Eskander & Fankhauser, 2020). However, the addition of policies alone does not ensure their collective effectiveness (Dubash, 2020). Policies remain absent in important mitigation areas (Nascimento, Kuramochi, Iacobuta, et al., 2022) and a mismatch between policy adoption and implementation is observed in key emitters (Silva Junior et al., 2021). Non-policy factors influence emissions as well. The global COVID-19 pandemic, for example, resulted in short-term emissions decrease and a global economic downturn (Le Quéré et al., 2020; Z. Liu et al., 2020). Yet, despite the multiple calls to use this moment to increase low-carbon investments, current recovery spending remains insufficient to put countries in a low-carbon trajectory (e.g., Andrijevic et al., 2020; Barbier, 2020; Hans et al., 2022; Rochedo et al., 2021). To periodically track changes in emissions projections under adopted policies, not only pledges, is fundamental to assess progress towards meeting the goals of the Paris Agreement.

Projected global emissions under adopted policies lead to higher emissions when compared to pledges (den Elzen et al., 2021). Diverse integrated assessment models show that recent policy-based emissions projections remain insufficient to meet global temperature goals (Sognnaes et al., 2021). The median of emissions across studies that use distinct quantification methodologies indicate that global emissions under adopted policies have not yet peaked and are not expected to do so before 2030 (den Elzen et al., 2021). Policies are sometimes also insufficient to meet countries' own NDCs (den Elzen et al., 2019; Kuramochi et al., 2021). Even though these results vary across countries, research suggests that collectively countries must implement substantial additional policies and actions to keep global temperature targets within reach.

Although research analysing the collective effect of adopted policies exists, the progress of national emissions projections is unclear. More precisely, the change in projections under adopted policies for individual countries, between 2015 and 2021, has not been quantified to date. Höhne *et al.* (Höhne et al., 2020) indicate whether 2030 emissions are lower or higher when comparing 2015 to 2020 projections but focus exclusively on trends in a few major emitters. Here, we aim to fill this research gap by investigating how emissions projections, which include most recently adopted policies and the COVID-19 pandemic, progressed in the G20 countries[6] since the adoption of the Paris Agreement. We compare emissions projections prepared in 2015 to projections prepared in 2021, both sets include the effect of the policies adopted at that time. We measure whether absolute emission levels in 2030 changed since 2015, evaluate how countries' estimates contribute to these changes and discuss factors that influence observed changes.

Our research is mostly descriptive as it does not attempt to attribute changes in emissions to specific national or international developments. For example, it does not quantify the effect of individual policies or changes in macro-economic outlooks. Instead, it presents national emissions trajectories up to 2030 and discusses factors explaining changes between projections developed in 2015 and 2021.

3.2 Data and methods

3.2.1 Definition of policy scenario and data sources

All emissions projections presented in our analysis can be termed 'adopted policies scenarios' or 'current policy scenario.' They are based on the full implementation of adopted climate and energy policies but exclude policies that were only planned or considered when projections were prepared. The 2015 projections include policies adopted at the latest by 2015, the 2021 projections have 2021 as cut-off date. NDC and other policy targets are not included unless they are supported by adopted policies or that sufficient evidence of their implementation exists. Due to legislative and data available differences across countries, the policy-selection criteria differ for each country. Our definition is compatible with other studies (den Elzen et al., 2019; Kuramochi et al., 2021). Here, we avoid the commonly used term 'current policy scenario' and use 'adopted policy scenario' instead because we discuss projections developed at different points in time. Policies in force in 2015 were 'adopted' at the time but are not necessarily 'current', which implies they are still in force.

For this paper we compiled emissions projections from the Climate Action Tracker (CAT) project to which the authors contributed since its inception (Climate Action Tracker, 2015, 2023). The CAT provides yearly updates to its 'current policy scenario' for all countries analysed here. CAT tracks country's climate change mitigation efforts since 2011 and is a well-established source of emissions trajectories (Höhne et al., 2011). Its data has also been used in a number of scientific publications (e.g., Ou et al., 2021; Rogelj et al., 2016) and is one of the major inputs to the UNEP emissions gap report (UNEP, 2021).

The CAT quantification method departs from an external reference emissions scenario and is complemented with add-on calculations that estimate the effect of policies on emissions projections. The inclusion of individual policies depends on the availability of quantifiable impact indicators and likelihood of implementation. For several countries, a range of emissions is provided to account for the

[6] We consider the European Union member states as one under the EU27+UK. In this research, the United Kingdom is considered as part of the EU due to its membership status in 2015. We use the term country to refer to the 'EU27+UK' region.

uncertainty in future policy implementation. However, emissions projections ranges are not available for all countries. This is mostly a result of still limited data availability for some countries, especially with regards to policy implementation and macro-economic drivers, such as the economic growth assumptions that underpins energy demand. Our projections are then harmonised to the latest available historical data, which varies across countries due to distinct reporting requirements (SM3 - Table 9). A more detailed description of the quantification method is available elsewhere (Fekete et al., 2021).

Projections developed in 2021 include the effect of the COVID-19 pandemic. We assumed that emissions intensity over GDP remains the same as it would under adopted policies excluding the impact of COVID-19 and that emissions reductions are induced by a slowdown in GDP growth. Whenever available, we reviewed and included external estimates for the effect of the pandemic on 2020 emissions (Friedlingstein et al., 2021; Z. Liu et al., 2020). In this research, we focused on emissions projections *including* the effect of the COVID-19 pandemic. However, the counterfactual scenario *excluding* the effect of COVID-19 is available and used to estimate the magnitude of the pandemic effect on the changes in projections between 2015 and 2021.

Here, we reported all emissions in carbon dioxide-equivalents (CO_2e) using 100-year global warming potentials (GWPs) from the IPCC Fourth Assessment Report (AR4) (IPCC, 2007). All CAT projections developed in 2021 are expressed in AR4 GWP terms using a country-specific approach, which includes a gas-by-gas conversion whenever possible. Older projections, w use GWPs from earlier IPCC Assessment Reports, were converted to AR4 GWPs using a fixed conversion factor based on the emissions ratio in the latest historical year. The conversion factor was extracted from a common database but calculated per country (Gütschow et al., 2021).

We focused on the progress in reducing emissions in energy, industry, agriculture and waste sectors since 2015 and excluded land use, land-use change and forestry (LULULCF) emissions from our analysis. To include LULUCF emissions is important for research that explores whether countries are on track to meet their self-determined targets or to reach net zero emissions (Fyson & Jeffery, 2019; Grassi et al., 2017). However, from a decarbonisation perspective, emissions in all sectors must be substantially reduced. To increase LULUCF emissions sinks, in parallel to reducing emissions in the other sectors, is important but outside the scope of this analysis. Additionally, emissions from LULUCF are notably uncertain and accounting methods vary greatly (Dooley & Gupta, 2017; Krug, 2018). This increases the uncertainty on emissions projections. However, we note that addressing land-use-related emissions is fundamental to keep the goal of Paris Agreement within reach (Fyson & Jeffery, 2019; van Soest, den Elzen, et al., 2021).

National population data is based on the United Nations World Population Prospects, medium fertility scenario (UN, 2019).

3.2.2 Analysis of emissions progressions

We assessed the progression of 2030 emissions projections for each G20 member by calculating differences between the latest projections (2021) and those developed in the year of the Paris Agreement (2015). We analysed several indicators to analyse this progression. First, we calculated the difference in 2030 emissions to estimate the absolute reduction in projected emissions. This metric clarifies whether the G20 group 2030 emissions are higher or lower and which countries' estimates explain most of the change. We also analysed full emissions trajectories for all countries in terms of absolute and per capita emissions to identify changes in trends and emission-peak years. We calculated the percentage change in emissions in comparison to the year of adoption of the Paris Agreement to improve comparability across countries and progress compared to a base year. Finally, we also calculated the yearly percentage change rates for both sets of projections (2015 and 2021) averaged between 2021 and 2030. This metric focuses on the rate instead the absolute change in the coming decade. We removed both upper and lower fifth percentile of the yearly change rate distribution to avoid including abrupt and significant variations, e.g., those induced by lockdown measures.

We analysed key developments that took place in the G20 since 2015, such as the adoption of new policies and the COVID-19 pandemic, and their effect on emission projections. Diverse initiatives have also led to the availability of more robust and up-to-date historical emissions information. Improvements in official inventory reporting, especially by non-Annex-I countries, and the availability of third-party datasets allow for recent trends to be included in our emissions estimates (Friedlingstein et al., 2021; Gütschow et al., 2016; UNFCCC, 2016). Decrease of key mitigation options costs have also affected external scenarios used in the modelling, even if with a delay (Xiao et al., 2021). Several policies have been adopted since the first projections (Nascimento, Kuramochi, Iacobuta, et al., 2022). We broadly discussed how these developments affect projections and presented a non-exhaustive list of reasons for the changes observed in each G20 country.

We also compared emissions projections *excluding* the effect of the COVID-19 pandemic to emissions projections including the effect of the pandemic, both developed in 2021 (Figure 3). By comparing our 2021 projections to the counterfactual, excluding COVID-19 scenario, we singled out the pandemic's contribution to the changes observed. We calculated the difference between projections including and excluding COVID-19 per country and compared it to the value of 2030 emissions developed in 2015.

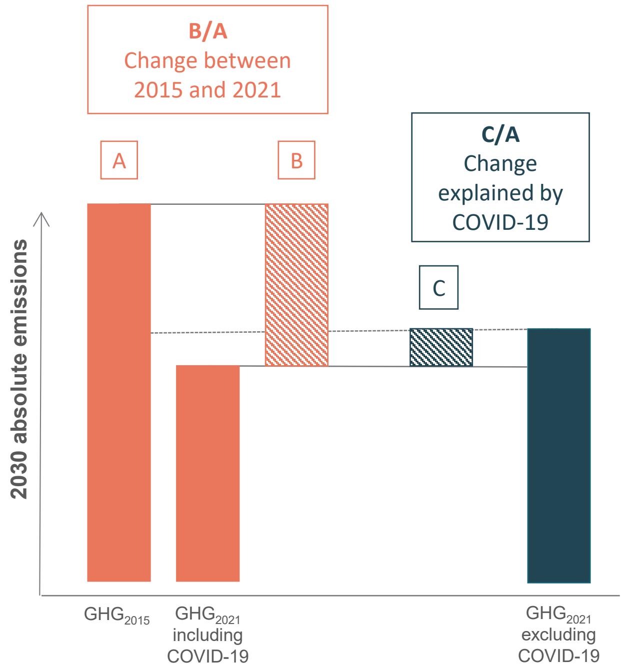


Figure 3: Approach to calculate change in 2030 absolute emissions per country between projections developed in 2015 (GHG_{2015}) and 2021 (GHG_{2021}) and estimate the contribution of COVID-19 to the change observed.

3.3 Results

3.3.1 Progression of emissions projections up to 2030

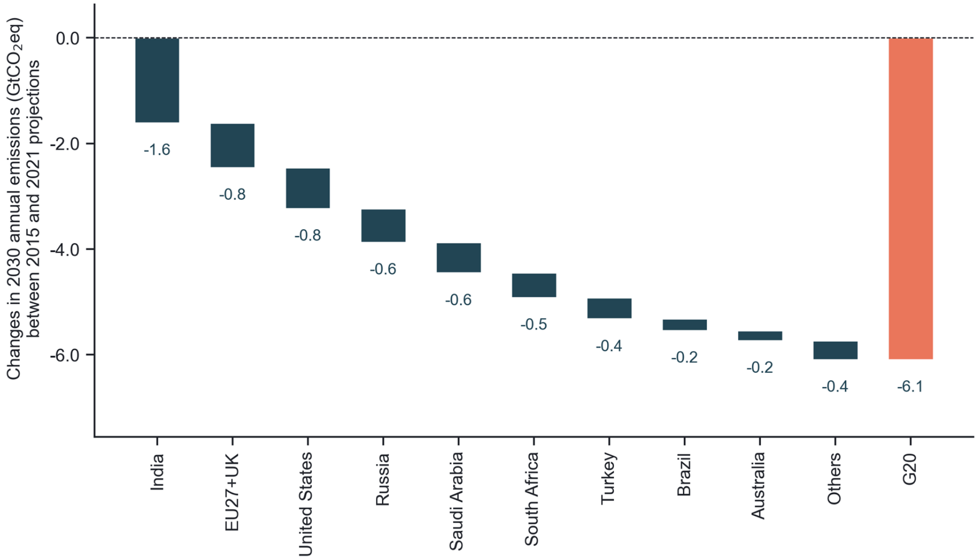


Figure 4: Change in 2030 absolute emissions projections. Negative values indicate that projections developed in 2021 are lower than those from 2015. Values based on the middle of the projection range.

Absolute 2030 emissions from the 2021 projections are expected to be 6.1 GtCO2eq (range: 5.9–6.3 GtCO2eq) or 15% lower than those projected in 2015 (Figure 4). The countries whose projections are more than 0.5 GtCO2eq lower in 2030 are India, the EU27+UK, the Unites States, Russia, Saudi Arabia and South Africa. GHG emission inventory revisions have varying effects across countries but do not substantially affect this finding. For example, inventory revisions result in lower historical, pre-2010 emissions in Mexico and Russia but higher emissions in Saudi Arabia and Japan. Aggregated changes in inventories were at least two orders of magnitude lower than the reduction observed in 2030 projections. The aggregated difference in historical emissions between the two projections sets (2015 and 2021) is approximately 200 and 10 $MtCO_2e$ in 2010 and 2015, respectively. The COVID-19 pandemic has resulted in substantial changes, which are discussed in more detail below (Section 3.3.2).

We do not observe major shifts in G20 countries' emissions projections between 2015 and 2021, with few noteworthy exceptions (Figure 5). Although the level varies, we observe a shift from increase to decrease in absolute emissions in South Africa, Australia, Canada, and the USA. We do not observe such shifts in other countries. Emissions projections developed in 2015 already showed decreasing emissions post-2020 for the EU27+UK but show a faster decrease rate now. Emissions in Japan remain on a similar downwards trajectory. We observe that other countries increase their emissions, but at a slower pace now (Argentina, Brazil, India, Mexico, Russia, Saudi Arabia and Turkey). South Korea's 2021 and 2015 projections show a similar decreasing trend for post-2020 emissions, but the absolute emission level is lower in 2030. In China, historical emissions have increased substantially but emissions are no longer expected consistently increase up to 2030. Indonesia is the only G20 country where the emission estimate for 2030 is now higher than before.

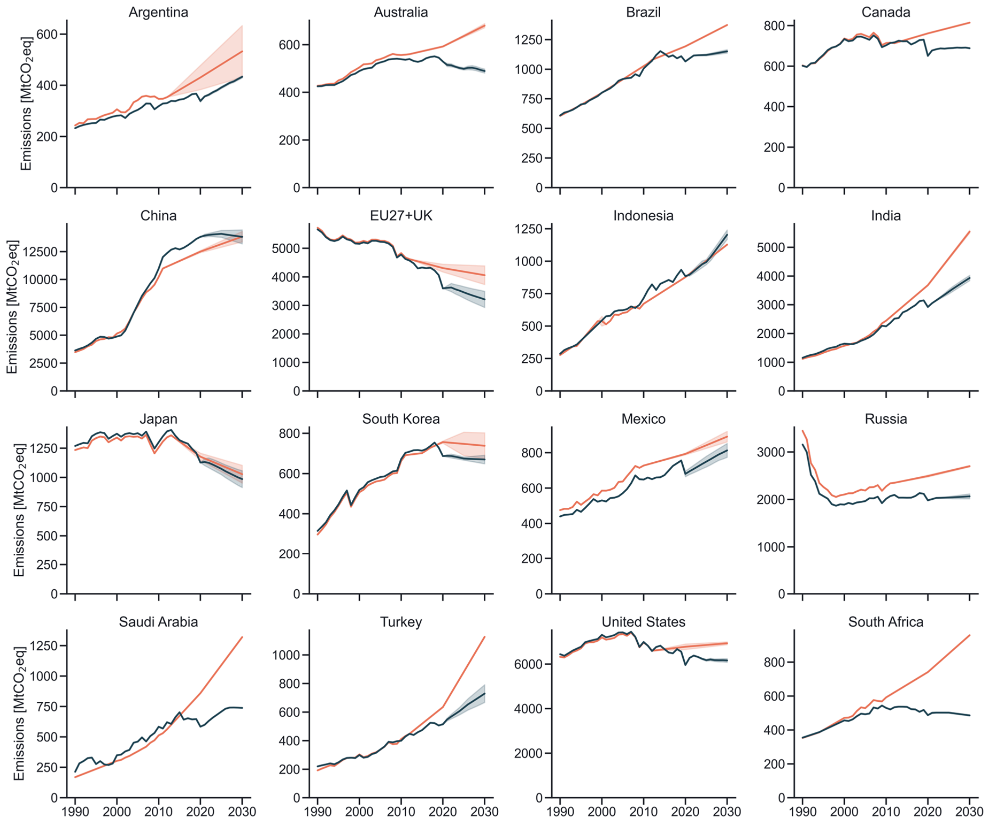


Figure 5: Emissions trajectories developed in 2015 (orange) and 2021 (blue) for the G20. Mind the y-axis for each country graph. Emissions exclude LULUCF and are reported in AR4 GWP-100.

Per capita emissions

Per capita emissions trajectories reveal astonishing differences across the G20 (Figure 6). Emissions per capita in India and Indonesia are expected to remain below 5 tCO2eq per capita in 2030. In India, even with low per capita emissions, emissions projections in 2021 indicate a slowdown in growth in comparison to 2015 projections. But in Indonesia emissions are expected to grow faster than projected back in 2015. The EU27+UK is the only emitter with decreasing emissions expected to be below 5 tCO_2eq per capita in 2030. Emissions in most G20 countries are expected to remain between 5 and 15 tCO_2eq per capita in 2030. South Africa and Japan have now similar emissions per capita levels. In South Africa, emissions per capita are now on a declining trajectory. In Japan, emissions projections were already in a declining trend back in 2015 and this has not substantially changed since. Emissions per capita in several other countries have stalled (Argentina, China, Mexico and Russia) or at least slowed down (Turkey). Emissions per capita are decreasing but remain above 15 tCO_2eq per capita in 2030 in Canada, Australia, the United States and Saudi Arabia. In the G20, emissions per capita tend to grow at a slower pace than absolute emissions (SM3 - Figure 17) due to an overall growing population. In most G20 countries, no growth in absolute emissions implies decline in per capita emissions.

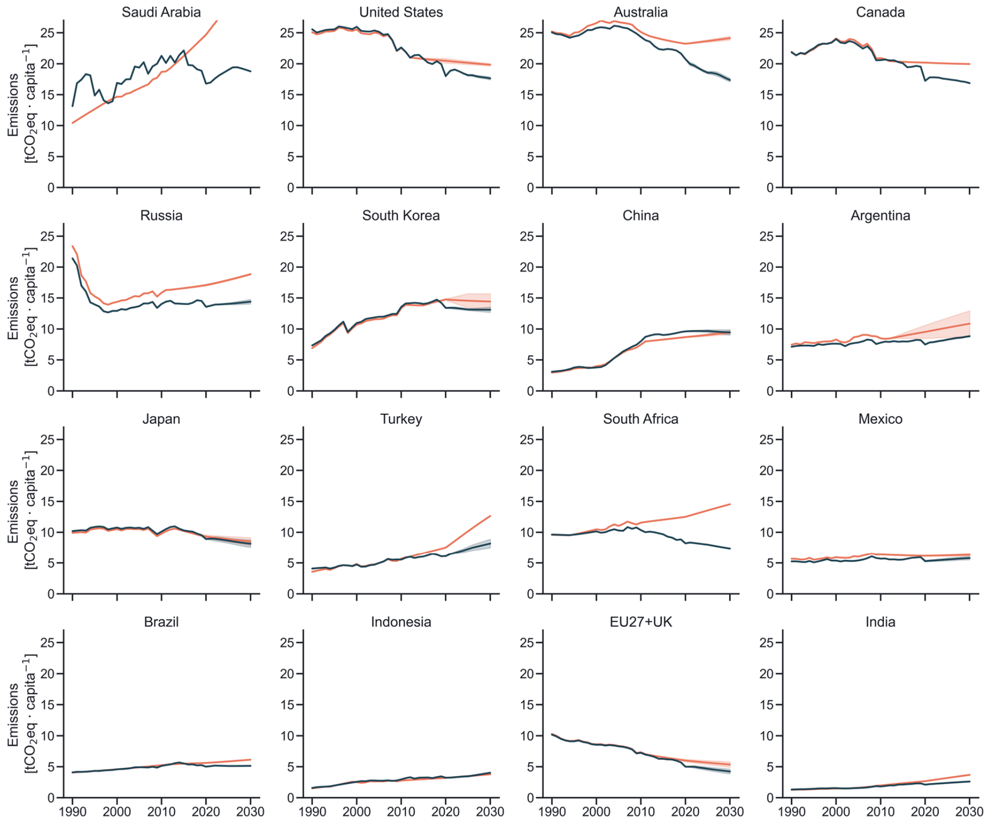


Figure 6: Emissions per capita trajectories developed in 2015 (orange) and 2021 (blue) for the G20 countries. Countries are sorted by emissions per capita levels in 2030. Emissions exclude LULUCF and are reported in AR4 GWP-100.

Expected peaking year

Since global emissions need to peak immediately to be in line with global scenarios that limit temperature increase to 1.5°C, we analyse whether individual countries' emissions have peaked and if so when. The EU27+UK is the only country analysed where emissions have peaked before 1990. It is followed by the United States, which peaked its emissions between 2000 and 2010. However, emissions decrease in the United States is expected to slow down in the coming decade. Trajectories of Australia, Japan and South Africa indicate that emissions have peaked between 2010 and 2020. To monitor actual emissions in the coming years is necessary to confirm whether these latter three countries have indeed already peaked their emissions and whether they will maintain a sustained decrease. Together, these five countries are responsible for one-third of the G20 emissions.

In the remaining eleven countries emissions have not peaked. China's trajectory indicates it will peak in the coming decade. In Brazil, Russia Mexico and Argentina, we expect a moderate increase in emissions. However, no policies in force indicate that emissions will peak before 2030. In South Korea and Canada, emissions are on a slightly decreasing trend. These seven countries are responsible for approximately half of the G20 emissions. In India, Indonesia, Saudi Arabia and Turkey, emissions are projected to remain on a strong upwards trend.

Comparison to 2015 base year

Emissions projections developed in 2015 indicate that only two G20 countries, the EU27+UK and Japan, were unambiguously on track to reduce their emissions in comparison to that year (Figure 7). Both countries had their total GHG emissions below 2015 levels in the older set of projections. In 2021, the number of countries with emissions below 2015 increased and now cover almost half of the G20 countries. Australia, Canada, the EU27+UK, Japan, South Korea, South Africa, and United States are expected to reduce their emissions below 2015 levels by 2030. Japan's reductions are quite substantial because 2015 emissions values represent a peak, that resulted from fossil-based replacing nuclear-based electricity after the Fukushima accident in 2011. We expect India, Indonesia and Turkey to increase their emissions by almost half between 2015 and 2030. Emissions in the G20 are now expected to remain between 1% below to 7% above 2015 levels by 2030. This is down from a 17%–22% increase calculated based on 2015 projections.

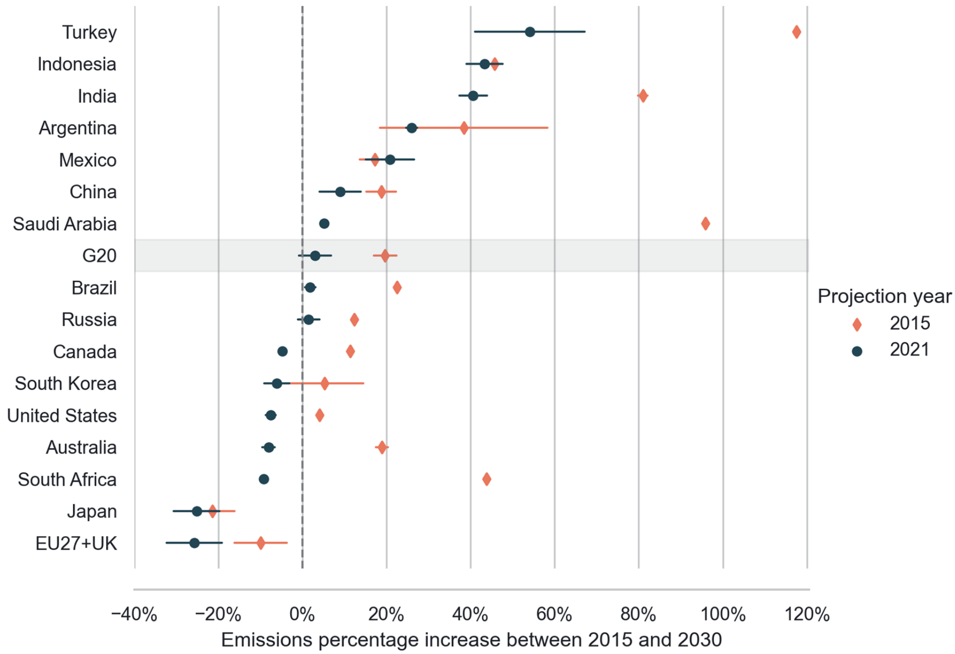


Figure 7: Emissions in 2030 compared to 2015 levels. The bars indicate the range of emissions for each set of projections. Positive numbers indicate an increase compared to 2015.

Growth rates between 2021 and 2030

The G20 emissions are expected to grow slower between 2021 and 2030 than expected in 2015 (Figure 8). The average annual growth rate is reduced from 1.2% (range: 1.1–1.4%) in 2015 projections to 0.3% (range: 0.0–0.6%) in 2021 projections. Today, more countries are expected to decrease their emissions. We observe negative change rates in the coming decade for Japan, the EU27+UK, Australia, South Korea, and South Africa. Two additional countries decrease their emissions when we consider the full range of emissions: China and the United States. However, most countries (nine) are still expected to increase their emissions.

We do not observe a substantial change in emission trajectories as required to meet the Paris Agreement temperature goals. In both sets of projections (2015 and 2021), the distribution of emissions change rates in the 2020s is not significantly different from the change rates in the 2010s (SM3 - Figure 18). This means that we do not expect currently adopted policies to substantially alter emissions trajectories in the 2020s when compared to the previous decade.

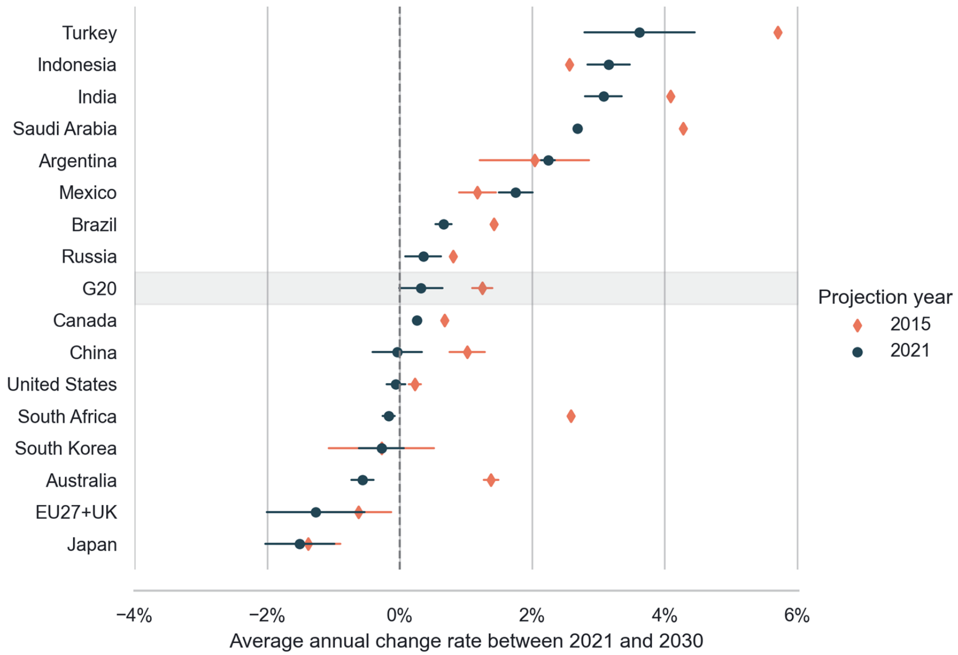


Figure 8: Average yearly change rate in GHG emissions projections between 2021 and 2030. Emissions are expected to grow faster in most recent projections for Indonesia, Mexico, and Argentina.

3.3.2 Factors influencing emissions projections

Here, we present a non-exhaustive list of factors that can explain changes in emissions projections for each G20 country (Table 3).

In 2020, COVID-19 resulted in drastic emissions reductions worldwide. This drop is induced by restrictions in emissions-intensive activities, such as aviation, urban mobility, and industrial production. Other researchers have analysed in detail the short-term impact of these restrictive measures on emissions across countries (Le Quéré et al., 2020, 2021; Z. Liu et al., 2020). The drop in emissions between 2019 and 2020 is significantly different from the national trend in almost all G20 countries (Tab S2). The pandemic also affects projections up to 2030 due to updated macro-economic forecasts and policy responses. We find that emissions are collectively 1.4 $GtCO_2eq$ (range: 1.3–1.6 $GtCO_2eq$) lower in 2030 due to COVID-19. This corresponds to a 3.6% (range: 3.1–4.2%) reduction compared to emissions projections excluding the effect of COVID-19. Our results are within that range of other studies, which find that COVID-19 policy responses and economic slowdown could reduce annual global emissions by 1-5 $GtCO_2eq$, or 1.5-8.5%, in 2030 (Dafnomilis et al., 2022; Kikstra et al., 2021; Lecocq et al., 2022). The reduction in 2030 emissions explained by COVID-19 is almost one-quarter of the total reduction observed when comparing 2021 projections to 2015 projections.

However, the level of the reductions in 2030 emissions explained by COVID-19 varies across countries ('2030 change COVID-19' in Table 3). In most countries, COVID-19 explains less than one-third of the reductions in 2030 emissions between projections prepared in 2015 and 2021 ('2030 change' in Table 3). In some countries, COVID-19 explain reductions in the same order of magnitude of the overall reductions observed in 2030 emissions. This is the case for Japan, Mexico and South Korea. In India, about one-third of the 30% reduction is explained by the pandemic and in Indonesia, the only country with an increase in 2030 emissions between 2015 and 2021, emissions would be substantially higher if not for the economic slowdown induced by COVID-19.

Table 3: Non-exhaustive list of reasons for change in 2030 emissions between projections prepared in 2015 and 2021. Percentage reduction figures are rounded to the nearest 5%.

Country	2030 change (B/A in Fig1)	2030 change COVID-19 (C/A in Fig1)	Reasons for emissions projections change
Argentina	-15%	-5%	Lower 2030 emissions result in part from updated historical data and the effect of COVID-19. However, the average emissions growth rate in the coming decade is slightly higher. This is attributed to the slower-than-expected uptake of renewable energy, caused in part by limited effectiveness of currently adopted policies intended to foster renewable electricity uptake (Ruggeri & Garrido, 2021).
Australia	-30%	-5%	Australia's emissions projections are now declining, in comparison to an increase expected back in 2015. Improvements in climate action are mostly driven by subnational actors (Christoff & Eckersley, 2021). Lower emissions are hardly a result of improved national policy. Australia has consistently supported fossil fuels and rolled back important climate policies (Crowley, 2021).
Brazil	-15%	0%	Emissions are projected to grow slower than projected in 2015. This is mostly attributed to updates in economic forecasts, especially after the 2015 recession, and adoption of additional policies, such as Brazil's latest biofuel support program (Denny, 2020; IMF, 2014, 2021; Sicsú et al., 2021). These findings do exclude LULUCF emissions. Recent LULUCF trends indicate an increase in deforestation-induced emissions and would counteract some of this reduction (SEEG, 2021; Silva Junior et al., 2021).
Canada	-15%	0%	The most recent estimates show a significant drop in 2020 emissions. This is induced by the introduction of new regulations to reduce emissions from oil and gas exploration and production (Government of Canada, 2018). The lower emissions growth projected in the coming decade is attributed to additional energy and climate policies (Government of Canada, 2021).
China	0%	0%	The 2010 historical emissions used in 2015 (CDIAC, 2012; IEA, 2014; US EPA, 2012) were 7% lower than those used in 2021 (Gütschow et al., 2021). Despite higher historical emissions, we expect lower growth rate in the coming decade, which could lead to peaking emissions before 2030. This is attributable to the adoption of additional policies, especially those aimed to reduce coal use (G. Liu et al., 2021; Tong et al., 2018).
EU27 + UK	-20%	-5%	The rate of emissions decline has accelerated in the EU27+UK but COVID-19 is also a contributor of lower 2030 emissions. Updated emissions projections are attributable to the adoption of new policies, which are reflected in updated data sources used as input for projections (EEA, 2020; European Commission, 2021). The effect of these policies can also be observed in emissions pre-2020.
India	-30%	-10%	Emissions are still expected to increase but at a slower pace than initially projected. This is also observed in historical emissions. This change can be attributed to lower energy demand projections and faster renewable electricity uptake, displacing some of the country's coal-fired electricity, which remain high (Dubash et al., 2018; Jones, 2021). COVID-19 is also a major contributor of observed changes.
Indonesia	5%	-15%	Historical emissions increased substantially since 2015. The latest available year in official GHG inventory back in 2015 was 2000. The use of governmental projections as historical data resulted in underestimation of actual historical emissions (Government of Indonesia, 2011). Projections now are in part determined by the ten-

Country	2030 change (B/A in Fig1)	2030 change COVID-19 (C/A in Fig1)	Reasons for emissions projections change
			year electricity supply plans released by the state-owned electricity utility. The latest plan, which now covers the whole period until 2030, indicates a continued dependency on coal (Republic of Indonesia, 2021).
Japan	-5%	-5%	Japan's updated projections are only slightly lower than previously estimated. Our estimates are now lower mainly due to higher renewable shares in Japan's electricity mix and the effect of the COVID-19 pandemic. The range is also narrower due to less uncertainty about nuclear future development.
South Korea	-10%	-10%	The expected emissions growth for the coming decade has not changed significantly but the COVID-19 pandemic resulted in substantial emissions reductions. Future emissions are highly dependent on the implementation of the Korean Emissions Trading Scheme, which could set emissions in a clearer downwards trajectory.
Mexico	-10%	-10%	Updated historical data and the COVID-19 pandemic explain the lower emissions observed in 2030. However, emissions are expected to grow faster in the coming decade. Mexico modified its Electrical Industry Law in 2021 to allow certain fossil plants to obtain clean-energy certificates, which were previously planned for renewable energy suppliers (Diario Oficial de la Federación, 2021).
Russia	-25%	-5%	In Russia, future emissions growth rates have been revised downwards but emissions are still expected to increase. This reduction is not a result of additional climate policies. Russia has maintained their fossil-centred energy policy almost unaltered since 2015 (Mitrova & Melnikov, 2019). A major revision to Russia's emissions inventory explains most of the drop observed in 2030 emissions. This revision included an update to carbon dioxide and methane emissions factors associated with fossil fuel exploration and production (Russian Federation, 2019).
Saudi Arabia	-45%	-5%	Most recent projections show substantially lower emissions in 2030 in Saudi Arabia. Emissions have grown and are likely to grow much slower than expected since 2015. This is caused by COVID-19 and better estimates of the country's projected energy demand (KAPSARC, 2021). However, the country has made little progress on the implementation of its renewable energy targets (IRENA, 2021).
South Africa	-50%	0%	South Africa is the country with the most significant change in projections, which flipped from a substantial increase to a decrease in emissions up to 2030. This is driven by the planned decommissioning of most of the country's coal fleet, as outlined in the latest Integrated Resource Plan published in 2019 (Department of Energy of the Republic of South Africa, 2019). Reductions in economic growth expectations also contribute to the lower emissions in 2030.
Turkey	-35%	0%	Turkey's expected emissions change rate is lower today but remains the highest in the G20 group. The country continues to expand coal use in parallel to renewables, but many policies have been adopted since 2015 to support the letter (Jones, 2021; Karapinar et al., 2019). The reduction observed is largely driven by changes in macro-economic forecasts, which now assume lower economic growth (IMF, 2021; Republic of Turkey Ministry of Environment and Urbanization, 2019).
United States	-10%	0%	Emissions are expected to grow slightly slower than projected in 2015. Projections in the country have not been consistently revised downwards due to policy rollbacks introduced by the Trump administration (Jotzo et al., 2018b). Despite the improvements observed since President Biden took office, current policies are insufficient to put emissions on a clear downwards trajectory.

Updates in historical data also influence emissions up to 2030 because projections are harmonised to the latest available historical year. The availability of additional and improved data sources increases the robustness of estimates. GHG emission inventory methodology improvements may result in shifts in the historical data series across the whole period analysed. More up-to-date historical data also include recent developments, such as the effect of adopted policies or short-term changes in the emissions drivers. The attribution of the resulting changes to specific factors is challenging since there are many overlapping effects. However, they essentially result from the inclusion of recent developments. Back in 2015, historical data was scarce and outdated for some countries; the latest historical data points were on average four years old (median: 2012, range: 2000–2013). In 2021, data was on average two years old (median: 2019, range: 2016–2020). In most G20 countries, pre-2020 emissions are substantially different between the two sets of projections.

Post-2020 emissions projections are influenced by the adoption of additional policies, especially those that reduce energy-related emissions. Since 2015, energy-related emissions have been periodically analysed by international organisations, such as the International Energy Agency (IEA). The IEA often revises their estimates to account for lower energy demand and higher rate of uptake of renewables (Fazendeiro & Simões, 2021). These revisions partly result from additional energy efficiency and renewable energy policies (Table 3). Even though research indicates that forecasts might still underestimate renewable energy developments (Carrington & Stephenson, 2018), latest projections result in lower 2030 projections in many G20 countries. Global developments to limit the use of coal also influence emissions projections (Jewell et al., 2019; Rauner et al., 2020). This is relevant in both Australia and South Africa, countries with decisive changes in emissions projections.

Information availability also affects our emissions projections. Some G20 countries (Australia, Canada, and the EU27+UK) publish official projections, that consistently update the list of policies included as well as their effect on future emissions. New or additional scenarios became available for all countries analysed since 2015. This results from more transparent and frequent communication of climate change mitigation progress by non-Annex I countries, that now submit Biennial Update Reports (BURs) to the UNFCCC. In ten G20 countries, most recent projections include additional sources.

3.4 Discussion

The periodic evaluation of progress is a fundamental element of the Paris Agreement ambition-raising mechanism. The official Global Stocktake focuses on global emissions projections and collective progress (UNFCCC, 2022) but ultimately, national governments need to continuedly update their NDCs as well as policies and actions to support them.

The G20 covers a large share of global emissions, and their emissions projections bear a strong influence on global progress. We find that emissions of the G20 as a group are projected to increase up to 0.6% per year between 2021 and 2030. An increase in the emissions of group covering such as high share of global emissions is certainly misaligned with the goals of the Paris Agreement (IPCC, 2018a). Global emissions should fall by more than 7% per year between 2020 and 2030 (Höhne et al., 2020; UNEP, 2019). Our analysis unpacks global trends and informs countries in updating their own policies and actions. We find that 2030 emissions are lower in most G20 countries when we compare 2021 to 2015 projections and that countries have often accelerated their efforts since 2015. Most countries with decreasing emissions are expected to decrease them faster and countries with increasing emissions, to increase them slower. National emissions change in the right direction.

Since the CAT analysis builds on or reviews many studies, the comparison to other literature is not trivial. Other country-specific analyses used as input to the CAT analysis show progress in the same direction and of similar magnitude to ours. Latest official projections for Australia and Canada show that emissions in both countries are approximately 40% and 30% lower compared to the 2015 projections, respectively (Australian Government, 2015, 2021; Government of Canada, 2021). Third-party estimates for the Unites States (Larsen et al., 2016; Pitt et al., 2021) show 2021 emissions projections 10% below (calculation based on middle of the range) those projected in 2016. Energy-related CO_2 emissions published by the IEA in their World Energy Outlook reports are also reviewed and often included in the CAT analysis. They show emissions lower than projected in 2015, except for Russia and China. Our

2021 estimates for Russia are lower than 2015 due to a revision in historical methane emissions, which are outside IEA's scope. The IEA shows an overall increase in energy-related CO_2 emissions of approximately 10% for the same period analysed in this study. Our results for China indicate emissions have not changed substantially but the IEA indicates an increase of approximately 5% in energy-related CO_2 emissions. The IEA scenario is used as part of the upper range of our analysis but is adjusted downwards to better reflect key national energy policies, such as the target to meet 20% non-fossil energy share in 2025 (which was missed by 3% in the IEA analysis). For all other countries analysed, IEA emissions projections are also expected to be lower than projected in 2015.

Even though national estimates for all G20 countries are unavailable, the UNEP Emissions Gap Reports and the Global Energy and Climate Outlook annually publish adopted policy emissions projections (Keramidas et al., 2022; Labat et al., 2015; UNEP, 2015, 2021). We compared 2015 and 2021 analyses from both groups and found that their 2030 emissions projections are now also lower than projected in 2015, even though they estimate a lower effect.

This lower effect is in part due to the method used by these reports. The UNEP Emissions Gap Report includes peer-reviewed literature, which is often a few years behind in terms of policy cut-off date and in some cases did not include the effect of the COVID-19 pandemic. Höhne *et al* (Höhne et al., 2020), which builds on the work prepared for the UNEP Emissions Gap Reports, compare projections under current policies for seven major emitters to find that 2030 emissions were lower in 2019 than projected in 2015 for the EU27 and India, at a similar level in China, the United States and Russia, and higher in Indonesia and Brazil. The differences between the findings of Höhne *et al* (Höhne et al., 2020) and our work are attributed to the inclusion of most recent trends. For example, our analysis includes the revision in inventory and COVID-19 impact for Russia and Biden's administration reinstatement of some climate and energy for the United States. In the case of Brazil, the exclusion of LULUCF emissions in the projections influences the results, since LULUCF emissions have increased but are not included in our analysis. Similar differences exist between our analysis and the 2021 version of Global Energy and Climate Outlook Report, which has 2019 as a policy cut-off date. Even though the report includes the effect of COVID-19 they do not reflect latest policies adopted. Nonetheless, we compared the G20 emissions projections to 2030 and find that they are at least 3.5 $GtCO_2eq$ lower comparing the 2015 and 2021 versions of the report. Argentina, Australia and Saudi Arabia were excluded from the 2015 version of the Global Energy and Climate Outlook Report. Including these countries would probably result in even higher emissions reductions.

Although our approach demonstrates clear trends in the G20 countries, it is subject to distinct limitations. Information availability, which substantially affect emissions projections, varies substantially across countries. The implementation of common reporting tables and timeframes for all countries to submit data to the UNFCCC will improve data reporting and support the development of more consistent historical emissions datasets and subsequently more accurate emissions projections under current policies (Mayer, 2019; Rajamani & Bodansky, 2019; Streck et al., 2019). Changes in data availability will likely become less frequent over time, considering the significant improvements achieved in the past years. The convergence of emission inventory methodologies and reporting years reduces uncertainty associated with historical data updates. As new historical data becomes available, the effect of COVID-19 in the short-term also becomes less uncertain (Friedlingstein et al., 2021; IEA, 2021a, 2021b; Z. Liu et al., 2023). However, COVID-19 policy responses and economic implications are likely to remain relevant for the next several years.

Even when these improvements are considered, the attribution of the changes in emissions projections to the adoption of climate policies remains challenging. The methods used in our research do not allow to comprehensively unpack the effects of distinct factors explaining changes in emissions trends. Studies that analyse the effect of policies on emissions often rely on statistical learning methods applied to many countries to establish associations between policies and emissions trends (e.g., Eskander & Fankhauser, 2020; Lachapelle & Paterson, 2013; Le Quéré et al., 2019). They provide empirical evidence of policies effect but cannot clearly single out the effect of specific policies or factors. Studies that investigate the effect of policies on specific mitigation options complement these analyses and help to translate high-level findings into policy advice (Carley, 2009; J. F. Green, 2021). Others discuss the role institutions, actors and national process in enabling policies' effect (Aklin & Urpelainen, 2013; Lamb & Minx, 2020). We argue that none of these can alone unpack climate policies' effect but that their combination is conducive to understanding the effect of adopted policies and improving global mitigation efforts.

Despite these limitations, the estimates here represent our best understanding of the situation at the time, given the difficulties with methods and different sets of adopted policies. Our best estimate is now lower emissions in 2030 than we projected in 2015. This constitutes an improvement, regardless of the exact individual effects of the different causes of change.

3.5 Conclusions

Policies adopted today affect GHG emissions for years and influence future climate change levels. The urgency of the challenge to limit the global temperature increase to 1.5°C demand a faster and stronger international response. To analyse projected and not only historical emissions helps to identify early issues with current mitigation efforts and steer towards meeting the international collective goals. Our research compares emission projections under adopted policies developed in 2015 to those prepared in 2021 to assess progress since the adoption of the Paris Agreement.

Our best available estimate of emissions projections for the G20 has improved since 2015 and is now approximately 6 $GtCO_2eq$ lower in 2030. The most substantial changes are observed in India, the EU27+UK, the United States, Russia, Saudi Arabia and South Africa. In all these countries, COVID-19 results in a substantial (higher than 5%) drop in estimated emissions between 2019 and 2020. Pandemic-induced policy responses and economic slowdown also reduce projected emissions in almost all countries and explains approximately one-quarter of the reduction in 2030 emissions observed in the G20. In most recent projections, Australia, Canada, the EU27+UK, Japan, South Korea, South Africa, and United States are expected to reduce their emissions below 2015 levels by 2030. Even though revised representation of historical effects and the pandemic influence our estimates, the adoption of additional policies explains lower emissions. Renewable uptake has been faster than projected before, efficiency improvements result in lower energy demand and coal phase out policies result in substantial shifts in emissions projections of some countries. These factors combined result in changes in most countries' 2021 projections when compared to those developed in 2015:

- South Africa presents the most significant change in emissions projections in the coming decade. The country has improved from substantial annual increase on its emissions to an annual decrease between 2021 and 2030.
- The EU27+UK and Japan were already expected to decrease their emissions in the coming decade but are expected to decrease it faster in 2021 projections. South Korea is likely to slightly decrease its emissions in the coming decade.
- The United States, Canada and Australia were expected to increase their emissions and now show a slightly declining trend. This is a positive development but their emissions per capita remain among the highest in the G20.
- China's 2030 emissions remain at similar levels than projected in 2015. The faster historical emissions growth is offset by slower emissions growth in the coming decade. Emissions are now expected to peak before 2030.

- Argentina, Brazil, Mexico, Russia and Saudi Arabia now show lower projected emissions in 2030 than estimated in 2015 but are expected to still increase their emissions. The implementation of Saudi Arabia's renewable targets could result in plateauing emissions before 2030.
- Turkey slowed their substantial expected emissions growth, but emissions show no sign of slowing down before 2030. Emissions in India and Indonesia increase up to 2030 but remain at low per capita levels (below 5 tCO_2eq) in 2030.

Emissions projections in the G20 shows signs of improvement but progress remains slow compared to what is needed under the Paris Agreement. Emissions of the G20 as a group are expected to slightly increase in the coming decade. No single G20 country shows rates of emissions decline in line with the necessary global rate to meet the goals of the Paris Agreement. Projected annual growth rates also do not differ statistically when compared to the previous decade. We do not observe the transformative change necessary to reach the global temperature goals. The G20 remain off track to curb their emissions before 2030.

Our research shows that progress is slow in major emitting countries but also that pivotal shifts in emissions trajectories took place since the adoption of the Paris Agreement. Countries with increasing emissions were able in half a decade to substantially reduce their projected growth or even put emissions projections in a downwards trajectory. Scenarios presented here estimate the effect of adopted policies and do not constitute a fixed, definite trajectory for the coming decade. Decisions that shape future climate are, and need to be, made today. The G20 group must urgently and drastically improve adopted policies and actions to limit the end-of-century warming to 1.5°C.

4 Twenty years of climate policy: G20 coverage and gaps

Summary

The number and coverage of climate change mitigation policies have increased in the past twenty years, but important policy adoption gaps remain. To analyse sectoral climate policy in the G20 over time (2000–2019), we compiled a dataset of climate change mitigation-relevant policies and identified 50 key policy options that constitute a comprehensive sectoral climate policy package. Approximately half of these policy options are not widely adopted. Adoption is particularly low for policies that aim to: phase out coal and oil and mandate energy reductions in electricity and heat supply; reduce industrial process emissions and incentivise fuel switch in industry; design urban planning strategies for retrofits; and support the use of renewable energy for cooking and heating/cooling purposes in buildings. Policies to remove fossil fuel subsidies and support carbon dioxide removal also need substantial improvement. However, many policy adoption gaps exist as the coverage of at least one policy option could be improved in each sector. Policy adoption gaps leave at least one-tenth of the G20's emissions completely uncovered. Filling these gaps is fundamental to realise the full mitigation potential of existing policy options and to advance the transition towards global net zero greenhouse gas emissions.

Nascimento, L., Kuramochi, T., Iacobuta, G., et al. (2022) 'Twenty years of climate policy: G20 coverage and gaps', Climate Policy, 22(2), pp. 158–174. doi:10.1080/14693062.2021.1993776

4.1 Introduction

The Paris Agreement presents a breakthrough in the fight against climate change. It created a framework in which most countries have agreed to a common goal of holding global average temperature increase to well below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C (UNFCCC, 2015b). To achieve this ambitious goal, mitigation measures should cover all anthropogenic greenhouse gas (GHG) emissions, hereafter ‘emissions’, and these measures must collectively be stringent enough to reduce emissions to net zero in the second half of the 21st century (Rogelj, Shindell, et al., 2018; UNEP, 2020).

Aggregate 2030 emissions reduction targets, committed by national governments as Nationally Determined Contributions (NDCs), and national climate change mitigation policies are projected to be insufficient to limit global warming to well below 2°C, let alone 1.5°C (Roelfsema et al., 2020; Rogelj et al., 2016). Lack of progress in the last decade has intensified the challenge (Höhne et al., 2020). Even though nine of the G20 members are on track to meet their unconditional NDC targets, their emissions are still projected to increase (den Elzen et al., 2019; Kuramochi, den Elzen, et al., 2020). Countries need to urgently strengthen their actions to mitigate the negative impacts of climate change.

The number of climate policies has increased as a result of multiple factors (Bassi et al., 2017; Le Quéré et al., 2019; Mundaca & Markandya, 2016). First, in the past twenty years the world has seen two international accords, which helped to create momentum for climate change mitigation (Iacobuta et al., 2018). Second, the passage of climate policies in specific countries has been reinforced by international policy diffusion, as countries tend to copy policies adopted elsewhere (Fankhauser et al., 2016). Finally, the evolution of ideas about the relationship between economic development and climate change mitigation, as observed over the past thirty years, resulted in broader consideration of policy choices (Meckling & Allan, 2020). A recent study finds that the adoption of more climate policies helps to reduce emissions (Eskander & Fankhauser, 2020).

However, existing literature agrees that policies can be strengthened. Surveys, that rely on national experts to rate key climate policies, suggest that they are not stringent enough in countries that create most of the global emissions (Burck et al., 2021). Comparing the effectiveness of key instruments across countries shows that policies do not always lead to significant emission reductions (Compston & Bailey, 2016; J. F. Green, 2021). Alternative metrics to measure policy stringency are based on implicit or explicit emissions costs (Althammer & Hille, 2016; Botta & Kozluk, 2014; OECD, 2018) or use policy characteristics to investigate their effect (Schaffrin et al., 2015; T. S. Schmidt & Sewerin, 2019). These studies show that significant cross-country variation exists and highlight implicit potential to improve climate policy via an increase in emissions costs and/or replication of good practice. A better understanding of the differential effort across sectors offers important insight and is necessary to leverage the historical adoption of climate policies (Dubash, 2020).

Improving policy coverage across sectors is a means to strengthen climate policies. It ensures that policies cover all relevant emissions sources and that key mitigation options are in place. Sectoral climate policies in combination with overarching and cross-cutting pricing instruments can result in significant emission reductions and reduce long-term barriers to implement mitigation measures (Kriegler et al., 2018; Roelfsema et al., 2018). High sectoral policy coverage also mitigates leakage effects within and across countries (Rajagopal, 2017). The absence of sectoral policies indicates entry points for raising ambition of climate policy (Kuramochi et al., 2018; Rogelj, Popp, et al., 2018).

Climate policy coverage across countries has increased over the past decades, but current evidence lacks detail on sectoral adoption (Dubash et al., 2013; Iacobuta et al., 2018). An analysis of a non-exhaustive set of sectoral policies in over 170 countries concludes that policy coverage has improved but remains heterogenous and that the transport sector is least targeted (N. M. Schmidt & Fleig, 2018). An investigation into fewer countries shows that major emitting economies tend to focus on forestry, renewable energy, fuel efficiency and electrification of passenger transport, but that policy adoption in other sectors lead to inconclusive insights (Fekete et al., 2021). Evidence on policy coverage at the sectoral level remains incomplete.

Against this backdrop, we define a set of policy options that constitute a comprehensive climate policy package. We then use these policy options to: i) analyse the breadth of sectoral policy coverage in G20 countries; ii) investigate main sectoral developments over the past two decades, and iii) identify current policy adoption gaps. The focus of analysis is the adoption of national policies in the G20 (we consider all European Union's member states, including the United Kingdom, as one under "European Union (EU)").[7] The term 'climate policy' refers to sectoral or overarching policies that result in lasting emission reductions. It includes not only policies with climate change mitigation as the primary focus, but also policies that may be driven by non-climate-mitigation goals, such as energy security. Policies that temporarily affect activity levels but do not reduce the nation's emissions intensity, e.g., economic lockdown measures, are not considered as climate policies. The G20 economies are responsible for about 75% of global GHG emissions, including land use, land-use change and forestry (FAOSTAT, 2019; Olivier & Peters, 2019). Therefore, a gap in policy adoption in the G20 represents a gap in global climate policy.

To fully understand the role of climate policies in decarbonisation efforts, additional considerations are necessary. Policies' ambition, stringency, credibility, feasibility and several design characteristics are key to ensure their effectiveness (Averchenkova & Bassi, 2016; Jewell & Cherp, 2020; T. S. Schmidt & Sewerin, 2019). We do not investigate these factors in this analysis, we focus instead on the question of policy coverage. The successful implementation of additional and strengthened sectoral policies leads to emission reductions beyond those expected under currently adopted policies (Roelfsema et al., 2018).

4.2 Data and methods

An overview of the analytical approach taken in this analysis is shown in Figure 9. We then explain how we systematically collect and categorise policies (Section 4.2.1), define a comprehensive matrix of policy options (Section 4.2.2), and finally how we investigate policy coverage to identify adoption gaps (Section 4.2.3). Our analysis focuses on policies in force between 2000 and 2019.

4.2.1 Step 1: Data collection and categorisation

Several data sources exist that cover certain subsets of policies, sectors, countries or periods (SM4 – S1 summarises the sources that were used in this analysis). However, to our knowledge, an up-to-date and comprehensive overview of climate change mitigation-relevant policies for G20 countries is unavailable. Our analysis is based on policies in force as of December 2019 that have resulted in emission reductions or are expected to between 2020 and 2030. Mid-century emissions reduction

[7] We use the term 'country' to refer to both the EU and the fifteen non-EU G20 economies.

policies, which are more uncertain, are excluded. The results include policies adopted before 2020 that are still in force and policies that have been superseded but were in force between 2000 and 2019.

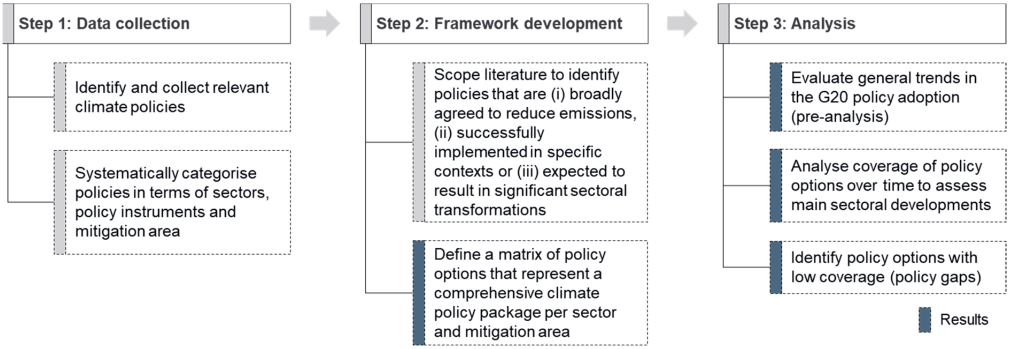


Figure 9: Overview of analytical approach.

The identification and coding of main policy characteristics allows for an objective, comparative, cross-country analysis. We code each policy considering its sector coverage, policy instruments and mitigation areas, which are broadly defined as strategies used in mitigation efforts, such as support for renewables or improvements in energy efficiency (SM4 – S2). The six sectors used in our analysis cover most G20 emissions (Table 4). We added the collected policies and categorisation used in this research to an open source, online database.[8]

Table 4: Overarching description of policies included per sector.

Sector	Policies included
General	Cross-sectoral policies or policies that apply to any sector and that provide framing for or enable the implementation of other sectoral policies. These include, but are not limited to, national or sectoral climate strategies and research and development (R&D) policies.
Electricity and heat	Policies related to energy supply and enabling infrastructure, such as transmission and distribution grids. This sector does not include policies related to fossil fuel exploration and production.
Industry	Policies covering both energy-generation for own use and process-related emissions. This sector also includes policies related to other non-energy emissions. For example, emissions related to waste or fossil fuel exploration.
Land transport	Policies related to all modes of land transportation and infrastructure programmes that might reduce transport needs (e.g., urban planning). Our research does not analyse policy adoption in marine or air transport.
Buildings	Policies that target energy-use in buildings. These policies address building structure, appliances, cooking and heating/cooling devices. It also includes urban planning strategies that include retrofits.
Agriculture and forestry	Policies to increase sustainable practice in agriculture and those targeting better forest management. Policies associated with sustainability standards for biomass used as a source for biofuels in other sectors are also included in this sector.

The coverage and depth of information available on climate policies are better for larger emitters and countries that are obligated to report in-depth on their policy implementation (e.g., Annex I countries to UNFCCC and OECD countries). To enhance data quality and consistency, our data collection and coding were substantiated by experts, working on the evaluation of international climate policies (Roelfsema et al., 2020). National experts reviewed a subset of policies considered to have high emissions reduction potential. Even if it was impossible to cover all policies to their fullest extent, the database provides insights about policy trends over time and supports claims about policy adoption and sector coverage of these policies in the G20.

[8] www.climatepolicydatabase.org

4.2.2 Step 2: Development of a matrix of key policy options

We defined a matrix of policy options to analyse climate policy adoption by sector, identifying six sector categories (Table 5 and SM4 - S1). The options were identified based on policies that are generally agreed to reduce emissions (IPCC, 2014) and that represent sector-level examples of policies that have been successful in specific contexts (UNEP, 2017; UNFCCC, 2018b), or that are expected to result in sectoral transformation to achieve emission reductions (GEA, 2012; IEA, 2018, 2019; Mitchell et al., 2011; OECD/IEA & IRENA, 2017). Even though the matrix does not show links between policies, it provides an overview of what constitutes comprehensive policy coverage. It does not judge the adequacy of the policy options, nor does it benchmark them against their emissions reduction potential. In many cases, the policy options identified can only lead to incremental emission reductions.

The term 'policy option' in this research refers to sector-specific measures that can reduce emissions and be achieved via distinct and multiple instruments. Policy instruments provide a link between desired policy outcomes and implementation of a policy option (Rogge & Reichardt, 2016). For example, support for renewable electricity generation is a policy option that can be supported by different instruments, whether subsidies or net metering schemes, among others.

Table 5: Matrix of key policy options by sector (rows) and mitigation area (columns); each bullet represents one policy option. Grey cells indicate not-applicable mitigation areas, or that no relevant policy option has been identified.

<table>
<tr><th></th><th>Energy service demand reduction and resource efficiency</th><th>Energy efficiency</th><th>Renewables</th><th>Other low-carbon technologies and fuel switch</th><th>Non-energy emissions</th></tr>
<tr><td rowspan="2">General</td><td colspan="5">• Climate strategy
• Emissions reduction target
• Coordinating body for climate strategy
• Support for low-emission or negative emissions R&D
• No fossil fuel subsidies</td></tr>
<tr><td></td><td>• Economy-wide efficiency target</td><td>• Renewable target for primary energy</td><td></td><td></td></tr>
<tr><td rowspan="2">Electricity and heat</td><td></td><td>• Support for highly efficient power plant stock
• Energy reduction obligation schemes</td><td>• Renewable energy target for electricity sector
• Support scheme for renewables
• Grid infrastructure development and electricity storage</td><td>• Coal and oil phase-out policies
• Support scheme for CCS
• Support scheme for non-renewable low-carbon alternatives</td><td></td></tr>
<tr><td colspan="4">• Overarching carbon pricing
• Energy and other taxes</td><td></td></tr>
<tr><td rowspan="2">Industry</td><td>• Strategy for material efficiency</td><td>• Support for energy efficiency in industrial production
• Energy reporting and audits
• Performance and equipment standards</td><td>• Support scheme for renewables</td><td>• Support scheme for CCS
• Support scheme for fuel switch
• Carbon dioxide removal development</td><td>• Landfill methane reduction
• Incentives to reduce CH_4 from fuel exploration and production
• Incentives to reduce N_2O from industrial processes
• Incentives to reduce F-gases</td></tr>
<tr><td colspan="5">• Overarching carbon pricing scheme or emissions limit
• Energy and other taxes</td></tr>
<tr><td rowspan="2">Buildings</td><td>• Urban planning strategies</td><td>• Building codes and standards as well as support for highly efficient construction
• Performance and equipment standards as well as support for highly efficient appliances</td><td>• Support scheme for heating and cooling
• Support schemes for hot water and cooking</td><td></td><td></td></tr>
<tr><td colspan="4">• Energy and other taxes</td><td></td></tr>
</table>

	Energy service demand reduction and resource efficiency	Energy efficiency	Renewables	Other low-carbon technologies and fuel switch	Non-energy emissions
Land transport	• Urban planning and infrastructure investment	• Energy/emissions performance standards or support for energy efficient for light duty vehicles • Energy/emissions performance standards or support for energy efficient for heavy duty vehicles	• Support scheme for biofuels	• Support for modal share switch • Support for low-emissions land transportation	
Land transport	• Tax on fuel and/or emissions				
Agriculture and forestry			• Sustainability standards for biomass use		• Standards and support for sustainable agricultural practices and use of agricultural products • Incentives to reduce CO_2 emissions • Incentives to reduce CH_4 emissions • Incentives to reduce N_2O emissions • Incentives to reduce deforestation, and enhance afforestation and reforestation

4.2.3 Step 3: Sectoral policy coverage and adoption gaps

First, we evaluate the prevalence of policies that match the defined policy options (as identified in the matrix) for G20 countries over the past twenty years. We evaluate both the number of countries with policies in force, and the share of the G20 emissions that these countries each represent to account for the large variation in absolute emissions within the group.

Then, we use a 'k-means' clustering algorithm as a statistical method to analyse the coded data to single out policy options with low coverage (k=1) from those with medium (k=2) to high (k=3) coverage. This algorithm groups data points based on the similarity of their features. In this case, the features are the emissions covered and the number of G20 countries with each policy option in force. The Calinski-Harabasz index is used to measure how well the groups identified reduce within-cluster variance and increase between-cluster variance. A policy option with 'high coverage' does not necessarily reduce emissions more than one with 'low coverage.' Its effectiveness is dependent, among other things, on the implicit ambition of its targets and on implementation. However, the successful implementation of additional and strengthened sectoral policies can lead to emission reductions beyond those expected under currently adopted policies (Roelfsema et al., 2018). Thus, the absence of sectoral policies presents an opportunity for raising ambition and more successful policy implementation.

4.3 Results

4.3.1 Overview of policy adoption in the G20

Jointly, the G20 countries have over 1,600 national climate policies in force as of December 2019 (Table 6). The 'electricity and heat' sector has the most policies in force. The early prevalence of policies in this sector is attributed to the wave of feed-in-tariffs and renewable standard portfolios in the beginning of the 2000s, and to the liberalisation of power markets in some countries (Carley et al., 2017; Meckling et al., 2017). Policies in 'land transport', 'buildings' and 'industry' followed, on average, no more than three years later. This is driven, among others, by the Kyoto Protocol and countries' intention to cut emissions, especially emissions related to fossil energy (McLaren & Markusson, 2020). Policy adoption in some sectors also reduces impediments in others (Pahle et al., 2018). Technology cost reductions might not transfer to other sectors, but learning from more refined governance and the existence of supportive coalitions led to inter-sectoral benefits and relaxed policy adoption barriers.

Table 6: Number of policies in force as of December 2019 per sector. The 'Year difference to first policy' is a measure of the sequencing of sectoral policies within the country. It is calculated by identifying the year when the first relevant policy was adopted in the country and subtracting it from the year where the first policy was adopted in each sector. This metric is calculated per country and then aggregated in the group.

Sector	Number of policies in force	Year difference to first policy median (5th - 95th percentiles)
General (cross-sectoral)	200	4.0 (0.7 – 11.3)
Electricity and heat	441	0.0 (0.0 – 3.0)
Industry	226	1.0 (0.0 – 8.8)
Land transport	309	0.5 (0.0 – 6.0)
Buildings	300	1.5 (0.0 – 7.3)
Agriculture and forestry	182	2.5 (0.0 – 13.0)

Adoption of land-use and cross-sectoral policies is spread over time much longer than what is seen in other sectors. In 'agriculture and forestry,' this is explained by the relevance of the sector. For example, Indonesia adopted policies in agriculture and forestry much earlier than Saudi Arabia. Both are late policy adopters overall, but the former has much higher agriculture gross value added and forest cover (World Bank, 2021). Some countries adopted cross-sectoral and sectoral policies early on (e.g., in Japan and the EU). By comparison, developed countries that ratified the Kyoto Protocol are more likely to have cross-sectoral policies in force in the beginning of the period analysed (Iacobuta et al., 2018). Other countries adopted policies that lead to benefits at the sector level first, and only then did they bring in cross-sectoral policies (e.g., Indonesia). The policy adoption spread demonstrated in cross-sectoral policies suggests that these policies are not a necessary condition for the implementation of sectoral policies.

The G20 has adopted diverse policy instrument types over the past twenty years (Figure 10). All G20 countries have adopted at least one policy instrument in every sector. Codes and standards, and fiscal and financial incentives, were more prevalent than other instruments in the beginning of the period analysed, especially in energy demand sectors. They are considered key instruments to address market failures or barriers to adopt efficient technologies (Somanathan et al., 2014). Prevalence of voluntary approaches are particularly high in industry (usually negotiated agreements) and buildings (usually public private partnerships or labelling initiatives). Market-based instruments experienced slower uptake compared to other instruments. Research indicates that they receive higher levels of civil opposition (Rhodes et al., 2017), but also that their absence presents a barrier to ambition raising efforts (Meckling et al., 2017).

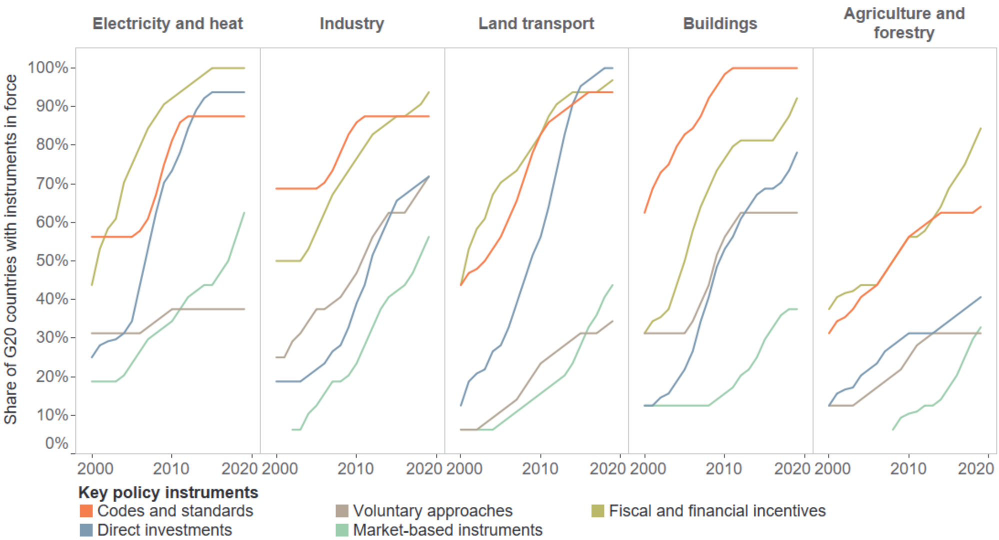


Figure 10: Time evolution (three-year moving average) of share of countries that adopted key policy instrument types by sector in the G20.

These trends support the existence of a multi-sector and multi-instrument approach to climate policies across countries (Averchenkova et al., 2017). These trends are driven by distinct benefits and trade-offs of different policy instruments and by policy makers' attempts to harness political support for climate policy adoption (Hughes & Urpelainen, 2015; Peñasco et al., 2021). The United States was the first country to adopt multiple types of policy instruments (SM4 - S3). Countries with higher development status (e.g., Republic of Korea and Japan) also had multiple types of policy instruments adopted before others. However, no clear hierarchy in terms of the Kyoto Protocol's country categories is demonstrated. Some Annex I countries are late adopters, especially the Russian Federation and Turkey. Alternatively, some non-Annex I countries, like Brazil and Mexico, adopted multiple policy instrument types already in the beginning of the period analysed, making them early adopters.

4.3.2 Analysis of sectoral policy coverage

We analyse policy adoption through the matrix of policy options to investigate sectoral policy coverage over time. The number of policies analysed is reduced (n=1340) to only include policies that match the options defined in Section 0. Information programmes, for example, are excluded since their effect on emissions likely mediates or is mediated by other identified policy options. In this section, numbers in parentheses indicate the number of countries with policy options in force and the share of G20 emissions covered by them (number of countries out of 16: share of G20 emissions). When the statement refers to aggregated mitigation areas, e.g., energy efficiency, the figures correspond to the average across all relevant policy options.

In most sectors and mitigation areas, few countries had mitigation-relevant policies in place twenty years ago (Figure 11). This picture has now changed. Countries with policy options in force, on average, cover two-thirds of the G20 emissions in comparison to only one-third coverage of G20 emissions twenty years ago.

Cross-sectoral, overarching policies, such as climate strategies, were rare in 2000 (4: 15%) but are mainstream throughout the G20 today (14: 84%). This suggests that climate change mitigation features higher in the national political agenda in comparison to twenty years ago. All countries have emissions reduction targets for the post-2020 period. Annex I countries already had emissions targets, climate strategies and coordinating bodies from the first commitment period of the Kyoto Protocol (Dubash et al., 2013), but by 2020, policy coverage had expanded to most G20 countries.

G20 countries restrict fossil-based energy use to improve energy efficiency or to incentivise a shift to clean energy and simultaneously subsidise fossil fuel use today. Fuel taxes (12: 74%) are more common than carbon-pricing instruments (9: 56%) to reduce fossil fuel use. Yet, all analysed countries still support fossil fuels in one way or another. In 2019, the G20 spent on average 0.5% of their GDP in fossil fuel support (IISD/OECD, 2021).

Energy efficiency and renewable energy are the two most well-covered mitigation areas in the G20. Energy efficiency policies are adopted across sectors in most countries (13: 87%). The prevalence of renewable energy policies (11: 69%) is lower. This is driven by the slower adoption of policies that support renewables in the buildings sector and the overall earlier focus on energy efficiency. Coverage of adopted policies to reduce energy service demand and increase material efficiency (9: 48%) or to address emissions related to activities beyond energy use (9: 59%) remains lower in the G20.

Policies in the 'electricity and heat' sector are split between the targeting of the uptake of low-carbon technologies and the maintenance of fossil fuel infrastructure. The low prevalence of policies that restrict fossil fuel use in the electricity sector is a key inconsistency in the sector (F. Green & Denniss, 2018). Only Canada has a plan to phase out coal and oil for electricity and heat generation (1: 2%) and all countries still support efficiency improvements in fossil fuel power plants. All G20 members have adopted policies to support renewables. Most countries also target improvements of the electricity grid (15: 98%), even though these improvements remain insufficient to truly enable scaling of renewables in the power sector (Bird et al., 2016).

Several member states of the EU have taken steps to phase out coal in their power supply. Germany, Italy, France and the UK have set phase out dates, albeit with varying degrees of ambition. Italy, France and the UK are expected to phase out coal by 2025, 2022 and 2025, respectively. Germany only plans to phase out coal by 2038 (Europe Beyond Coal, 2021). These countries are not considered here because their emissions are only counted once as part of the EU.

Switching from direct burning of fossil fuels to electricity or hydrogen in 'industry' is directly targeted by very few countries (2: 6%), despite the clear need identified for such policies in deep decarbonisation scenarios (Nilsson et al., 2021). The majority incentivise fuel switching indirectly through energy taxes or through carbon pricing (9: 56%). Less than half of G20 countries adopted policies to address non-energy GHG emissions (6: 50%). Policy support for other low-carbon technologies is also limited. Support for both the development of carbon dioxide removal (CDR) technology and the rollout of carbon capture and storage (CCS) for carbon-intensive industrial processes is also rather limited (4: 28%), even though they are key components in long-term mitigation scenarios (Rogelj, Shindell, et al., 2018). In the past twenty years, many countries adopted policies to improve material efficiency (11: 86%), which is an area that can deliver significant emission reductions (Scott et al., 2019).

In the 'buildings' sector, standards for appliances are prevalent in all G20 countries. In the past twenty years, standards for energy-efficient construction have also become common (15: 96%). By comparison, direct support via policy adoption for renewable energy in buildings (4: 21%) and urban planning strategies (5: 22%) has been lower. A potential explanation for the slower uptake of renewable energy technologies in buildings is the high upfront costs, which lead to short-term cost increases for households (Knobloch et al., 2019; Lucon et al., 2014). The lack of urban planning strategies hinders mitigation efforts since buildings are long-lived infrastructure and deep renovations remain uncommon.

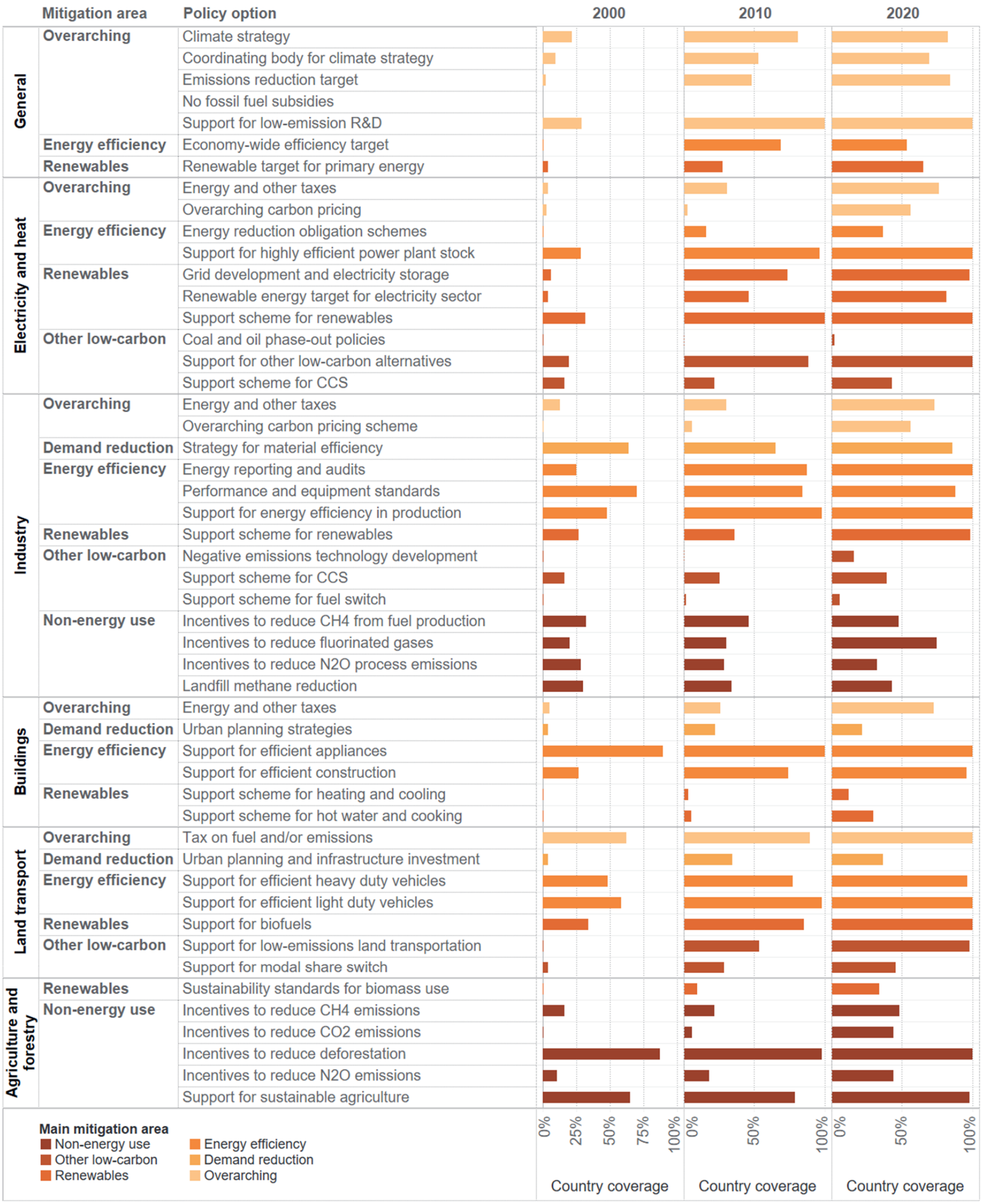


Figure 11: G20 country coverage of key policy options by sector. Bar charts indicate country coverage weighted using G20 members' share of total emissions in 2018. For visualisation purposes, the names of some policy options were shortened.

Countries use the whole range of options to mitigate emissions in the ‘land transport’ sector. Standards for light- and heavy-duty vehicles are prevalent in most countries (15: 98%). Energy or fuel taxes and support for biofuels are adopted in all countries. More recently, countries have initiated support for low-carbon transport, which is also in force in most countries (15: 98%). Coverage of urban planning-related policies to minimise transport needs also increased but remain comparatively low (10: 36%). The high coverage of distinct policy options is a fundamental step to achieve deep emission reduction in the sector, which requires strong and integrated policy mixes (Axsen et al., 2020).

Most of the policies adopted in the ‘agriculture and forestry’ sector aim to achieve sustainable practices in agriculture (15: 98%) and reduce deforestation or enhance afforestation and reforestation. Policies that target agricultural emissions (CH_4, CO_2, N_2O), are less prevalent (7: 59%). Sustainability standards for biomass use exist only in a minority of countries (7: 34%), despite the relative widespread use of biofuels, especially in the transport sector. The results suggest that most countries promoting the use of biomass or biofuels as a renewable energy source do not ensure that their use will lead to net emission reductions.

4.3.3 Key sectoral policy gaps and ambition entry points

We use both the number of countries and their emissions shares to cluster the 50 identified policy options and identify key policy adoption gaps (Figure 12). As noted, the number of clusters is defined using a knowledge domain approach (k=3) but is compatible with the first local maximum of the Calinski-Harabasz index. Approximately half of the policy options identified are mapped to the cluster ‘high coverage’ (SM4 - S4). This cluster includes policy options that are in force in more than eleven G20 countries that cover at least 70% of the group’s emissions. The number of high coverage policy options shows the progress in the past twenty years (Section 4.3.2). However, fifteen policy options are clustered under ‘medium coverage’ and an additional nine options are ‘low coverage.’

In this section we focus on policies clustered in the ‘low coverage’ and ‘medium coverage’ groups (Figure 4). ‘Low coverage’ policy options are in force in fewer than six of the G20 countries, that collectively cover up to 40% of the group’s emissions. These are critical areas for future policy adoption since policy options in this research have been identified by different disciplines as important mitigation interventions (SM - S2). ‘Medium coverage’ options are in force in fewer than two-thirds of the G20 countries, that, in some cases, cover up to 75% of the group’s emissions. While their adoption is more advanced in comparison to ‘low coverage’ policies they are still relevant improvement areas.

The G20 lacks some overarching policy options. Despite the high prevalence of energy efficiency and renewable energy policies (Section 4.3.2), policies that set national energy efficiency and primary energy renewable targets are still missing in key emitters (medium coverage). Targets require additional policies to mitigate emissions. However, they set goals and influence important indicators used to track climate mitigation progress (G. P. Peters et al., 2017). Targets indicate ambition and signal commitment to relevant stakeholders (Iacobuta et al., 2018). In addition, no G20 country has yet successfully removed fossil fuel subsidies. This measure could result in significant emission reductions, even though it alone remains insufficient to achieve the climate goals of the Paris Agreement (Jewell et al., 2018; van Asselt & Kulovesi, 2017).

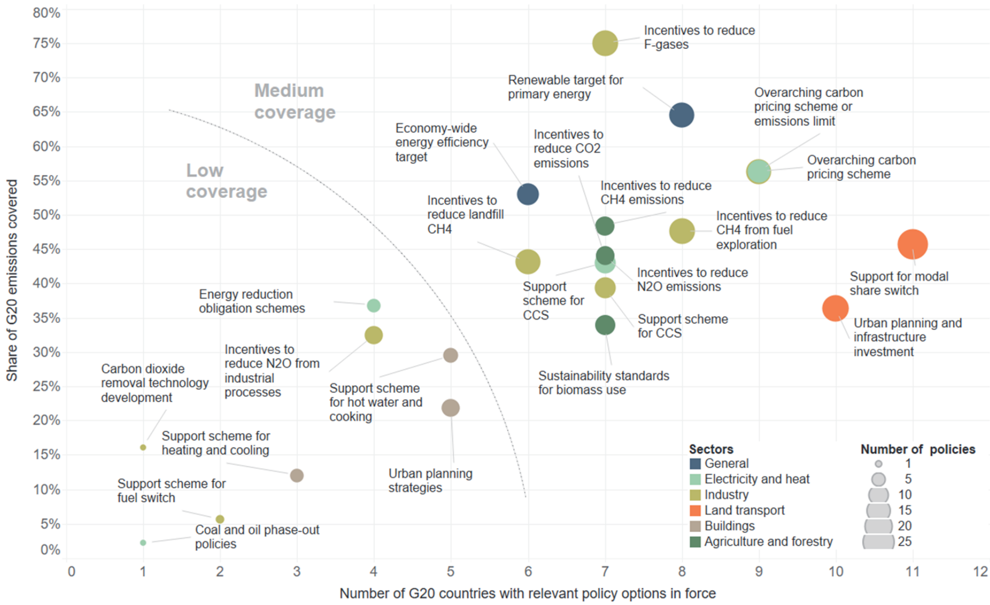


Figure 12: Low and medium coverage policy options (emissions weighted country coverage vs number of countries covered). High coverage options are excluded for visualisation purposes but included in (SM4 - S4). The curve represents an illustrative, not actual, boundary.

A number of sectoral policy gaps are identified and many of these are in areas that can lead to emission reductions beyond current policies, if successfully replicated in other countries (Fekete et al., 2021). For example, to impose limits on coal-fired power plants via phase out policies or energy reductions schemes, and the reduction of fugitive emissions, are both good practice examples to reduce energy-related emissions. The reduction of fluorinated gases has also been identified as an impactful option, but it is in force in less than half of the G20 countries. The strong overlap between low coverage and good practice policy options indicates a clear gap in policy making.

With respect to non-energy GHG emissions, seven key policy gaps can be identified: policies to reduce agricultural emissions (CH_4, CO_2 and N_2O); methane from fossil fuel exploration and landfill waste; nitrous oxide from industrial processes; and fluorinated gases. These sub-sectors were responsible for a quarter of G20 emissions in 2018 (FAOSTAT, 2019; Olivier & Peters, 2019), yet these emissions are not widely covered. The policy gaps in these sub-sectors left approximately one-fifth of G20 emissions uncovered two decades ago. This has improved over time, but approximately one-tenth of total G20 emissions remains uncovered due to a lack of climate policies in this area today.

4.4 Discussion

Our research is one of the first to develop a comprehensive and up-to-date database on mitigation-relevant policies, adopted in G20 countries and that cover most global emissions. The results provide insights into the evolution of sectoral climate policy adoption and constitute a stepping stone for further quantitative analysis of climate policies (Kern et al., 2017; T. S. Schmidt & Sewerin, 2019). Our analysis does not explicitly address the ambition or effectiveness of climate policies. It does, however, have implications for the process of strengthening climate action and respective emission reductions.

We define a matrix of options to unpack sectoral climate policy adoption and to identify policy gaps by sector. These options represent sector-level measures that are recognised to reduce emissions, but that may not be widely adopted in the G20. This analysis complements previous studies that focus on the number of policies in force (Eskander & Fankhauser, 2020; Le Quéré et al., 2019). To increase the number of climate policies in force is a necessary but not sufficient condition to reach the collective goals of the Paris Agreement. The absence of sector policy and weak coverage indicate that additional emissions can still be avoided and that a significant portion of global emissions remain uncovered by climate policies.

The matrix of climate policy options is both scientifically and politically relevant. It provides a framework that investigates climate policies through the lens of their objectives instead of their policy instrument. The matrix provides a comprehensive tool for policy analysts and policy makers, allowing for a systematic comparison of policy adoption across countries and the identification of national policy adoption gaps. Combined, this analysis can support ambition raising efforts and better policy implementation. However, future research will be needed to update the data and policy options to account for new evidence about their roles and trends in their implementation.

Despite an increase in the number and coverage of policies, significant adoption gaps remain in all sectors. Our analysis supports findings that the number of climate policies increased and that a multi-sector and multi-instrument approach to climate change mitigation exists in every G20 country (Averchenkova et al., 2017; Eskander & Fankhauser, 2020; Mundaca & Markandya, 2016). Some policy gaps, e.g. carbon pricing, were previously identified by others who also analysed policy coverage (N. M. Schmidt & Fleig, 2018). However, our sector level granularity enabled the identification of several additional areas where climate policy adoption could be improved. Information about policies in the buildings and agriculture sectors, for example, has been limited (Fekete et al., 2021); here, our analysis contributes to better understanding about the state of play and policy adoption in these sectors.

Our findings indicate that action at sector level provides clear opportunities for raising ambition. We find that sectoral policies were adopted before and independently of cross-sectoral, overarching policies. Sectoral climate policies also spread across sectors and countries faster than cross-sectoral policies. Filling the identified policy gaps will be challenging and will require strong coalitions to reduce dynamic distributional barriers and to drive down technology costs (Meckling et al., 2015; Pahle et al., 2018). However, successfully implementing sectoral policy options can align current policies with the collective goals of the Paris Agreement (Blok et al., 2020). Filling policy gaps is an important step to support the implementation of sectoral mitigation measures and realise the deep emission reductions in line with these goals.

Addressing adoption gaps is important, but further analysis of the effect of climate policies on emissions remains necessary. Assessing elements of successful policy adoption, e.g. sectoral policy instrument balance, and some measure of policy stringency, are important ingredients of such analysis (OECD, 2018; Schaffrin et al., 2015; T. S. Schmidt & Sewerin, 2019). However, it should also consider socio-political and economic factors, that can influence emissions, to isolate the effect of the policies (Lamb & Minx, 2020). A detailed account of these factors could be used to explore the causal relationship between historical policy adoption and emissions trends (Le Quéré et al., 2019). Our database and analytical approach contribute to a granular representation of policy adoption and provide a useful foundation and means to study the effects of climate policies.

Although our approach is innovative, it is limited in certain aspects. The policy coverage results may be underestimated for some countries and sectors because we only considered national policies. This is also relevant for the exclusion of EU member state policies. Many important policies are also adopted at subnational levels (Hsu et al., 2019; Martin & Saikawa, 2017). Existing non-governmental actions and targets can help deliver significant emission reductions additional to those committed nationally (Kuramochi, Roelfsema, et al., 2020; Lui et al., 2020; Mi et al., 2019). The resulting underestimation is prominent for urban planning strategies, which could be led by cities without initiative or guidance by national governments. For all other policy areas, the addition of sub-national policies should not strongly change the results of our analysis as most countries also use national policies.

The emissions share in our analysis is based on economy-wide, rather than sectoral, emissions. Additionally, policies that target a subset of actors in the country are counted as targeting the whole country. This is because sectoral emissions databases, especially those which allocate electricity emissions to end use sectors for all G20 countries, were unavailable. Given the large differences in overall emissions between countries and the smaller differences in sectoral emissions shares, economy-wide emissions are sufficient to assess policy adoption gaps. This share can be interpreted as an upper bound for the G20 emissions covered by policies.

4.5 Conclusions

Our research analysed sectoral climate policy coverage in the G20. We defined a matrix of mitigation and mitigation-related policy options that describes a comprehensive climate policy package, to analyse the adoption of policy and concrete opportunities to strengthen climate change mitigation efforts.

Countries' approach to climate policy has evolved in the past twenty years. The number of sectoral climate policies and their coverage in G20 countries and at sector level has increased. Countries with relevant policy options in force cover on average two-thirds of total G20 emissions, in comparison to only one-third twenty years ago. Countries also implement the climate policy options identified using multiple policy instruments. Market-based instruments are more common than they were twenty years ago, but their adoption is slower than observed for other policy instrument types. A detailed analysis of sectoral policy adoption shows that multiple gaps remain. To address them is key to realise the full mitigation potential of existing policy options and to advance policy mixes towards the goal to systemically reduce emissions to net zero globally by mid-century.

Our analysis show the prevalence of incoherent policy goals and diverse policy adoption misalignments in the G20. Policies to support renewables are common, but complementary policies to reduce fossil energy are scarce. Countries simultaneously support the uptake of renewables and the maintenance of emissions-intensive infrastructure. Policies that regulate production and exploration of fossil fuels or phase-out of oil and coal are rare in the G20. Countries still subsidise fossil fuels, despite taxing energy in key sectors. Inconsistencies beyond fossil energy exist. The use of biofuels, for example, is supported in many countries without ensuring the sustainability of the biomass supply chain.

Approximately half of the policy options identified are missing in at least one-third of the G20 countries. Also, approximately one-tenth of G20 country emissions remain uncovered by climate policies. Filling these glaring policy gaps (low coverage) is a first step towards more comprehensive climate policy and constitutes an opportunity to realise additional emission reductions. Specifically:

- **General**: Removal of fossil fuel subsidies

- **Electricity and heat:** Coal and oil phase out and energy reduction obligation schemes
- **Industry:** Reduction of industrial process emissions, incentives for fuel switching and development of carbon dioxide removal
- **Buildings:** Support for renewable energy in cooking and heating/cooling purposes and planning strategies supporting buildings' retrofits

Currently adopted climate change mitigation policies are insufficient to reduce emissions at the rate required to meet the climate goals of the Paris Agreement. The slow progress towards closing the global emissions gap calls for all hands of deck. We argue that sector policies present a key entry point to raise ambition. To minimise inconsistencies and improve coverage of existing policy options, in parallel with efforts to strengthen individual policies, will help to advance sectoral, national and global mitigation efforts and realise the full potential of sectoral climate policy.

5 Expanding climate policy adoption improves national mitigation efforts

Summary

To identify means to improve mitigation efforts, we investigated whether the number of climate policies is associated with emission projections up to 2030 and compared policies' prevalence across country groups. We find that larger and more comprehensive policy portfolios are conducive of emission reductions, regardless of whether absolute emissions increase or already decline. However, country groups have distinct entry points to expand climate policy. Countries with fast increasing emissions have significantly fewer policies overall but policies are especially missing in energy-demand sectors, such as buildings and transport. Countries with stalling emissions lack climate strategies and other cross-sectoral policies. This suggests the need for better coordination of mitigation efforts across sectors. In all country groups that fail to reduce emissions, policies to reduce energy and material demand are also substantially fewer. Despite the collective increase of policies in force, countries can still expand climate policy to use of the full breadth of mitigation options available.

Nascimento, L. and Höhne, N. (2023) 'Expanding climate policy adoption improves national mitigation efforts', *npj Climate Action*, 2(1), p. 12. doi:10.1038/s44168-023-00043-8

5.1 Introduction

Climate change results in unprecedented and rapid changes of the Earth's systems (IPCC, 2021). These changes are expected to reach devastating levels if countries do not reduce their greenhouse gas emissions, hereafter emissions, to zero and collectively limit end-of-century temperature increase to 1.5°C (IPCC, 2018b). To mitigate climate change, countries adopt and implement several policies. These policies include those with explicit mitigation objectives, such as climate strategies; energy policies, that help to decarbonise energy supply and/or reduce demand; and policies that introduce low-emissions practices to non-energy sectors (Fekete et al., 2021). However, policies to date have been insufficient to curb historical global emissions (Friedlingstein et al., 2021; Z. Liu et al., 2023).

Although policies adopted so far fail to secure emissions reductions in line with global decarbonisation, their number increased in the past few decades (G. Peters et al., 2020). Distinct statistical analyses provide evidence of policies' aggregated effect (Best et al., 2020; Eskander & Fankhauser, 2020) or of their relationship to country characteristics (Best & Zhang, 2020; Skovgaard et al., 2019). These analyses show that collectively climate policies have led to a net-positive effect and contributed to a reduction of historical emissions (Dubash et al., 2022). This shows that increasing the number of climate policies has improved climate change mitigation efforts. However, the pathways leading to impact require further investigation (Dubash, 2020).

Additionally, evaluating emission projections resulting from adopted policies constitutes an important tool to assess whether current efforts are sufficient to limit temperature increase (IPCC, 2022). In 2021, adopted policies resulted in lower emission projections up to 2030 than estimated in 2015 (Nascimento, Kuramochi, & Höhne, 2022). However, global emissions are projected to remain on an upwards trend (den Elzen et al., 2022a). This suggests that additional strategies to improve global climate policy remain necessary to curb global emissions within this decade. Identifying and expanding good practice policy approaches, that have a substantial effect on emissions, would close part of the gap between current emission projections and pathways compatible with limiting temperature increase to 1.5°C (Baptista et al., 2022; van Soest, Aleluia Reis, et al., 2021).

Climate change mitigation efforts rely on a combination of policies, each of which have different effects (Peñasco et al., 2021). Balancing these effects increases the chance that collective objectives are met and that instruments lead to net-positive outcomes (van den Bergh et al., 2021). Although an increase in the total number of policies help reducing emissions, the distribution of policy instruments across sectors probably influences their collective effect. We argue that empirical research focusing on these distributions enables identifying potential policy entry points to slow down projected emission growth.

In our research, we compared the number of policies in force across country groups to identify means to expand and improve climate policy. First, we evaluated whether the prevalence of policies is associated with lower projected emission change rates between 2021 and 2030. This clarifies that expanding climate policy adoption is desirable to slow down future emissions. Second, we compared the number of policies across country groups to identify areas with substantially fewer policies. This supports identifying means to expand climate policy adoption in line with best-performing countries.

We use a comprehensive policy dataset to calculate the number of climate policies in force, or policy density. This dataset has been used in previous publications and is periodically updated to reflect recent policy adoption (NewClimate Institute, 2021; Schaub et al., 2022). We associate this dataset with emission projections developed between 2015 and 2021. Emission projections are based on the 'current policy scenario' developed in the Climate Action Tracker (CAT) project (CAT, 2021). We analyse 40 countries (SM5 - Table 19), which together account for 84% of global emissions in 2019 (FAO, 2023; Olivier & Peters, 2021).

In our research, we used linear regressions to investigate whether the total number of climate policies, or policy density, explains the variance in projected emission-change rate distributions. We also used clustering analysis and statistical significance tests to evaluate how policy density varies across country groups. The linear regression analysis clarifies whether a larger policy portfolio is associated with lower projected emissions. The country group comparisons add nuance by considering that countries are in different stages of climate change mitigation efforts. In this case, we compare the number of policies across groups to identify which ones are less prevalent in country groups with higher projected emission growth. We identified policy expansion entry points by benchmarking adoption against the best-performing country group (See 'Methods').

5.2 Results

5.2.1 Country clusters

We used a clustering approach to explicitly consider country differences without relying on development-based categorisations, such as Annex-I in the UNFCCC context. We instead used country characteristics closely related to their future mitigation efforts. We applied this approach because of our focus on projected emission change rates. Although current political economy constraints will likely remain relevant, we argue that countries' future emissions are highly dependent on countries' interpretation of their fair-share contribution to minimizing the impacts of climate change, as outlined in the Paris Agreement (UNFCCC, 2015c). We included historical GDP and emission per capita because they are important indicators to distribute future mitigation responsibilities and are also commonly mentioned in countries own mitigation targets to justify their ambition (Rajamani et al., 2021). We also used countries' projected emission change rates to account for the already expected direction of change. Collectively, these indicators also account for many other important country characteristics. For example, emission per capita is a measure of the emission intensity of the country. Therefore, it is affected by high dependency on fossil fuels for energy or economic development.

Our analysis identified three country clusters with distinct characteristics. The clusters are defined by countries' historical emissions per capita, GDP per capita and projected emission change rates. We do not observe any overlap between groups across historical emissions and GDP per capita nor do we observe a change in the cluster the country belongs to over time (Figure 13a). This indicates that the clusters are sufficiently heterogeneous, and that the categorisation is time invariant within the period considered. GDP per capita and emission change rates show an inverse and monotonic relationship ($R^2 = 0.43$; p-value < 0.01). Countries with higher economic capability tend to have lower emission change rates between 2021 and 2030 (Figure 13b). The relationship between historical emission per capita and projected emission change rate is less significant ($R^2 = 0.25$; p-value < 0.01) but is probably concave. Emissions in countries with both low and high per capita emission levels are projected to grow faster (Figure 13c). The different clusters are described in more detail below.

The 'high growth' cluster includes 25 countries with a projected mean annual emission change rate of 2.3%—the highest among the three clusters. Its countries tend to have lower emissions and GDP per capita. It includes all low-income and some emerging economies, such as Argentina, Brazil, China, India, Indonesia, Mexico, South Africa and Turkey. Together the countries in this cluster represent approximately half of global emissions (FAO, 2023; Olivier & Peters, 2021). In the past two years, South Africa's emission change rate is substantially lower than the other countries in the same cluster.

The 'moderate growth' cluster includes nine countries with a projected mean annual change rate of 0.9%. It is strongly defined by high historical emission per capita, which is for all countries above

13 tCO_2eq. Together these countries represent almost a quarter of global emissions. This cluster includes several developed countries, including some that that have curbed emissions growth, such as Australia, Canada, South Korea and the United States. It also includes a few countries with increasing emissions, such as Saudi Arabia and Kazakhstan. Despite these differences, fossil fuel dependency for economic or energy purposes play a substantial role in this cluster, which includes several of the world's top fossil fuel producers (BP, 2021).

The 'moderate decline' cluster includes six of the countries analysed and has a projected mean annual emission change rate of -0.9%. This cluster is characterised by medium-to-high GDP and medium emissions per capita. Together the countries in this cluster represent approximately one tenth of global emissions. Japan, Switzerland, Norway, the European Union as a group and the United Kingdom, after its exit from the European Union, all show declining emissions in the period analysed. Singapore is the only country in this cluster where emissions still increase.

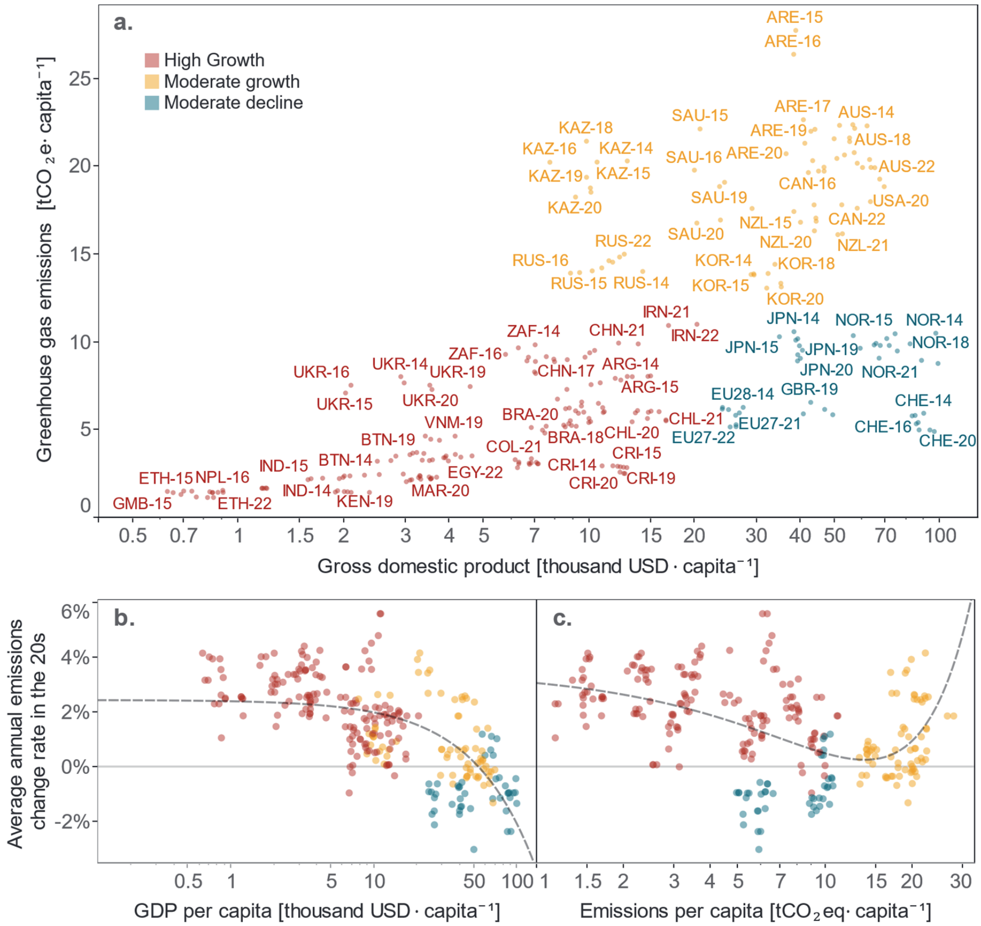


Figure 13: Clustering analysis results. Mind the log scale in all charts. The three letters represent the country's ISO-3 code and the two digits the year of the data (historical GDP/capita, historical emissions/capita and projected average change rate developed in the respective year).

5.2.2 Policy density is associated with projected emissions

We find that countries with more policies have lower projected emissions up to 2030. The total policy density is associated with lower average emission change rate between 2021 and 2030 (Figure 14a). These results are robust when controlling for rule of law, per capita values for historical emissions and GDP and the number of high-impact policies. Also, although the magnitude of the effect varies across clusters, policy density is associated with lower emissions growth across all clusters (Figure 14b).

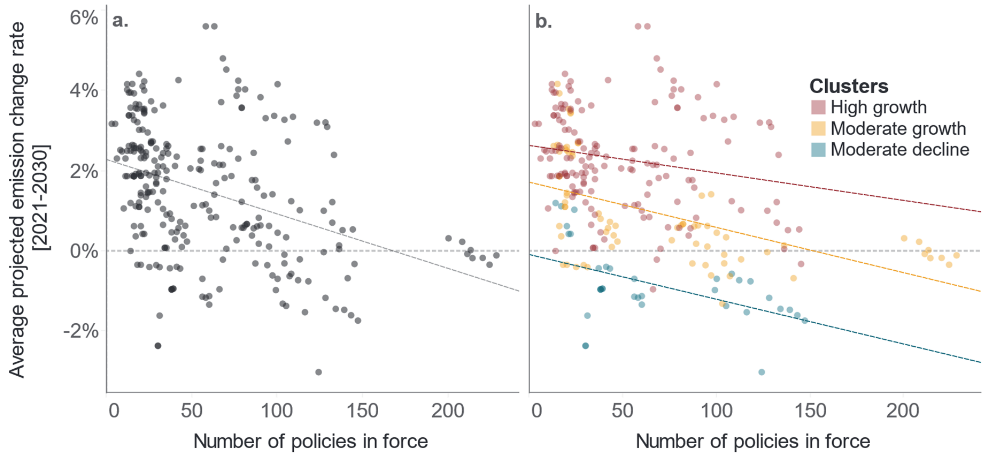


Figure 14: Relationship between average annual projected emission change rates and number of policies. Countries with more climate policies have lower projected emission change rates (a). This result is valid across clusters although to a different degree (b). Results are statistically significant despite variance.

In our regression analysis, we controlled for the number of high impact policies and rule of law, even though we did not explicitly account for the stringency of policies in force (SM5 - Table 20). The number of high-impact policies controls for the prevalence of policies that are considered to have substantial effect in emissions or are prominent in the national policy debate. These policies are often also used in the quantification of future emissions. Rule of law is used as a proxy for the quality of law making and enforcement. Including these variables accounts for potential bias in the development of current policy projections and varying degrees of potential policy implementation. Both these variables are associated with projected emissions. Stronger rule of law is associated with lower projected emissions. However, the number of high-impact policies is not. The number of high-impact policies is substantially lower than the total number of policies in force and our findings suggest that a higher number of these policies alone is insufficient to reduce projected emissions. We also control for GDP and emissions per capita, since these two variables are important to contextualise future mitigation efforts. We find that the policy density is important to reduce future emissions in countries independently of their emissions intensity per capita and economic capability. However, countries with higher economic capability tend to have lower projected emissions.

No other study analysed the effect of policies on emission projections using similar methods, but some have analysed the effect of policies on historical emissions. Eskander & Fankhauser (2020) found that countries' climate policy portfolio reduced annual emissions change rate by 0.8 p.p. between 1990 and 2016. Our average-sized portfolio is expected to reduce annual emissions growth by 0.8 p.p. by 2030. We note that substantial differences in the size of the average portfolio exists between the two studies due to differences in climate policy definition (Schaub et al., 2022). Also, closed-form functions describing the effect of policies on emissions are only relevant for comparison purposes as actual causal relationships are substantially more complex. Nonetheless, both studies suggest statistically significant effect on the same direction and of similar magnitude.

Although policies reduce projected emission growth, adoption varies within countries. Policy density is not homogeneous across sectors (SM5 - Figure 23). The agriculture sector has the fewest adopted policies (mean: 4). This probably contributes to the lack of progress in reducing agricultural emissions (Lamb et al., 2021). Countries adopt most policies (mean: 21) in the electricity and heat supply sector. This is partly explained by the earlier start of climate policy adoption in this sector (Nascimento, Kuramochi, Iacobuta, et al., 2022). We also find a strong relationship between the number of policies in the electricity and heat supply and other sectors (SM5 - Figure 24). In other words, countries with many policies in this sector tend to have many policies in others too. This supports the existence of positive cross-sectoral policy feedbacks lowering adoption barriers across sectors. These findings combined suggest that the electricity and heat sector has been an entry point for policy expansion.

Similarly, the number of policies across instrument types varies (SM5 - Figure 23). Market-based (mean: 2) and voluntary approaches (mean: 3) are the least adopted instrument types. Their low prevalence is partly explained by policy instrument sequencing since both instruments are often implemented last across countries (Linsenmeier et al., 2022). These two instrument types are therefore more common in mature climate policy portfolios. Other instrument types are substantially more prevalent. For example, countries adopt more fiscal and financial incentives (mean: 15) and regulatory instruments, such as codes and standards (mean: 12). These two instrument types rely on very distinct mechanisms. While the former intends to provide benefits to low-carbon interventions, the latter aims to penalise polluters. Literature investigating instrument sequencing suggests that benefits are introduced first and then are followed by regulatory policies (Meckling et al., 2017). Now both approaches are almost equally prevalent.

Considering the relationship across policy instrument types, we observe that countries with many Research & Development (R&D) and information policies tend to adopt more policies across instrument types (SM5 - Figure 24). R&D policies are insufficient to reduce emissions alone but foster innovation, which help reducing mitigation options' costs (Bosetti et al., 2011). Information and education policies support behavioural changes, the adoption of low-carbon technologies and lower adoption barriers for more stringent climate policies (Dubash et al., 2022). These relationships suggest that such policies represent important means to expand climate policy adoption.

Policy density across mitigation areas also indicates that some are more prevalent than others. Countries adopt more policies related to energy efficiency (mean: 32) and renewable energy (mean: 26) in comparison to the other three mitigation areas analysed. Other studies also found that countries with declining historical emissions have a substantially higher number of renewables and energy efficiency policies (Le Quéré et al., 2019).

5.2.3 Entry points to expand climate policy adoption

Considering that an increase in the number of policies is associated with lower projected emissions growth, we aim to identify potential entry points to expand policy adoption using countries with moderate decline in emissions as a reference. Therefore, we compared policy density in the 'high growth' and 'moderate growth' clusters to that of the 'moderate decline' cluster (Figure 15). Significance statements in the text are based on p-value results from the non-parametric comparison of policy density distributions.

The ‘high growth’ cluster has the highest average emission change rate expected in the coming decade and has significantly fewer policies across almost all sectors, policy instrument types and mitigation areas (Figure 15).

Countries in the ‘high growth’ cluster adopt fewer energy-demand-related policies (dark blue squares in Figure 15a). Energy-related sectors are responsible for a large share of ‘high growth’ countries’ historical emissions (Lamb et al., 2021). However, the average number of policies in transport, buildings and industry is in each sector approximately half compared to the ‘moderate decline’ cluster. Although policy density is lower in some sectors, countries in this group adopt similar number of electricity and heat supply, agriculture, and cross-sectoral policies. This suggests that expanding policy adoption in these sectors is not as critical as in energy demand, although it would probably still lead to positive outcomes. The disproportionally lower number of policies targeting energy demand sectors represents a clear entry point to further reduce emissions in these countries.

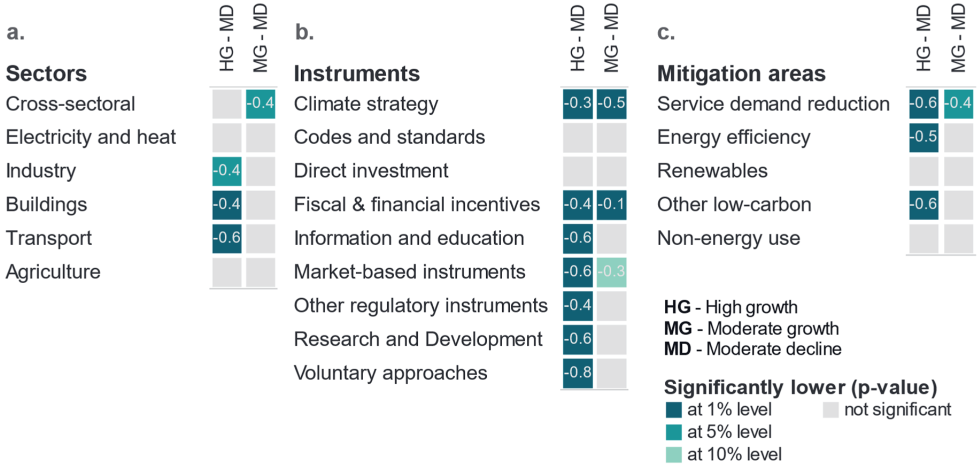


Figure 15: Comparing policy density to Moderate decline cluster. Results from Mann-Whitney U one-tailed test comparing policy density across sectors (a), policy instrument types (b) and mitigation areas (c). Colours indicate whether policy density is significantly lower when compared to the ‘moderate decline’ cluster. Labels present the percentage difference of the medians. For example, the median number of climate strategies in the ‘high growth’ and ‘moderate growth' clusters are respectively 30% and 50% lower compared to the ‘moderate decline’ cluster.

Countries in the ‘high growth’ cluster also have a significantly lower number of policies in almost all policy instruments (Figure 15b). This indicates that countries in this cluster can still substantially improve the size and diversity of their climate policy portfolio.

The ‘high growth’ cluster adopts less than half of the number of information and education, R&D, market-based and voluntary instruments. Some of these differences are anticipated. Voluntary approaches and market-based instruments are often implemented latest in policy instrument sequencing (Linsenmeier et al., 2022). Annex-I countries, which have older commitments to reduce emissions in comparison to countries in the ‘high growth’ cluster, started implementing climate policies earlier. This contributes to a more diverse set of policies in force. Research and development policies are also expected to be more prevalent in these countries, which spend more on research (World Bank, 2022b). However, we also observe significant fewer information and education policies, which constitute a low-hanging fruit approach to expand policy adoption in this cluster.

Countries in the ‘high growth’ cluster also have significantly fewer policies across all mitigation areas, except non-energy and renewables (Figure 15c). The number of policies is substantially and significantly lower in energy efficiency, service and demand reduction policies and low-carbon alternatives to increase renewable energy supply. Demand-side policies, including energy efficiency, reduce greenhouse emissions and has numerous benefits to other development goals (Creutzig et al., 2022). Their adoption represents clear strategy to improve climate change mitigation efforts. Other low-carbon alternatives, such as nuclear energy, and fuel switch, such as coal phase out policies, are also important and significantly lower in the ‘high growth’ cluster (Fell et al., 2022; F. Green & Denniss, 2018).

Countries in the ’moderate growth’ cluster have succeeded in slowing down projected emissions, which are still not declining despite the relatively high capability (GDP per capita) and high responsibility (emissions per capita). This cluster has, in general, more policies in force compared to the ‘high growth’ cluster but significantly lower number of policies in some policy instrument types and mitigation areas when compared to the ‘moderate decline’ cluster.

Countries in the ‘moderate growth’ cluster adopt a similar number of sectoral policies when compared to ‘moderate decline’ but have a less integrated approach to mitigation efforts, due to fewer cross-sectoral and framework policies. Cross-sectoral policies, per definition, are those that target multiple sectors or provide a framework policy for climate change mitigation. Countries in this cluster have on average 40% fewer cross-sectoral policies adopted compared to ‘moderate decline’ countries. This result is supported by the significantly fewer climate strategies, which frame mitigation commitments and efforts and indicate the scale of effort necessary (Dubash et al., 2013; Iacobuta et al., 2018).

The ‘Moderate growth’ cluster also have a significantly lower number of fiscal and financial incentives and market-based instruments compared to the ‘moderate decline’ cluster, albeit the latter at a lower significance level. However, they have more regulatory instruments, direct investments, information and education programmes, voluntary approaches, and R&D policies. The comparison of policy instruments across these two clusters does not yield substantial insights, except for indicating that countries adopt policies using different approaches and that improving the number of market-based instruments and fiscal and financial incentives will probably improve mitigation efforts. Like the ‘high growth’ cluster, the ‘moderate growth’ cluster has a significantly lower number of policies in low-carbon and service demand reduction areas.

5.3 Discussion

Our research contributes to the comparative climate-policy literature. Here, we use statistical methods to associate policy adoption to emission projections up to 2030. We find that increasing the number of policies in force is associated with slower emissions growth or faster emissions decline. By comparing distributions of policies, we account for national differences and obtain more statistically robust results than when comparing individual countries. The empirical evidence presented here indicates common approaches associated with emissions reductions and potential entry points to expand climate policy. Overall, considering the distribution of policies across sectors, policy instrument types and mitigation area improves our understanding of the effect of climate policies.

We find that expanding climate policy adoption is associated with stronger climate change mitigation. Countries with more policies in force have lower projected emission change rates, independently of their historical emissions and GDP per capita and of the number of high-impact policies. However, GDP per capita is still strongly associated with emission change rates: high income countries are more likely to decline emissions. The addition of policies slows down emissions whether a country is starting their mitigation efforts or already show declining emissions. This evidence suggests that larger and more comprehensive climate policy portfolios are conducive of emissions reductions.

We also do not suggest that countries should adopt more policies independently of their content but find that increasing the number of policies increases the probability that these policies collectively reduce emissions. Different causal mechanisms are probably at play. A few stringent policies might be responsible for a large share of the observed effect (Fekete et al., 2021) while weaker policies play a supportive role, e.g. by enabling their adoption. Alternatively, weaker policies might collectively cause the observed effect by reinforcing each other and balancing policymaker's priorities (Karlsson et al., 2020). The dominant mechanism remains unclear. More research on the interaction between climate policies, instead of their individual effect, is needed to explore the mechanisms leading to impact.

We identified potential policy entry points for policy expansion. Policies that aim to reduce demand beyond energy efficiency improvements (e.g., policies to reduce energy needs via improved urban planning) and to set climate change mitigation strategies are significantly and substantially fewer in countries that fail to decline projected emissions. We also find that countries with many policies targeting electricity and heat supply tend to have multiple policies in other sectors too. This, combined with the evidence that countries' started climate policy adoption in this sector, suggests that addressing electricity and heat supply is a good entry point for sectoral policy adoption, especially in countries with fewer policies in force. These options represent clear opportunities to expand and improve climate policy adoption across countries.

However, countries at different stages of mitigation would benefit from differentiated approaches to expand their policy portfolios. Countries with fast growing emissions have lower number of policies in almost all sectors, policy instrument types and mitigation areas. While some of these are expected, key options to expand climate policy adoption include: education and information policies and programmes and policies that address energy use sectors. Countries that stalled their emissions growth have similar number of policies compared to countries with declining emissions. A key difference is their significant lower number of cross-sectoral, framework policies, such as climate strategies.

Our findings do not mean that expanding specific policy types alone will reduce emissions. All results must be analysed in the context of the policy portfolio. Research indicates that a progression of policy adoption over time exists (Pahle et al., 2018). Market-based instruments are usually the last type to be adopted in major emitting economies (Linsenmeier et al., 2022). Cross-sectoral policies are also adopted later than sector-specific ones (Nascimento, Kuramochi, Iacobuta, et al., 2022). Finding that cross-sectoral and market-based instruments are lacking in countries with increasing emissions implies that these policies alone reduce emissions or that portfolios that contain these policies reduce emissions. Considering that the former mechanism is valid supports expansion of these specific policy instruments. Considering that the latter mechanism is valid builds evidence of which characteristics of a mature climate policy portfolio contribute to slower projected emission change rates. Both interpretations generate valuable insights in the context of policy expansion, which remains fundamental to address climate change.

Climate change is a highly complex problem that contains multiple interdependencies with other societal issues (Sun & Yang, 2016). Stakeholders have multiple, often value-laden perspectives about the problem relevance and the choice of solutions (Head & Alford, 2013). This implies the existence of diverse policy objectives intended to address conflicting viewpoints, foster agreement and enable coherent action (Head, 2019). Therefore, the adoption of multiple policy instruments is key to address multiple objectives (Bouma et al., 2019; Tinbergen, 1952). Additionally, adopting multiple instruments aid in managing future uncertainty, addressing diverse market failures and improving governance (Bouma et al., 2019). Different studies find that larger policy portfolios contribute to sustainable transitions (Campbell & Coenen, 2017; Rosenow et al., 2017). Here, we provided empirical evidence that larger and more comprehensive climate-policy portfolios reduce projected emissions growth.

However, expanding the number of climate policies has diverse policymaking implications. For example, expanding policy adoption leads to additional feedback effects (Pierson, 1993). Attention to these feedbacks during the policy formulation process is fundamental to ensure positive outcomes (Leipprand et al., 2020). Parallel development of administrative capacity to implement policies is also a condition to harness the positive effects of policy expansion (Limberg et al., 2021). However, we argue that policymakers are not required to anticipate all potential effects to implement climate policies, since sub-optimal policies combined can also lead to substantive emissions decline (Bertram et al., 2015). Also, policy portfolios result from a process of policy and political change (Howlett & Rayner, 2013). Their development implies some degree of patching existing portfolios through policy expansion and dismantling (Kern et al., 2017; Knill et al., 2012). Although re-structuring policy portfolios poses its own challenges, progressively improving solutions helps to avoid the risks of failing in the pursue of single, first-best solutions (Levin et al., 2012). Further research on the policymaking process, considering policy expansion implications, will probably help accelerating climate policy adoption.

Our research is subject to distinct limitations, some of which we discuss here. For example, it implicitly compares policy adoption to countries with the fastest emissions decline. However, their average decline rate is insufficient to meet the collective goals of the Paris Agreement (Höhne et al., 2020). This indicates that emissions reductions will remain insufficient even if countries replicate these policy approaches. Implementing some of the findings in this research will result in incremental improvements at best and must be combined with other interventions to keep the goals of the Paris Agreement within reach.

Additionally, investigating the effect of climate policies on emission projections developed using adopted climate policies potentially may lead to bias in the estimates. In other words, when policies are used to develop emission projections, they are by design associated with those projections. To this we respond using two main arguments. First, we investigated the effect of the size of the policy portfolio, or policy density, on emission change rates. The policies used as input in these quantification efforts may or may not have a relationship with policy density. This effect is potentially concerning if all policies in the portfolio are used as input for the emissions modelling, which is not the case. Emission projections under current policies are based on the quantification of a subset of high-impact policies. Here, we also included a proxy for these quantifiable policies as a control variable and found that the total number of policies remain statistically associated with projected emissions. Second, the effects observed on emission projections are also observed on historical emissions. This shows that even historical emissions, which are not resulting from modelling exercises, are similarly associated with policies adopted. The use of projections enables analyses of the longer-term effect of climate policies and is therefore more adequate to analyse policy adoption since the Paris Agreement. We find that the relationship between the total policy density and future emission growth rates remains valid, even when projections are based on adopted policies.

Despite the increase in number of policies adopted in the previous decades, countries must adopt new climate policies. Even countries with higher number of policies fail to decrease emissions at the necessary rate to meet the collective goals of the Paris Agreement. Improving mitigation efforts is thus essential considering the urgency to reduce global emissions. Expanding climate policy adoption to align with historical best-in-class approaches presents a clear strategy to improve mitigation efforts. Although policy adoption differences exist between countries, many opportunities to expand policy adoption remain. Worldwide emissions can well be reduced with already existing mitigation options.

5.4 Methods

Our analysis relies on panel data for 40 countries between 2014 and 2022. We included one data point for each country and year when emissions were projected, whenever data were available. The use of panel data improves our statistical findings. The sample used in this research consists of 263 data points.

Emissions data

We used emission projections developed under the CAT project, which provides yearly updates to its 'current policy scenario' for the countries analysed (CAT, 2021). CAT data were used in many scientific publications (e.g., Höhne et al., 2021; Rogelj et al., 2016) and is a central input to the UNEP Emissions Gap Report (UNEP, 2022). These projections are based on the full implementation of selected climate policies in force at the time the projections were developed. They constitute the best-available consistent estimate of policies' effect on future emissions considering present information for multiple countries. Emission projections exclude emissions from land use, land-use change and forestry (LULUCF).

CAT projections depart from country-specific reference scenarios, that are adjusted to include the effect of individual policies (Fekete et al., 2021). For the reference scenario, CAT relies on most recent government documents, such as a Biennial Update Reports (BUR) submitted to the UNFCCC, or on analyses from authoritative organisations, such as the International Energy Agency (IEA, 2022; UNFCCC, 2019a). The choice of reference scenario depends on many factors such as the coverage of policies and assumptions regarding key emission drivers. When the reference scenario includes only energy-related CO_2 projections, projections are complemented to ensure coverage of all emissions sources, including, for example, the US Environmental Protection Agency (EPA) report for non-CO_2 emissions (U.S. EPA, 2019).

When a recently adopted relevant policy is outside the scope of the reference scenario, its effect is included with add-on calculations. For example, CAT relies on the business-as-usual scenario from the Asia Pacific Energy Research Centre to estimate emission projections for Indonesia (APERC, 2019). The scenario estimates that coal will represent 51% of national electricity generation by 2030. However, Indonesia's official ten-year electricity supply plan indicates that coal will still represent 64% of electricity generation by the same year (Republic of Indonesia, 2021). To account for this policy, CAT estimated emissions associated with electricity generation considering the total electricity demand presented in the official plan and applying emission factors for the relevant fossil technologies. They complement electricity-only estimates by assuming other sectors follow the growth projected in Indonesia's latest BUR. The different scenarios are included in the projections analysed here as a range of emissions up to 2030. Similar approaches are taken for all countries analysed across the years.

We calculated the annual emission change per country between 2021 and 2030 and then averaged the results. The focus on average emission change rates highlights the expected dynamic in the coming decade instead of absolute changes in emission levels. In this calculation, we removed outliers (5^{th}-95^{th} percentiles), such as abrupt change resulting from economic lockdown measures in response to the COVID-19 pandemic. These outliers were removed for each country's projected annual change rate distribution before calculating the mean decadal change rate.

Policy data

Policy data were extracted from the Climate Policy Database (NewClimate Institute, 2021). As of the end of 2022, this database included over 3,000 national climate policies for the countries analysed. The policy database contains policies that affect country's long-term emissions, even if policies do not have an explicit climate change mitigation objective. Our analysis includes national policies only. Considering the sectoral scope of emissions projections, we excluded LULUCF-related policies.

The database includes categorisation for each policy in terms of policy instrument types, sectors and mitigation area. Policy instruments, such as voluntary approaches or subsidies, are tools used to implement policies and constitute a link between policy objectives and implementation (Rogge & Reichardt, 2016). The database uses a list of policy instrument types from the International Energy Agency (IEA, 2020a) that was adapted to better reflect climate-policy-related instruments. It also includes, for example, climate strategies, which are economy-wide framework policies that support coordination of mitigation efforts across sectors. Mitigation areas are broadly defined as distinct strategies to reduce emissions, such as supporting renewable energy or energy efficiency. The taxonomy used in this research is introduced in Nascimento et al. (2022) but summarised in the (SM5 - Supplementary Methods). The database also includes a field that identifies high-impact policies. The high-impact categorisation reflects country experts' expectations about policies effect and indicates policies that were often used to create the current policy projections.

In this research, the term policies refer to laws, legislations, executive orders, or their equivalent. Each policy is one entry in the database but can be coded as multiple policy instrument types, sectors and mitigation areas depending on its scope. For example, the Argentine Law No. 27,640 on biofuels establishes a biofuel blending mandate on gasoline and diesel (*Law 27,640 – Biofuel Regulation*, 2021). This policy is coded in multiple sectors since the mandate affects energy end-use sectors, such as transport and industry. Similarly, the Brazilian Law No. 13,755 aims to improve energy efficiency of vehicles sold within the country (*Law No 13,755 – Establishing Mandatory Requirements for the Commercialization of Vehicles*, 2018). It establishes mandatory requirements to manufacture or import vehicles in the country and offers tax reliefs for companies that prove research and development spending in line with the goals of the law. This law is coded as both a fiscal incentive and as a standard.

In our research, we focus on policy density, which describes the level of policy activity within a country(Schaub et al., 2022). Here, policy density was measured as the number of policies in force, as it is usually implemented in the relevant literature (Knill et al., 2012). We do not explicitly consider the stringency or intensity of policies in force. This concept relates to the implementation of policies. It is associated with the resources mobilised, both from an institutional and policy design perspectives, to implement policy instruments (Schaffrin et al., 2015). However, its operationalisation is not straightforward. Some researchers create metrics or indexes to assess stringency of the policy portfolio to rank or compare countries (Botta & Kozluk, 2014; Burck et al., 2021). In other cases, the stringency of individual policies is determined by their own target indicators (Roelfsema et al., 2022). This latter operationalisation of stringency depends on clear impact indicators and national counterfactual scenarios, which are often unavailable (Somanathan et al., 2014). These different evaluation approaches also affect the stringency of distinct policy instrument types. For example, carbon pricing instruments are probably more cost effective than regulatory instruments (Dubash et al., 2022). Therefore, when evaluating carbon pricing's stringency based on this criterion, they perform better. However, a review of ex-post analyses suggests that they have a limited effect on reducing emissions (J. F. Green, 2021). Conclusions derived from different approaches to assess policy stringency are not necessarily robust across countries and a common metric to measure stringency is unavailable (Galeotti et al., 2020).

We therefore assess whether policy density alone explains projected emissions, without addressing the difficult issue of stringency. Additionally, although the stringency of policies matter, climate policies are missing in many important areas (Nascimento, Kuramochi, Iacobuta, et al., 2022). Expanding countries' policy portfolios ensures that existing options to mitigate climate change are in place. Increasing policies' stringency and expanding climate policy are both necessary to improve mitigation efforts. Our research helps to identify areas that are disproportionally unaddressed and potential entry points to improve national and global climate policy.

To characterise policy adoption, we calculated the total policy density as the count of distinct policies. This includes the stock of climate policies in force at the respective date, not only policies adopted within the period analysed. Since policies are not homogeneously distributed in a country, we also calculated policy density across sectors, mitigation areas and policy instrument types. Instead of counting the total number of policies, we calculated, for example, the number of policies in each sector, which corresponds to the policy density of each sector.

Other data

National population data are based on the United Nations World Population Prospects and especially its medium fertility scenario (UN, 2019). We calculated historical levels of emissions per capita based on CAT emissions and UN population estimates. We used historical GDP per capita from World Bank (World Bank, 2022a). The rule of law, used a control variable in the regression analysis, is taken from the Worldwide Governance Indicators database (Kraay et al., 2010).

Cluster analysis

We clustered countries based on their projected emission change rate, historical per capita gross domestic product (GDP) and historical per capita emission levels. This initial step is used to identify groups in the data based on country characteristics. We used the k-means clustering algorithm, that aims to identify groups in data by minimising within-group variance (Arthur & Vassilvitskii, 2007) and chose the number of clusters that maximised the Calinski-Harabasz score (Caliński & Harabasz, 1974).

Linear regression

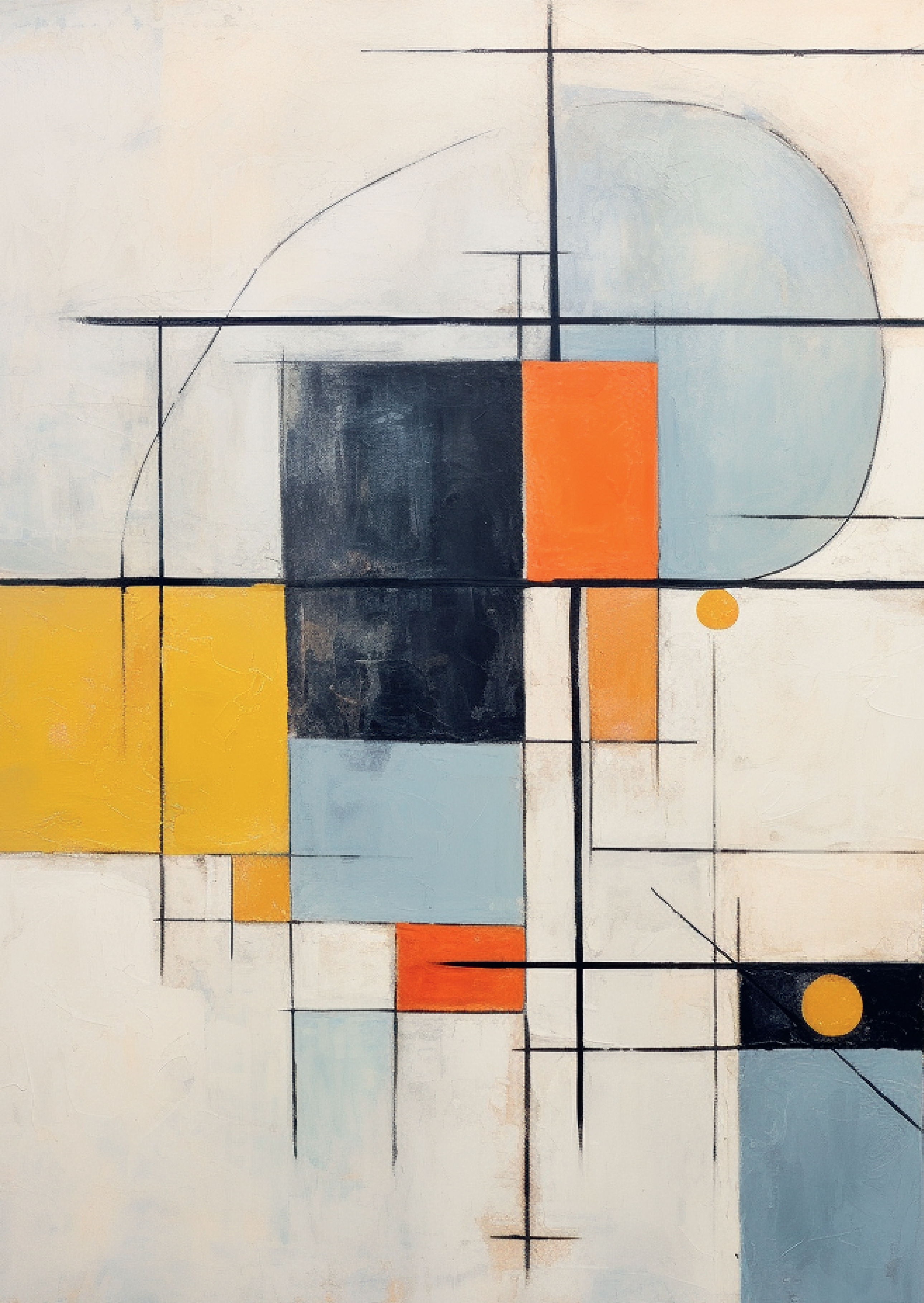
We modelled the relationship between policy density and projected emission change rates using linear regressions. We used the total policy density as the independent variable and the projected mean annual project emission change rate as the dependent variable. We modelled this relationship using Ordinary Linear Regressions with robust errors. This choice is based on the result of Breusch–Pagan tests that showed the presence of heteroskedasticity (Breusch & Pagan, 1979). Before building the regression model, we harmonised the data using the Z-score for each data point. This score measures the number of standard deviations by the which the value differs from the distribution mean.

We controlled for historical GDP and emissions per capita, as described above. We also control for the number of high-impact policies, which are often used in the quantification of the emissions projections, to minimise hidden-variable bias and avoid endogeneity related to the development of current policy projections. Additionally, we controlled for the rule of law. Although, we did not explicitly account for the stringency of policies in force, this variable measures to which extend the population of a country has confidence in societal rules, for example considering contracts and courts (Kraay et al., 2010). Similarly to Eskander & Fankhauser (2020), we used this variable as a proxy to control for the implementation effectiveness of the policies in force.

Statistical tests

We compared policy density across country clusters to analyse in which cases policy density in countries with increasing emissions is lower compared to countries with decreasing emissions.

We divided the data into distinct samples, one for each cluster and used the Mann-Whitney U test to compare policy density distributions. Mann-Whitney U is a non-parametric test that measures whether the probability that distribution underlying two samples is the same under its null hypothesis (Mann & Whitney, 1947). We ran one-tailed tests to compare the policy density between clusters.



6 Synthesis and implications

6.1 Introduction

In this chapter, I synthesise my thesis' key findings and put them in the context of future efforts to limit climate change. My thesis has two main objectives. First, I assessed progress since the adoption of the Paris Agreement, which is the main international mechanism coordinating climate-change matters (Chapters 2 and 3). Second, I identified means to improve climate-change mitigation efforts through expanding climate policies (Chapters 4 and 5). As I pursued these objectives, I (together with my collaborators) developed methods to improve the understanding of the implications of the Paris-Agreement mechanism and investigate climate policies' adoption. I integrated insights from distinct disciplines and constructed interdisciplinary analytical frameworks that result in actionable insights to policymakers and the scientific community. This chapter offers a reflective synthesis of my findings, delineates the implications for policy and practice, and identifies potential avenues for further research.

More concretely, I investigated four research questions (RQs):

1. How effective was the ambition raising cycle of the Paris Agreement in terms of improving national emission targets?
2. How have national emissions projections under current policies changed since the adoption of the Paris Agreement?
3. What are measurable changes in the adoption of policy options to reduce greenhouse gas emissions in the past twenty years and which main policy adoption gaps remain?
4. How does policy adoption affect projected greenhouse gas emissions and what are key entry points to expand policy coverage?

These four questions were investigated in the research chapters, each of which correspond to paper published in a peer-reviewed journal. This synthesis chapter is structured as follows: first, I discuss the findings for each RQ in the context of the two objectives of this thesis (Sections 6.1 and 6.2). I then combine the results and insights of the four RQs to identify cross-chapter recommendations (Section 6.3). I also outline potential venues for research to advance the topics discussed in my thesis (Section 6.4). Finally, I present my concluding remarks, where I reflect on the results of the thesis and its implications for international cooperation (Section 6.5).

My thesis was prepared between 2020 and 2023. This helps clarifying some of its contributions. First, in 2020 the COVID-19 pandemic changed the way humans live and triggered additional analyses beyond health disciplines. Several scholars quantified the effect of lockdown measures on short-term greenhouse gas emissions (Le Quéré et al., 2020). Others investigated how distinct economic recovery packages influence long-term emissions (Dafnomilis et al., 2020; Hans et al., 2022; Shan et al., 2021). Developing emission projections during these years required the development of additional methods to quantify and distil the effect of the pandemic. Although this was not the focus of my thesis, the work presented here contributed to quantify the pandemic's effect (Chapter 3). Second, the Global Stocktake, which aims to inform Parties to the Paris Agreement in their future climate change mitigation efforts, took place between 2021 and 2023. The Global Stocktake is bound by UNFCCC rules and processes (Hermwille et al., 2019). It has the mandate to assess collective progress; it, for example, does not single out or assesses the progress of individual countries. Under such approaches to assess progress in climate change mitigation, laggard countries can hide within aggregated analyses. Many other insights are also missed when the national perspective is ignored. In my thesis, I argue that the scientific community is well positioned to fill this gap by providing relevant, up-to-date analyses, which are not bound by UNFCCC constraints.

6.2 Progress since the adoption of the Paris Agreement (RQ1 & RQ2)

My first objective is to assess progress since the adoption of the Paris Agreement. This complements the Global Stocktake process by providing national-level, up-to-date evidence of progress in climate change mitigation. It also supports identifying potential underlying drivers for the observed changes and adds nuance to global studies that evaluate countries' policies and targets.

National greenhouse gas emission projections, especially when annually updated, provide valuable insights when evaluating progress since the adoption of the Paris Agreement. I used greenhouse gas emissions projections that were based on countries' adopted policies and targets, to evaluate progress towards the climate change mitigation goals of the Paris Agreement. Many analyses in existing literature focus on evaluating targets (e.g., den Elzen *et al.*, 2022; Meinshausen *et al.*, 2022). They show that updated targets are more ambitious than original ones but lack national-level detail or ignore countries' adopted policies.

To analyse ambition raising under the Paris Agreement, I developed a framework that accounts for countries targets (both original and updated) and policies (Chapter 2). This framework enables a more detailed assessment of the ambition-raising mechanism since it considers whether countries are projected to meet their own original and updated targets. First, this approach bypasses difficult questions regarding the absolute adequacy of targets since it benchmarks them against countries' own policies. Second, it enables identifying different countries ambition raising patterns. For example, by clarifying whether more ambitious targets push countries beyond their currently adopted policies. I also used greenhouse gas emission projections that were developed based on policies adopted in different points in time, to measure progress on the absolute emission level implied by them in 2030 (Chapter 3). This expands existing literature by measuring the progress in adopted policies instead of targets. It also enables identifying national levers to improve climate policy.

Countries submitted more ambitious targets at the end of the first ambition raising cycle of the Paris Agreement, but overall impact remains limited (RQ1)

The Paris Agreement establishes an ambition raising mechanism for countries to improve their Nationally Determined Contributions (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. Ideally, original NDCs include a 2030 target to reduce emissions below those implied by adopted policies. Once these NDCs are adopted, they stimulate national action that reduces projected emissions. A country projected to meet its original NDC is well positioned to improve its target. Since updated NDCs represents a progression in comparison to the previous, a country would be projected to miss its updated NDC shortly after it was updated. However, over time additional policy adoption is expected to reduce emissions further so countries also meet their updated NDCs.

Updated NDC targets result in emissions in 2030 approximately one-tenth lower compared to original ones (den Elzen et al., 2022b; UNFCCC, 2021). This is certainly an improvement but considering policies in force provides important additional context to these targets.

First, many countries submit more ambitious NDCs without adopting sufficient policies to meet their original ones. In almost one-quarter of the 25 countries analysed, countries raised the ambition levels of their NDCs but did not adopt sufficient policies to meet their original targets, which were set over seven years ago. This intensifies the implementation gap, which is the difference between the emission level implied by countries' promises (i.e., NDC targets) and countries' actions (i.e., climate policies) (Roelfsema et al., 2020). Although, we recognise that ambitious target setting is beneficial, we raise caution to analysing these targets without considering actual policies in force. For the Paris Agreement ambition raising mechanism to work, countries need to adopt sufficient policies to meet their own targets.

Our results indicate that many countries would need to substantially expand their climate policies to meet their own NDCs.

Second, many countries are projected to meet their NDC targets without improving their climate-change mitigation efforts. This means that a substantial share of global emissions is currently not covered by ambitious targets, even when these targets are compared to countries own policies. Among the 25 countries analysed, eighteen are projected to meet their original targets and eleven are projected to meet their updated NDCs. A decrease in the number of countries meeting their NDCs was expected since updated targets often result in lower emissions than the original ones. However, eleven countries are directly projected to meet their updated NDCs at the time these 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 have a limited effect on guiding additional mitigation policies. Appropriate sequencing of ambition raising and sufficient policy adoption remains needed to translate the Paris Agreement into action.

Our findings also indicate that addressing national barriers to climate action will potentially improve the sequencing between targets and policies. Many political-economy factors hinder national climate action. These include lack of public climate awareness or exposure to fossil fuel extraction activities (Lamb & Minx, 2020). These factors are often intertwined and function as barriers to climate policy adoption (Lamb & Minx, 2020). In our research, we evaluated whether these constraints also affect ambition-raising patterns — the sequencing between internationally pledged NDC targets and nationally adopted policies. In an ideal ambition-raising sequence, countries adopt sufficient policies to meet existing NDC targets before they submit more ambitious ones. We found that this is more often the case in countries with fewer national constraints to adopt climate policies. Therefore, patterns of ambition raising are influenced by national constraints, especially those related to reliance on fossil fuels for energy supply or economic revenues. This suggests that strategies to reduce national constraints also affect international climate-policy outcomes.

Projections based on current policies lead to lower emissions compared to projections from before the Paris Agreement, but progress remain slow to meet global goals (RQ2)

Emissions projections up to 2030 for the G20 countries have improved since 2015 and are approximately 6 $GtCO_2eq$ or 15% lower when estimated in 2021 compared to 2015 estimates. The most substantial relative changes are observed in India, the EU27+UK, the United States, Russia, Saudi Arabia and South Africa. In all these countries, COVID-19 results in a substantial (i.e., higher than 5%) drop in estimated emissions between 2019 and 2020. Pandemic-induced policy responses and economic slowdown also reduce projected emissions in almost all countries. In most recent projections, Australia, Canada, the EU27+UK, Japan, South Korea, South Africa, and United States are expected to reduce their emissions below historical 2015 levels by 2030.

The reasons for these reductions in emission projections under adopted policies vary. The COVID-19 pandemic resulted in a dip in greenhouse-gas emissions and affected long-term emissions, due to both revisions in economic forecasts and financial and fiscal stimulus response packages (Shan et al., 2021). We found that approximately one-quarter of the 2030 emission changes observed between 2015 and 2021 are explained by the effects of the pandemic. However, this effect is not the same in all countries. In some, almost all difference between 2015 and 2021 projections is driven by the pandemic and in others the effect of the pandemic on 2030 greenhouse-gas emission projections is negligible. Expansion of climate policies and updated expectations on technology development also played important roles. These results indicate that progress is measurable in policies adopted – not only in NDC targets.

Although revised representation of historical effects and the pandemic influence our estimates, the adoption of additional policies partly explains lower emissions. Renewable uptake has been faster than projected before, efficiency improvements result in lower energy demand and coal phase out policies result in substantial shifts in emissions projections of some countries. Annual emissions now are projected to grow slower in the coming decade than projected in 2015. This is a positive development. However, the existing gap between global current policies and the goals of the Paris Agreement is approximately three to four times larger than the improvement observed between 2015 and 2021 (UNEP, 2022). Countries need to substantially accelerate their efforts to meet the collective goals of the Paris Agreement.

Our results also show how considering national differences is fundamental in analyses of climate change mitigation efforts. Changes in emission projections over time and their causes vary among countries and must be discussed when assessing global progress towards the goals of the Paris Agreement. For example, we found that projected emissions per capita will still vary substantially across countries by 2030. Even among major emitting G20 economies the differences are striking. For example, in Australia and Canada the emissions associated with each person will remain until 2030 over four times higher than those projected in India and Indonesia. This points at the need for developed countries, with long commitments to address their greenhouse gas emissions, to reduce their emissions at a faster rate than currently observed.

Finally, our research illustrates how scenarios, even those under adopted policies are mutable. Estimates of adopted policies do not constitute a fixed trajectory for the coming decade. Decisions that shape future climate are made today. We observed substantial improvements in the past years. However, these improvements remain insufficient to meet the collective goals of the Paris Agreement. Countries must double down on existing climate change mitigation efforts to limit end-of century temperature increase to 1.5°C.

6.3 Climate policy expansion entry points

The second objective of my thesis is to identify means to improve climate change mitigation efforts through expanding climate policies. Climate policies are an important lever to reduce emissions. Expanding their adoption helps ensuring that all relevant sectors are addressed and that existing mitigation options are in force.

To identify policy-expansion entry points, we developed methods to analyse the growing number of climate-change mitigation policies based on their prevalence in different categories of interest. First, we developed a list of policy options and assessed their prevalence across the G20 countries. This list is based on existing literature and summarises main existing policy options to reduce emissions. We categorised thousands of policies[9] into this list to identify which policy options are adopted across most countries and which ones are missing. This supports identifying policy adoption gaps, which constitute potential entry points for policy expansion. Second, instead of comparing individual policy options across countries, we compared policy distributions across country groups. We first identified a country group with declining absolute emissions and compared its policies adopted in different sectors, mitigation areas and policy instrument types to other country groups. This supports identifying policy-expansion entry points that consider different stages of climate change mitigation.

[9] The policies collected in this research have been added to an open-access database: climatepolicydatabase.org.

The number and coverage of climate policies substantially increased in the past two decades, but sectoral opportunities to expand climate policy remain (RQ3)

We identify multiple sectoral entry points to improve climate policy adoption. We first identified and categorised climate policies adopted by the G20 countries between 2000 and 2019. We mapped these policies to a list of fifty climate policy options, which outline distinct strategies to reduce emissions. We then assessed the prevalence of these policy options in the period analysed.

We find that countries' approach to climate policy has evolved in the past twenty years. The number of sectoral climate policies and their coverage in G20 countries and at sector level has increased. Countries with relevant policy options in force cover on average two-thirds of total G20 emissions, in comparison to only one-third twenty years ago. Countries also implement the climate policy options identified using multiple policy instruments. However, a detailed analysis of sectoral policy adoption shows that multiple gaps remain.

Our results indicate a sequence of policy adoption across sectors. In line with existing literature (Averchenkova et al., 2017), we found that the number of policies and diversity of policy instrument types in force increased steadily since the 2000s. However, the increase varies across sectors. We found that the electricity and heat sector is often a starting point to climate policy adoption. Countries usually adopt climate policies in this sector first. Also, it has the highest number of policies in force, especially considering policies that support renewables and energy efficiency. The sequencing of policy adoption across sectors also varies but countries tend to follow energy supply policies with policies in energy-demand sectors, such as buildings, transport and industry. The agriculture sector is often the latest to be addressed and currently has the fewest policies in force. Our findings support the hypothesis that the adoption of policies relaxes barriers for the adoption of additional ones (Pahle et al., 2018).

However, approximately half of the identified policy options are not widely adopted. Their prevalence is particularly low for policies that aim to phase out coal and oil and mandate energy reductions in electricity and heat supply; reduce industrial process emissions and incentivise fuel switch in industry; design urban planning strategies to reduce energy needs, incentivise retrofits, and support the use of renewable energy for cooking and heating/cooling purposes in buildings. Policies to remove fossil-fuel subsidies and support carbon dioxide removal also need substantial improvement. These options are important sectoral entry points to improve global climate policy adoption. Slow progress towards reducing global emissions and meeting the collective Paris climate goals calls for more comprehensive climate-change mitigation policies. Filling policy adoption gaps presents a concrete strategy to improve sectoral, national and global climate policy.

Expanding climate policies slows down global future emission growth, however policy entry points vary depending on projected emissions increase (RQ4)

Existing literature clarifies that climate policies helped to reduce historical emissions (Eskander & Fankhauser, 2020). In this thesis, we investigated whether the total number of climate policies is also associated with lower projected emissions up to 2030. This clarifies whether expanding climate policy portfolios is desirable to curb emission projections. We also compared policies' prevalence across three country groups with distinct projected emission growth rates (increasing, plateauing and decreasing emissions) to identify policy-expansion entry points.

We find that larger and more comprehensive policy portfolios are conducive of emission reductions, regardless of whether absolute emissions are projected to increase or decline. Our analysis contributes to the literature in multiple ways. First, it presents a different approach to investigate policies' effects. Policies usually reduce emissions over time. Their effects are usually smaller shortly after their adoption and increase after some years (Eskander & Fankhauser, 2020). Statistical analyses of policies effects usually relies on many years of emissions data (Eskander & Fankhauser, 2020; Lachapelle & Paterson, 2013). Therefore, analysing the effects of policies since the adoption of the 2015 Paris Agreement is challenging. To include additional emissions data, we used emissions projections instead of historical emissions. This approach clarifies the long-term effect of policies in force today and enables comparative analyses of policy adoption since the Paris Agreement. Second, our analysis shows that expanding climate policy is desirable whether countries already have many policies and declining emissions or whether they only start to adopt climate policies and still have increasing emissions. Therefore, we provide empirical evidence for arguments to expand climate policies. Despite the collective increase in the number of policies in force, countries can still expand climate their climate policies to use of the full breadth of mitigation options available.

However, we also find that country groups have distinct entry points to expand climate policy. Countries with fast increasing emissions have significantly fewer policies overall, but policies are especially missing in energy-demand sectors, such as buildings and transport. Countries with plateauing emissions lack climate strategies and other cross-sectoral policies. This suggests the need for better coordination of mitigation efforts across sectors. In all country groups that fail to reduce emissions, policies to reduce energy and material demand are also substantially fewer. These findings point to the need to better account for country differences in analyses of climate change mitigation efforts. Although detailed country analyses hinders the replicability of the findings, one set of policy recommendations for all countries does not necessarily improve it.

6.4 Overarching implications of our findings

The four research chapters of my thesis have diverse implications for the forthcoming implementation phases of the Paris Agreement and consequently for national and global reduction of greenhouse gas emissions. Assessing progress since the adoption of the Paris Agreement supports identifying potential mechanisms to improve the coming ambition raising cycles. Identifying means to expand climate policies supports its implementation. First, I discuss key implications of our findings for the official UNFCCC process, with a focus on the Global Stocktake. Second, I discuss what our results regarding best-performing countries mean for the Paris Agreement effectiveness.

The Global Stocktake must raise the sense of urgency to reduce emissions and move towards national analyses to inform ambition raising

My research indicates that the Global Stocktake needs to call for steep acceleration of current climate-change mitigation efforts. One of the potential functions of the Global Stocktake is setting the agenda for global cooperation and reinforcing the Paris Agreement signals (Hermwille et al., 2019). Increasing the sense of urgency strengthens the signal that incremental climate-change mitigation solutions are now insufficient. Progress in greenhouse-gas emission projections since the adoption of the Paris Agreement show that both targets and policies are better. However, the downwards progression of projected emissions remains slow. Emissions reductions must speed up at least three to four times if the world desires to meet the goals of the Paris Agreement in 2030. As part of the official mechanism to assess international progress, the Global Stocktake process must effectively communicate this urgency.

We find that focusing on NDCs offers a limited perspective and likely inflates the sense of progress. The Global Stocktake process also has the mandate to inform the preparation of new NDCs. Current NDC targets result in lower emissions compared to the ones adopted together with the Paris Agreement, especially globally. However, we analysed both targets and policies at the country level and uncovered important patterns. Emissions that are implied by the G20 NDCs and current policies both reduced by 10-15% in 2030 since the adoption of the Paris Agreement. This constitutes an argument for setting substantially stronger targets, that can guide additional policy adoption. However, this relationship between targets and policies requires much further scrutiny since raising the ambition of targets without adopting sufficient policies to meet them does not substantially advance the implementation of the Paris Agreement (c.f. RQ1). We found that this is still the case in many countries. Evaluating targets in isolation does not sufficiently clarify progress in implementing the Paris Agreement.

More generally, our research calls for additional analyses on the process instead of the outcome of ambition raising. Such analysis should especially consider national constraints. To better understand patterns of ambition raising, we explored how they relate to national characteristics. We found that countries with fewer national constraints to adopt climate policies tend to perform better internationally; they adopted sufficient policies to meet their original targets and then submitted more ambitious ones. This suggests that engaging with countries using an international ambition argument is not the only means to improve international outcomes. Building coalitions to support national policy adoption will likely have spillover effects to international targets, push feasibility boundaries and help meeting the global goals of the Paris Agreement.

Best-performing countries can proactively support the implementation of the Paris Agreement by improving rollout of well-established mitigation options

The Paris Agreement is a necessary framework for international cooperation on climate change related issues but when pursued in isolation will probably remain insufficient to reduce greenhouse gas emissions in line with its own goals. Therefore, complementary mechanisms are paramount to accelerate emission reductions.

Although many other fora for international cooperation already exist, our findings highlight important elements to potentially increase their effectiveness. Analysing national evidence of progress shows that some countries perform better than others. These countries provide examples for others but can also directly support replication of climate-change mitigation measures. Instead of relying on the Global Stocktake process to highlight good practice examples and sharing knowledge, best-performing countries interested in supporting additional mitigation efforts should take a more proactive role in advancing climate change mitigation.

Expanding ambitious climate coalitions or clubs, for example, will probably complement ongoing international cooperation efforts. The Paris Agreement was designed to incentivise broad participation. Alternatively, climate clubs start with fewer members (Hovi et al., 2016). Clubs are structures that incentive members to set normative commitments, facilitate communication and agreement among its members or set legally binding membership rules to trigger changes in member institutions (Falkner et al., 2022). If such clubs coordinate on their functions and goals, they can be complementary to existing cooperation frameworks, such as the Paris Agreement. However, in practice their foundation is often driven by political opportunity instead of a systematic analysis of their potential benefits or how they relate to the existing cooperation frameworks (Weischer & Morgan, 2012). Climate clubs can offer platforms for ambition raising that are more malleable than official UNFCCC processes. In these cases, the UNFCCC, for example through the Global Stocktake process, can use its position to call for or ignite the formation of relevant climate clubs that support advancing global climate policy.

Our research indicates that international cooperation, which aim to replicate existing well-established approaches to mitigate climate change, can have a substantial effect on global climate-change mitigation efforts. Improving the number and coverage of climate policies is associated with lower projected emissions. Important policy options are absent in many countries. Existing country coalitions to improve climate change mitigation often focus on policy outcomes, such as increasing the sales electric vehicles or stopping deforestation. However, coalitions focused on the more procedural elements of policy adoption are largely absent outside of the UNFCCC process. Cross-national coalitions and/or climate clubs can support navigating the trade-offs and synergies of different choices and help identifying the key steps to formulate good practice climate policies. For example, such a club could support members in the adoption of necessary mitigation options, such as building codes or fuel standards. This support can entail identifying and circumventing barriers for their adoption, mapping important elements to be included in policy formulation to avoid backsliding or the lock-in of unambitious standards, among others. Countries that successfully adopted such options are in position to directly share insights to foster institutional learning which is likely fundamental to adopt additional and more ambitious climate policies.

Best-performing countries can provide good practice examples for others. Replicating their approaches, such as adopting a diverse portfolio of climate policies, must consider national circumstances and differentiated mitigation requirements. However, good practice cases show that such outcomes are possible and, in some cases, even plausible. Considering the urgency to reduce global emissions, best-performing countries are well positioned to take a more active role in supporting and inspiring climate policy adoption across countries.

6.5 Opportunities for additional research

The research in my thesis advances the analysis of progress since the adoption of the Paris Agreement and the understanding of the current state of climate policy adoption across major emitting economies.

In general, the scope of my research is limited in depth due to its broad research focus. However, the multiple methods and interdisciplinary approaches used in my thesis provided insights about the link between the adoption of the Paris Agreement and climate policies. My research provided empirical evidence to advance our understanding of topics that are the focus of a substantial research and subject to different, and often value-laden, perspectives. However, the research in my thesis can be improved in multiple ways, some of which I discuss here.

Emissions projections developed based on adopted policies are helpful tools to investigate progress in climate change mitigation. However, such projections are only available for a few countries. Improving the number of available national projections would certainly help to expand the insights resulting from the frameworks and analyses developed in this thesis. Although some initiatives to improve national-level modelling capacity exist, independent estimates remain fundamental to cross-validate nationally developed projections. The same constraint applies to the availability of data about climate policies in force. Both projections and policy data collections efforts are time intensive and quickly outdated. Considering these limitations, our analyses focused on a limited number of major emitting economies, such as the G20 group, that cover most of global emissions. The results therefore offer valuable insights about national progress, but do not advance our understanding of climate policy adoption and their effects across most countries in the world. In some cases, results are not based on robust statistical analysis and just offer indicative findings about broader patterns in climate-change mitigation efforts. Improving data availability of consistent emission projections and climate policy data is an important step to expand our research and further validate its findings.

Additionally, the causal mechanisms leading to climate policies' effects require further investigation. Our research does not clarify which exact policies help to reduce emissions nor the broad conditions that enable their effect. We found that more comprehensive climate policy portfolios are conducive of stronger climate change mitigation efforts. We also uncovered that some variation in policy adoption is associated with projected emission change rates. However, our analyses cannot identify whether the observed effects results from a few or all policies in the climate policy portfolio. Our research helps to narrow the scope for more detailed analyses and indicates important mitigation options to expand climate policies. More detailed case studies, that reduce the number of countries analysed but add depth, are important tools to complement the analyses presented in my thesis.

Our findings also indicate that the Paris Agreement is necessary but alone remains insufficient to trigger sufficient societal transformation to realise global decarbonisation. We found that well-established mitigation options, which are already in place in some countries, are a potential entry point for enhanced cooperation to complement the Paris Agreement existing mechanisms. However, we did not clarify how such cooperation can take shape. Identifying how distinct cooperation mechanisms to rollout well-established climate change mitigation options fit into the Paris Agreement framework helps to evaluate whether that is an effective proposal. For example, proposing a new climate club focusing on the peer-exchange on policy implementation, instead of agenda setting or policy formulation, can complement the Paris Agreement or undermine its effectiveness by competing for funding and distracting from other initiatives. More research focusing on such interactions helps to identify how countries can foster the expansion of climate policies.

6.6 Concluding remarks

My thesis has two main objectives: to assess progress since the adoption of the Paris Agreement and to identify means to improve climate-change mitigation efforts. To contribute to these goals, I answered four research questions on existing research gaps and on political discussions within the Paris Agreement. In the process of answering these questions, I developed a set of tools and frameworks to advance both research and policymaking.

I showed that progress in climate-change mitigation efforts is measurable and presented concrete entry points to expand climate policies.

First, today's policies in force lead to lower emissions than policies in force in 2015, when the Paris Agreement was adopted. This constitutes a clear improvement in climate-change mitigation efforts (Chapter 3, Section 6.1). However, in many countries policies still lead to emissions that are substantially above their original targets set in the Paris Agreement (Chapter 2, Section 6.1). This indicates that many years after the targets were adopted, policy adoption following target setting is still insufficient. Even though many countries updated their NDC targets, they often still result in emissions substantially above those implied by adopted policies. This suggests that some targets will probably have a limited effect in driving additional climate-change mitigation efforts. Overall, the Paris Agreement had a positive effect on lowering global emissions but the ambition raising mechanism requires much stronger scrutiny to ensure sufficient policy adoption to meet its collective global goals.

Second, the number and coverage of climate policies substantially increased in the past two decades, but sectoral opportunities to expand climate policy remain. We found that expanding climate policies is conducive of lower emissions, independently on whether emissions still increase or already decline (Chapter 5, Section 6.2). Countries with relevant policy options in force cover on average two-thirds of total G20 emissions, in comparison to only one-third twenty years ago (Chapter 4, Section 6.2). However, many existing policy options to reduce emissions are not widely adopted. Countries with fast increasing emissions lack policies in energy-demand sectors, such as buildings and transport. Countries with plateauing emissions lack climate strategies and other cross-sectoral policies. This suggests the need for better coordination of mitigation efforts across sectors. In all country groups that fail to reduce emissions, policies to reduce energy and material demand are substantially fewer. Filling policy adoption gaps presents a concrete strategy to improve national and global climate policy.

During this research, I developed tools to support assessing progress in the mitigation component of the Paris Agreement and identifying climate policy adoption gaps. I, together with my collaborators, developed a matrix of policy options to reduce emissions. This matrix allows assessing progress in the adoption of these policy options and identifying policy adoption gaps across countries (Chapter 4). This matrix also constitutes a comprehensive policy package and function as a benchmarking tool for policymakers and analysts, who now have a tool to assess policy adoption within a country. We also developed a framework to assess the ambition raising cycle of the Paris Agreement accounting for both countries climate-change mitigation targets (as set by their NDCs) and policies (Chapter 2). This framework supports analytical efforts to understand how countries progress in the implementation of the mitigation component of the Paris Agreement.

In my thesis, I showed that many countries have progressed in their climate change mitigation efforts both in terms of adopting policies and reducing emissions. Analysing progress is important to highlight that climate action matters and helps shaping future emission pathways. My research indicates that current efforts work but that they need to be improved to avoid the worst impacts of climate change. We also found that expanding climate policies in line with the findings of my thesis is an important means to improve national climate action and that international cooperation plays an important role in facilitating it. Countries that successfully established comprehensive policy portfolios can help others to identify and mitigate trade-offs of distinct policies and actions to enhance climate change mitigation. In the future, such cooperation will benefit from more explicit links to biodiversity, poverty alleviation and other sustainable development goals to improve the development of synergetic solutions that address complex, cross-sectional societal issues. Strengthening international cooperation will be fundamental to realise the collective goals of the Paris Agreement.

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Supplementary material

Supplementary materials

SM2 - Supplementary material Chapter 2

Emissions per capita

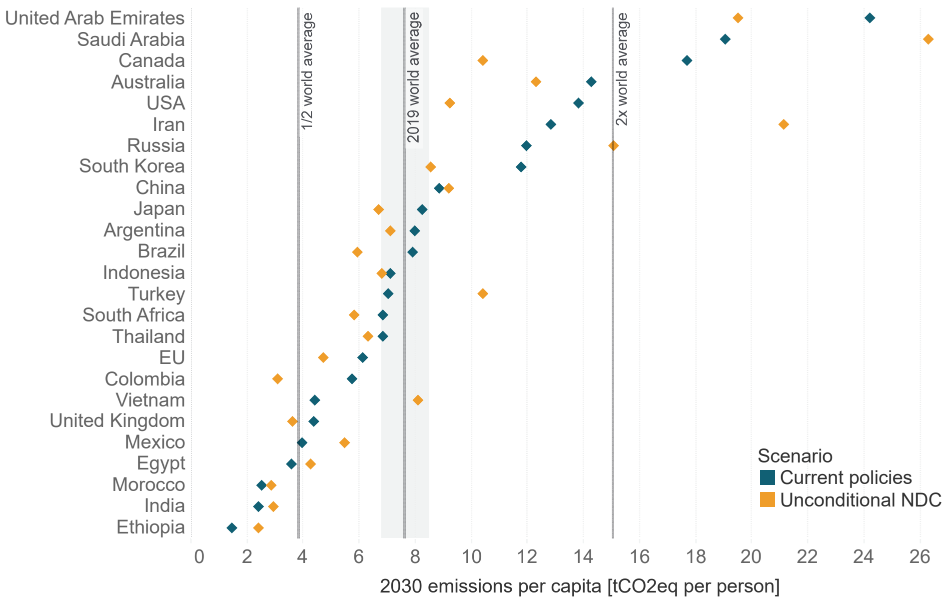

Figure 16: Emissions per capita levels in 2030 for the countries analysed under current policy and unconditional NDC scenarios, except for Egypt where the conditional target is presented.

Quantification of NDC targets

To quantify NDCs, we first identified their typology (King & van den Bergh, 2019). For example, we identified whether targets are communicated as a reduction below emissions in a reference year or as an absolute emission level in the target year (Table S1). We also analysed whether the target includes all sectors and estimated emission levels including or excluding land-use, land-use change and forestry (LULUCF), depending on the target scope.

In our research, original NDCs are those submitted between 2014 and 2016, around the date of adoption of the Paris Agreement. Our analysis of updated NDCs includes targets submitted up to September 2022 (den Elzen et al., 2022a; Nascimento, Kuramochi, Dafnomilis, et al., 2022).

Table 7: Quantification of NDC targets

Country	Target type	LULUCF treatment in NDC	Comment
Argentina	**Fixed-level target**	**LULUCF included in NDC. There is no baseline year, it is an absolute target**	
Australia	**Base year**	**LULUCF included in NDC**	
Brazil	**Base year**	**LULUCF included in NDC**	
Canada	**Base year**	**LULUCF sector is excluded in the baseline year and included in the target.**	
China	**Intensity and non-GHG**	**LULUCF included in NDC**	**Emissions associated with NDC targets were calculated using the TIMER energy model** (van Vuuren et al., 2017) **for energy- and industry-related emissions and the GLOBIOM/G4M land use model** (Havlík et al., 2014) **for the land use, land-use change and forestry (LULUCF)** (den Elzen et al., 2016)**. The different targets are also calculated using bottom-up estimates as described in the assumptions based of Climate Action Tracker's country assessments (Climate Action Tracker, 2022).**
Colombia	**Baseline specified**	**LULUCF included in NDC. The NDC's deforestation emissions reduction target is calculated independently and in a unified manner at the national level in line with NREF projections to 2030.**	**Non-LULUCF emission estimates based on Climate Action Tracker estimates**
Egypt	**Sectoral baselines specified**	**LULUCF sector is excluded in the NDC target**	**Non-LULUCF emission estimates based on Climate Action Tracker estimates. Updated NDC includes a conditional target only. Original target included no quantifiable target.**
Ethiopia	**Baseline specified**	**LULUCF included in NDC**	**Non-LULUCF emission estimates based on Climate Action Tracker estimates**
European Union	**Base year**	**LULUCF included in NDC**	
India	**Base year intensity and non-GHG**	**LULUCF is included in the target, however, levels are unclear for the baseline year and the intensity targets.**	**Similar approach to China, see also** (den Elzen et al., 2022a) **. The different targets are also calculated using bottom-up estimates as described in the assumptions based of Climate Action Tracker's country assessments (Climate Action Tracker, 2022).**
Indonesia	**Baseline specified**	**LULUCF included in NDC**	
Iran	**Base year**	**LULUCF included in NDC**	**Non-LULUCF emission estimates based on Climate Action Tracker estimates. No updated target.**
Japan	**Base year**	**LULUCF sector is excluded in the baseline year however it is included in the NDC target.**	
Mexico	**Baseline specified**	**LULUCF included in NDC**	
Morocco	**Baseline specified**	**LULUCF included in NDC**	
South Korea	**Base year**	**LULUCF sector is excluded in the baseline year however it is included in the NDC target.**	
Russia	**Base year**	**LULUCF included in NDC**	
Saudi Arabia	**Trajectory**	**LULUCF sector is excluded from the NDC target**	**Non-LULUCF emission estimates based on Climate Action Tracker estimates. Substantial uncertainty about the NDC emission level remains.**
South Africa	**Trajectory**	**LULUCF included in NDC**	**Original and updated NDCs include only conditional targets.**
Thailand	**Baseline specified**	**LULUCF sector is excluded from the NDC target**	**Non-LULUCF emission estimates based on Climate Action Tracker estimates**
Türkiye	**Baseline specified**	**LULUCF included in NDC**	**No updated target.**
UAE	**Baseline specified**	**LULUCF sector is included in the target and the base year.**	**Original NDC only included a clean energy target, which is still quantifiable in terms of emissions.**
United Kingdom	**Base year**	**LULUCF included in NDC**	
United States	**Base year**	**LULUCF included in NDC**	**Original NDC only covers period up to 2025.**
Viet Nam	**Baseline specified**	**LULUCF included in NDC**	

Quantification of current policies

We quantified the effect of policies on projected greenhouse gas emissions using distinct models. Emissions projections (excluding LULUCF) were calculated using the integrated assessment model IMAGE (Roelfsema et al., 2022), and a bottom-up model based on spreadsheets calculations.

IMAGE 3.2 divides the world into twenty-six regions, which include a few major emitting countries such as China, United States and India. Calculations depart from the latest SSP2 (no new climate policies) reference scenario. The baseline is adjusted to account for the impact of country-specific policies (Roelfsema et al., 2022; van Vuuren et al., 2017). It also accounts for the impact of COVID-19 due to the slow-down in GDP and short-term impact on activity levels (Dafnomilis et al., 2022).

The bottom-up model relies on spreadsheet calculations that depart from country-specific reference scenarios. Sources for these reference scenarios include official documents submitted by the Parties to the UNFCCC (UNFCCC, 2019b) and publications from international organisations, such as the Asia Pacific Energy Research Centre (APERC, 2019) and the International Energy Agency (IEA, 2021c). These reference scenarios often include the effect of some policies. When countries adopted relevant policies that are outside the scope of the published reference projections, we separately estimated their effect (Climate Action Tracker, 2023; Fekete et al., 2021; Kuramochi et al., 2021). The bottom-up calculations also include the effect of COVID-19 by assuming that emission intensity over gross domestic product (GDP) remains the same.

We also projected the effect of policies on land use, land-use change and forestry (LULUCF) emissions and removals up to 2030. These projections are based on the GLOBIOM model and global forest model G4M (Gusti & Kindermann, 2011; Havlík et al., 2014).

Table 8: Quantification of current policies. Uncertainty calculated as the difference between the minimum and maximum of the range and divided by the average.

Country	Approach for quantification, all countries include LULUCF projections	Last year of historical data	Current policy scenario uncertainty
Argentina	Bottom-up calculations only	2018	2%
Australia	IMAGE and bottom-up calculations	2019	24%
Brazil	IMAGE and bottom-up calculations	2018	10%
Canada	IMAGE and bottom-up calculations	2019	3%
China	IMAGE and bottom-up calculations	2014 / 2019 (extended using PRIMAP)	17%
Colombia	Bottom-up calculations only	2018	2%
Egypt	Bottom-up calculations only	2015 / 2019 (extended using PRIMAP)	18%
Ethiopia	Bottom-up calculations only	2013 / 2019 (extended using PRIMAP)	13%
European Union	IMAGE and bottom-up calculations	2019	23%
India	IMAGE and bottom-up calculations	2016	9%
Indonesia	IMAGE and bottom-up calculations	2019	10%
Iran	Bottom-up calculations only	2010	11%
Japan	IMAGE and bottom-up calculations	2019	17%
Mexico	IMAGE and bottom-up calculations	2019	18%
Morocco	Bottom-up calculations only	2018	38%
South Korea	IMAGE and bottom-up calculations	2019	15%
Russia	IMAGE and bottom-up calculations	2019	0%
Saudi Arabia	Bottom-up calculations only	2016	17%
South Africa	IMAGE and bottom-up calculations	2017	6%
Thailand	Bottom-up calculations only	2016 / 2019 (extended using PRIMAP)	0%
Türkiye	IMAGE and bottom-up calculations	2019	20%
UAE	Bottom-up calculations only	2014	16%
United Kingdom	Bottom-up calculations only	2019	12%
United States	IMAGE and bottom-up calculations	2019	14%
Viet Nam	Bottom-up calculations only	2016 (2014 for LULUCF)	8%

SM3 - Supplementary material Chapter 3

Historical data

The latest historical year varies across countries due to distinct reporting requirements (Table 9). Historical emissions data was primarily based on reports by national governments submitted to the UNFCCC, such as national communications (NCs), national inventories reported in common table format (CRF) for Annex I Parties and Biennial Update Reports (BURs) for non-Annex I Parties. These reports were supplemented by other estimates to provide up to date and complete historical time series (Gütschow et al., 2016).

Table 9: Data sources for historical data used in 2015 and 2021 projections.

Country	2015		2021	
	Last reported year	References	Last reported year	References
Argentina	2012	NC3	2016	BUR3
Australia	2012	CRF 2014	2020	(DISER, 2021)
Brazil	2012	GHG Inventory + SEEG 2014	2020	BUR3 + SEEG 2021
Canada	2012	CRF 2014	2019	CRF 2021
China	2010	(CDIAC, 2012; IEA, 2014; US EPA, 2012) + GHG Inventory	2019	PRIMAP + GCP
EU27 + UK	2012	CRF 2014	2019	(EEA, 2021)
India	2010	(CDIAC, 2012; IEA, 2015b; US EPA, 2012) + GHG Inventory	2019	PRIMAP + GCP
Indonesia	2000	GHG Inventory	2019	PRIMAP + GCP
Japan	2013	CRF 2014	2019	CRF 2021
Mexico	2010	NC5	2017	(INECC, 2018)
Russia	2012	CRF 2014	2019	CRF 2021
Saudi Arabia	2012	GHG Inventory	2019	PRIMAP + GCP
South Africa	2010	(DEA, 2013)	2017	(Republic of South Africa, 2021)
South Korea	2012	GHG Inventory	2019	PRIMAP + GCP
Turkey	2012	CRF 2014	2019	CRF 2021
United States	2012	CRF 2014	2019	CRF 2021

Legend:

- **CRF**: Common Reporting Format: National Inventory Submissions 2021 | UNFCCC
- **BUR #**: Biennial Update Report for non-Annex-I countries: Biennial Update Report submissions from Non-Annex I Parties | UNFCCC
- **GHG Inventory**: UNFCCC Greenhouse Gas Emissions Inventory: Greenhouse Gas Inventory Data - Time Series - Annex I (unfccc.int)
- **PRIMAP**: The PRIMAP-hist national historical emissions time series: Paris Reality Check: PRIMAP-hist (pik-potsdam.de)
- **NC #**: National Communications for non-Annex-I countries: National Communication submissions from Non-Annex I Parties | UNFCCC
- **GCP:** Global Carbon Budget project: GCP - Carbon Budget (globalcarbonproject.org)
- **SEEG:** Sistema de Estimativa de Emissões de Gases de Efeito Estufa: Total Emissions | SEEG - System Gas Emissions Estimation

Other supplementary figures and tables

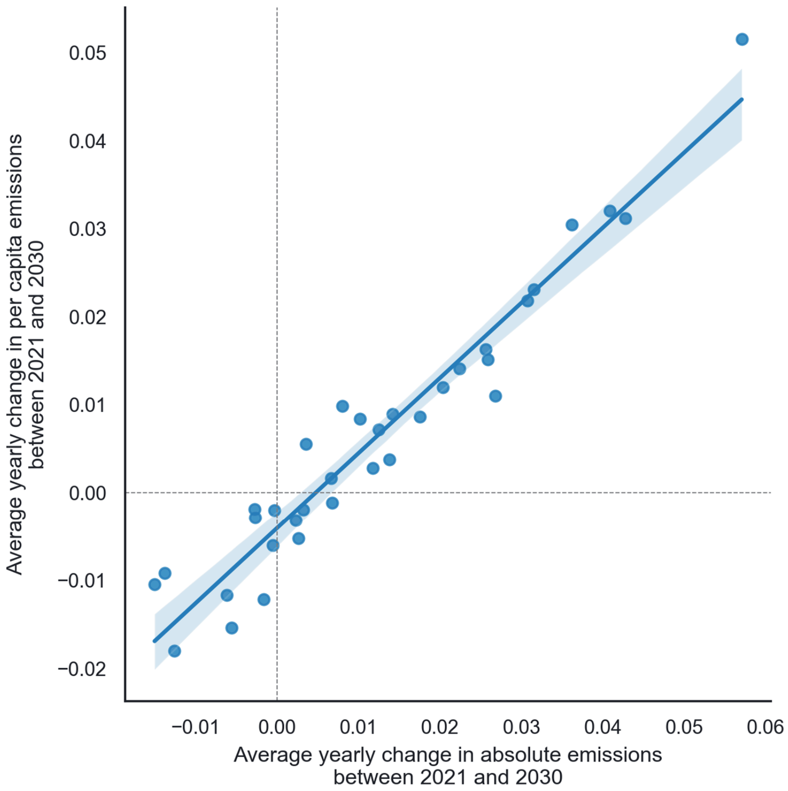

Figure 17: Comparison of emissions rate per capita and absolute. Each dot represents one of the G20 countries. Robust relationship (p-value < 0.001).

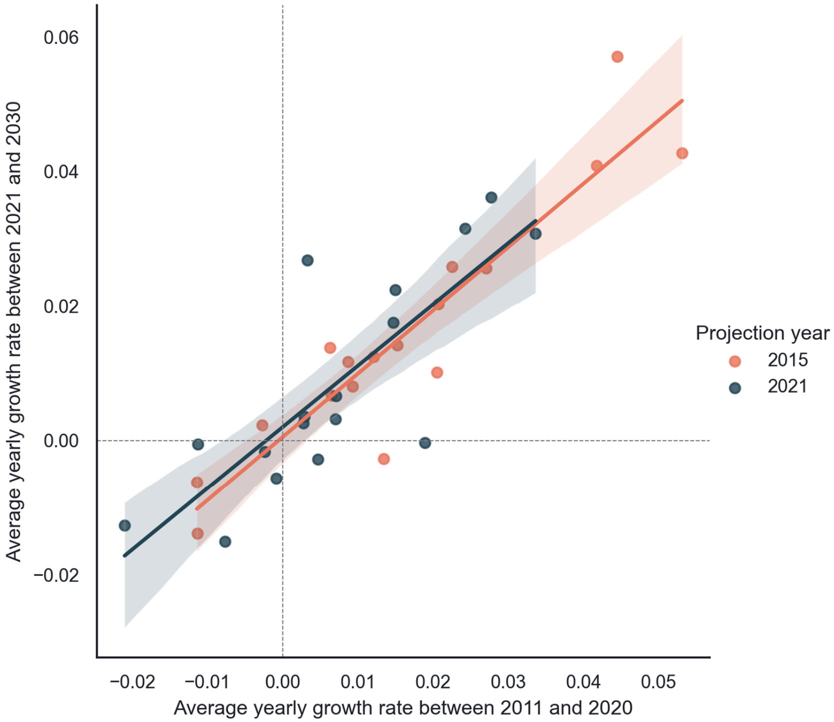

Figure 18: Comparison of average growth rates per country in the 2010s and 2020s. Each dot represents one of the G20 countries. The two distributions are not statistically different (p-value > 0.1).

Table 10: Countries with increase or decrease (above 3%) in historical emissions trajectories per period analysed. We use 'significant' for differences larger than 5%. For changes 'before 2010' and 'between 2010 and 2019', the percentage differences are calculated by comparing 2021 to 2015 projections. To estimate the effect of COVID-19 historical drop we calculate the difference between the annual change rate in 2020 to the average annual change rate in the decade before.

Country	Changes before 2010	Changes between 2010 and 2019	COVID-19 effect in 2020
EU27+UK	-	Significant decrease	Significant decrease
ARG	Significant decrease	Significant decrease	Significant decrease
AUS	Decrease	Decrease	-
BRA	-	Decrease	Decrease
CAN	-	-	Significant decrease
CHN	Significant increase	Increase	-
IND	Significant decrease	Decrease	Significant decrease
IDN	Increase	Significant increase	Decrease
JPN	Increase	Decrease	Decrease
KOR	-	Decrease	Significant decrease
MEX	Significant decrease	Significant increase	Significant decrease
RUS	Significant decrease	-	Significant decrease
SAU	Increase	Significant decrease	Decrease
ZAF	Significant decrease	Significant decrease	Significant decrease
TUR	-	Significant decrease	-
USA	-	Decrease	Significant decrease
Significant in # countries	6	7	9

SM4 - Supplementary material Chapter 4

S1 Policy matrix definition and policy categorisation

This section is structured according to sectors in the policy matrix. It provides an overview of the policy options and the reasoning behind adding them to the policy matrix, together with some examples. The matrix supports the identification of policy gaps across sectors and policy areas, it includes policy options which are recognized as leading to direct or indirect emissions reductions. The developed matrix contains 50 policy options distributed across six sectors and five mitigation areas. Information and education policies are excluded, as their contribution to emissions reductions is often mediated by the identified policy options.

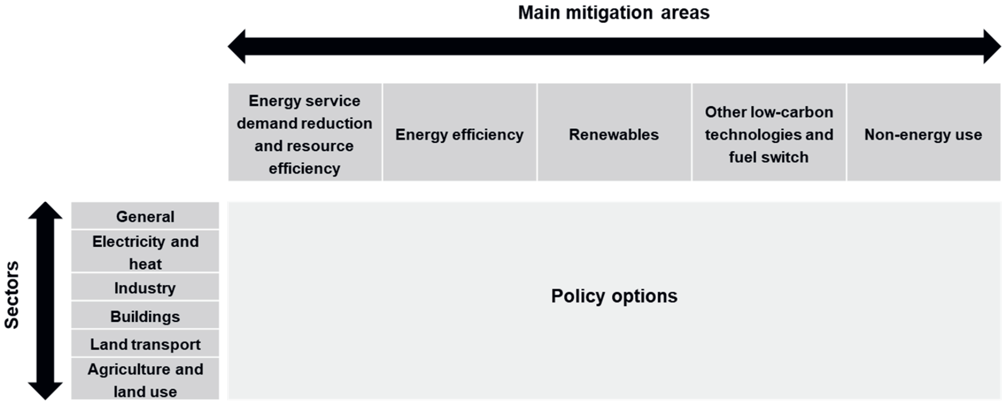

Figure 19: Structure of the matrix of policy options

Policy options

This section describes the policy options presented in the policy matrix in more detail. Please note that the selection of policy options is based on policies that are generally agreed to contribute to greenhouse gas emissions reductions, are sector-level example policies which have been successful in specific contexts or are expected to result in sufficient sectoral transformation to achieve greenhouse gas emissions reductions. This section is structured along the sectors in the policy matrix.

Table 11 Policy options classified under the sector 'general'

Policy option	Description	Further information
Climate strategy	Overarching national plans for the implementation of measures related to climate change. National strategies must have been approved or adopted by a government body.	(Dubash et al., 2013; Iacobuta et al., 2018)
GHG reduction target	Targets related to GHG emissions reductions. Applies to absolute emissions targets as well as reduction below business-as-usual trajectories and intensity targets. More uncertain mid-century targets were not considered.	(Iacobuta et al., 2018; IEA, 2015a)
Coordinating body for climate strategy	Institutions with the main purpose of coordinating the implementation of climate strategies as well as overseeing activities related to climate change.	(Iacobuta et al., 2018; IPCC, 2014)
Support for low-emission or negative emissions RD&D	Support for research and development of low- or negative-emissions technologies that help the transition to a low-carbon economy.	(IEA, 2017; IPCC, 2018a; UNFCCC, 2014a)
No fossil fuel subsidies	Removal of all fossil fuel subsidies enabling the achievement of development goals and paving the way to a transition to green technologies.	(Jakob et al., 2015; Rentschler & Bazilian, 2017)
Economy-wide energy efficiency target	Targets resulting in energy consumption below a business-as-usual trajectory. Usually presented as a reduction in energy intensity over GDP or as a total energy consumption target.	(Grubler et al., 2018; IEA, 2015a)
Renewable target for primary energy	Renewable target associated to primary energy demand. Targets related to electricity alone are included in the electricity and heat sector. Setting short- to mid-term targets for renewable electricity generation or capacity provides certainty for investors.	(IEA, 2015a; REN21, 2018)

Table 12 Policy options classified under the sector 'electricity and heat'

Policy option	Description	Further information
Support for highly efficient power plant stock	Policies addressing energy efficiency for the electricity and heat sector, ensuring the phase-out of inefficient power plants.	(IEA, 2015a, 2019; Somanathan et al., 2014; UNEP, 2017)
Energy reduction obligation schemes	Schemes where electricity producers must ensure energy savings internally or support energy use reduction of end-users.	(UNFCCC, 2014b, 2015a)
Renewable energy target for electricity sector	Renewable electricity targets that support policy making, i.e., formulation, implementation, as well as monitoring and evaluation of renewable uptake.	(IRENA, 2015; REN21, 2018)
Support scheme for renewables	Incentives to increase the share of renewables in the grid via increasing cost-effectiveness, allowing or facilitating grid integration as well as direct government investments.	(Carley et al., 2017; IEA, 2015a, 2019; IPCC, 2014; UNFCCC, 2018b)
Grid infrastructure development and electricity storage	Measures for the development of the electricity grid and storage, allowing installation of high shares of variable renewable electricity, such as solar PV and wind, in the system.	(IRENA, 2016; IRENA et al., 2018; Lund et al., 2015).
Emission-intensive phase-out policies	Policies setting a strategic plan for the phase out of emissions-intensive technologies, primarily coal- and oil-fired technologies.	(Jakob et al., 2020; Kriegler et al., 2018; Kuramochi et al., 2018)
Support scheme for CCS	Support schemes for the development and uptake of Carbon Capture and Storage (CCS) in the electricity sector.	(IPCC, 2018a)
Support scheme for non-renewable low-carbon alternatives	Support for options, besides renewable electricity and heat, such as nuclear and hydrogen-based technologies.	(Deetman et al., 2015; IPCC, 2018a)

Table 13 Policy options classified under the sector 'industry'

Policy option	Description	Further information
Strategy for material efficiency	Policies that aim to introduce resource-efficient processes or changes in materials used, and designs or enhance recycling and re-use of products.	(Fischedick et al., 2014; IPCC, 2014; Kuramochi et al., 2018; UNEP, 2017)
Support for energy efficiency in industrial production	Policies that support energy efficiency improvements. It often taken the form of voluntary agreements, which can play a major role of facilitating cooperation among firms, industrial associations, and governments to identify and realise low-cost emissions reduction measures.	(IEA, 2019; Somanathan et al., 2014; UNEP, 2016; UNFCCC, 2018b)
Energy reporting and audits	Policies that foster the implementation of energy management systems, e.g., energy monitoring and auditing, and energy data collection.	(Somanathan et al., 2014; UNEP, 2016)
Performance and equipment standards	Mandatory energy efficiency requirements for equipment used in industrial production and for overall energy use.	(IEA, 2020b; UNEP, 2017)
Support schemes for renewables	Policies that encourage or impose the uptake of renewables to address own energy consumption.	(BigEE, 2016; IEA, 2020b)
Support scheme for CCS	Support schemes for the development and uptake of Carbon Capture and Storage (CCS) in the industry sector.	(Åhman et al., 2017; IEA, 2020b; Kuramochi et al., 2018)
Support scheme for fuel switch	Policies supporting fuel and feedstock switching away from fossil fuels, such as the use of biofuels, electrification or hydrogen.	(Agora Energiewende & Wuppertal Institut, 2019; Fischedick et al., 2014; UNEP, 2017)
Carbon dioxide removal technology development	Policies that aim to develop options for carbon dioxide removal such as Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Capture with Carbon Storage (DACCS), enhanced weathering and mineral carbonation as well as develop stable, predictable, efficient and large support mechanism for mature CDR technologies.	(Cox & Edwards, 2019; IPCC, 2018a; Kuramochi et al., 2018; Luderer et al., 2018; van Vuuren et al., 2018)
Landfill methane reduction	Policies that aim to address emissions associated with landfill waste and provide a clear mandate or strategies to reduce methane emissions.	(Powell et al., 2016)
Incentives to reduce CH4 from fuel exploration and production	Policies that regulate fossil fuel extraction, aiming at the reduction of fugitive emissions, particularly those associated with coal and gas exploration.	(Erickson et al., 2018; Roelfsema et al., 2018)
Incentives to reduce N2O from industrial processes	Policies addressing non-energy related industry emissions, especially those related to chemical processes.	(IEA, 2015a; Somanathan et al., 2014)
Incentives to reduce fluorinated gases	Regulations to accelerate the phase out of F-gases, originally introduced to replace ozone-harming chemicals.	(IEA, 2015a; IPCC, 2014; Roelfsema et al., 2018)

Table 14 Policy options classified under the sector 'buildings'

Policy option	Description	Further information
Urban planning strategies	Policies that address the overall future directions for the retrofit of old buildings, promotion of compact cities, improving infrastructure that promotes energy efficiency and use of renewable energy.	(BigEE, 2016; Dulal et al., 2011; Somanathan et al., 2014; UNFCCC, 2015a)
Building codes and standards as well as support for highly efficient construction	Policy instruments aiming at reducing energy consumption in buildings such as building codes and standards (including individual building components), and incentives to support energy efficiency in both existing and planned buildings.	(Kuramochi et al., 2018; OECD/IEA & IRENA, 2017; UNEP, 2016; UNFCCC, 2018b).
Performance and equipment standards as well as support for highly efficient appliances	Policies to reduce energy use in buildings by improving the energy use of appliances, including heating/cooling and cooking devices. As there are few policies addressing electrification of end use, policies aiming to increase the use of heat pumps and/or induction cookstoves were included as support for 'efficient appliances.'	(Climate Action Tracker, 2016, 2018; Knobloch et al., 2020; Roelfsema et al., 2018)
Support scheme for heating and cooling	Policies such as support schemes for the use of renewable energy in heating and cooling (e.g., biomass, geothermal, and solar thermal).	(Mitchell et al., 2011)
Support scheme for hot water and cooking	Policies supporting the use of renewable technologies to heat water such as solar heaters and cooking, e.g., biogas.	(UNEP, 2015; UNFCCC, 2014a)

Table 15 Policy options classified under the sector 'land transport'

Policy option	Description	Further information
Urban planning and infrastructure investment	Urban planning strategies that support the reduction of land transport emissions. Strategies that ensure investment in well-connected and frequent public transport options or invest in infrastructure for better connectivity and traffic fluidisation.	(Somanathan et al., 2014; UNFCCC, 2015a, 2017)
Energy/emissions performance standards or support for energy efficient for LDVs	Vehicle fuel efficiency and emissions standards or fiscal/financial incentives for light vehicles.	(Axsen et al., 2020; IEA/IRENA, 2017; IEA, 2019; Roelfsema et al., 2018; UNEP, 2017)
Energy/emissions performance standards or support for energy efficient for HDVs	Vehicle fuel efficiency and emissions standards or fiscal/financial incentives for heavy-duty vehicles.	
Support for biofuels	Targets and specific support policies (e.g., tax relief, mandatory blending) to support the uptake of biofuels.	(Daioglou et al., 2017)
Support for modal share switch	Policies that encourage modal shift programmes, such as investments in public transport or subsidies for two- and three-wheelers.	(Axsen et al., 2020; UNEP, 2017; Wright & Fulton, 2005)
Support for low-emissions land transportation	Policies that support low-emissions land transport via, for example, the use of electric vehicles for light-duty transportation or hydrogen.	(IEA/IRENA, 2017; Knobloch et al., 2020; Kuramochi et al., 2018; Roelfsema et al., 2018; UNFCCC, 2018b)

Table 16 Policy options classified under the sector 'agriculture and forestry'

Policy option	Description	Further information
Standards and support for sustainable agricultural practices and use of agricultural products	Standards and support for sustainable agricultural practices and agricultural products that incentivise emissions reductions in the agriculture sector.	(IPCC, 2014; Kuramochi et al., 2018; Roe et al., 2020; UNFCCC, 2018b)
Incentives to reduce CO2 emissions from agriculture	Incentives to reduce emissions in subsectors, including CO2 emissions from agricultural soils. Emissions related to energy-CO2 are covered in the Electricity and heat sector.	(Ray et al., 2020)
Incentives to reduce CH4 emissions from agriculture	Incentives to reduce emissions in subsectors, including CH4 emissions from animals, such as incentives for improved livestock production management.	(Frank et al., 2018, 2019; Herrero et al., 2016)
Incentives to reduce N2O emissions from agriculture	Incentives to reduce emissions in subsectors, including N2O emissions from animals and soils, such as those addressing the inefficient use of nitrogen fertilizers.	(Frank et al., 2018, 2019; Herrero et al., 2016; Thompson et al., 2019)
Incentives to reduce deforestation and support for afforestation /reforestation	Incentives to reduce deforestation and encourage good forestry management via regulatory measures (command-and-control instruments), protection of areas of forests, or economic instruments (e.g., grants or subsidies to protect forests).	(Kuramochi et al., 2018; Roe et al., 2020)
Sustainability standards for biomass use	Standards for biomass production and use, ensuring that the biomass use leads to overall GHG emissions reductions.	(Booth, 2018; Daioglou et al., 2017; Johnson, 2009)

Considering the nature of climate policies, the options in each coded category are not mutually exclusive.

Mitigation Area

Energy service demand reduction and resource efficiency

Policies that indirectly reduce energy demand by supporting activity changes (e.g., reducing material use in manufacturing industries or developing urban planning strategies to minimize transport needs).

Energy efficiency

Policies that reduce energy consumption in the different sectors. It includes both framing policies which a goal to reduce energy consumption, such as energy efficiency targets, as well as policy options that support energy reductions.

Renewables

Policies that support the development of renewable technologies. This support might take a direct form, via subsidies or loans, or indirect e.g., by developing grid infrastructure technology, that support the integration of high share of variable electricity generation technologies.

Other low-carbon technologies and fuel switch

Policies that tackle the uptake of non-renewable low-carbon technologies and options that impose limitations on the use of emissions-intensive technologies, e.g., coal- and oil-fuelled technologies.

Non-energy

Policies that reduce non-energy related emissions. For example, policies to reduce fugitive emissions in fossil fuel production or process-related industrial emissions.

Cross-area policy options

Some economic policy instruments target broad energy prices and are applicable across all sectors (Somanathan et al., 2014). Some examples of such instruments include energy and carbon taxes, cap-and-trade emission trading schemes, tradable energy saving certificates, and removal of fossil fuel subsidies.

Policy instruments

The policy instruments typology was developed based on the IEA policies database, to which a set of new categories were added. The database includes all policy instruments in Table 17. The definition of subsides and taxes, and the information available per country, varies. Others have estimated subsidies and taxes using consistent methodologies without always providing policy details (Climate Transparency, 2019; IMF, 2019; OECD/IEA, 2019; OECD, 2019; World Bank Group, 2020). We rely on their data to analyse these instruments.

The main policy instrument types in our analysis are summarized below:

- **Economic instruments**: Support certain technologies, activities, behaviours or investments using financial supports and price signals to influence the market. Due to the diversity of economic instruments we further divide this category into:
    - Direct investments
    - Fiscal or financial incentives
    - Market-based instruments

- **Regulatory instruments:** Cover a wide range of instruments which impose targets, obligations and standards on actors or technologies. These include, for example, performance standards for appliances, equipment, and buildings.

- **Other approaches**: Include several policy instruments that support policy adoption, such as RD&D support and overarching target and strategies. Voluntary approaches refer to measures undertaken voluntarily or negotiated among actors. These commitments can also be initiatted by public actors who invite private actors to submit commitments. Negotiated agreements may require reporting and be subject to audits.

Table 17 Policy instruments in the database

Category	Sub-category	Policy instrument
Economic instruments	**Direct investment**	**Funds to sub-national governments**
		Infrastructure investments
		Procurement rules
		RD&D funding
	Fiscal or financial incentives	**CO2 taxes**
		Energy and other taxes
		Feed-in tariffs or premiums
		Grants and subsidies
		Loans
		Tax relief
		User changes
		Tendering schemes
		Retirement premium
		User charges
	Market-based instruments	**GHG emissions allowances**
		GHG emission reduction crediting and offsetting mechanism
		Green certificates
		White certificates
Regulatory instruments	**Codes and standards**	**Building codes and standards**
		Product Standards
		Sectoral Standards
		Vehicle fuel-economy and emissions standards
		Auditing
		Monitoring
		Obligation schemes
		Other mandatory requirements

Information and education	**Performance label**	**Comparison label**
		Endorsement label
		Advice and aid in implementation
		Information provision
		Professional training and qualification
Policy support		**Institutional creation**
		Strategic planning
RD&D	**Research programme**	**Technology deployment and diffusion**
		Technology development
		Demonstration project
Voluntary approaches		**Negotiated agreements (public/private sector)**
		Public voluntary schemes
		Unilateral commitments (private sector)
Barrier removal		**Net metering**
		Removal of fossil-fuel subsidies
		Removal of split incentives
		Grid access and priority for renewables
Climate strategy		**Formal & legally binding climate strategy**
		Political & non-binding climate strategy
		Coordinating body for climate strategy
Target		**Energy efficiency target**
		GHG reduction target
		Renewable energy target

Mapping of policy documents to the policy matrix

Policies, once coded, are mapped to the policy options presented above. Table 18 presents an overview of the coding per policy option.

Blue text – coding criteria

- Any policy document can be categorized into more than one cell – ensure that its applicability to other cells is verified, and that the verification does not stop after one cell is found valid.

PI – policy instrument
PT – policy type
S – sector
SS – sub-sector
; - or (either of the given options)

Table 18 Mapping of policy documents to policy options

	Energy service demand reduction and resource efficiency	Energy efficiency	Renewables	Other low-carbon technologies and fuel switch	Non-energy
General	• Climate strategy (PI: Climate Strategy, PT: any, S: any) • GHG reduction target (PI: GHG reduction target, PT: any, S: any) • Coordinating body for climate strategy (PI: Coordinating body for the climate strategy, PT: any, S: Any) • No fossil fuel subsidies (PI: Removal of fossil-fuel subsidies, PT: Any, S: General, SS: Any • Support for low-emission or negative emissions R&D (PI: Research & Development and Deployment (RD&D); RD&D funding, PT: any, S: Any)				
		• Economy-wide energy efficiency target (PI: Energy efficiency target; PT: Energy efficiency, S: either	• Renewable target for primary energy (PI: Renewable energy target. PT: Renewables, S: either		

		“general” or more than 1 sector)	“general” or more than 1 sector)		
Electricity and heat		• Support for highly efficient power plant stock (PI: Codes and standards; Fiscal/financial incentives, PT: Energy efficiency, S: Electricity and heat, SS: any) • Energy reduction obligation schemes (PI: Obligation schemes, PT: Energy efficiency, S: Electricity and heat, SS: any)	• Renewable energy target for electricity sector (PI: Renewable energy target. PT: any, S: electricity and heat) • Support scheme for renewables (PI: green certificates; fiscal/financial incentives; obligation schemes; net metering; direct investment, PT: Renewables, S: Electricity and heat, SS: any) • Grid infrastructure development and electricity storage (PI: Infrastructure investments, Grid access and priority for renewables, PT: Any, S: Electricity and heat, SS: any)	• Coal and oil phase-out policies (PI: Strategic planning, PT: Other low-carbon technologies and fuel switch, S: Electricity and heat, SS: Coal) • Support scheme for CCS (PI: Fiscal/financial incentives; Demonstration project, Infrastructure investments, PT: Other low-carbon technologies and fuel switch, S: Electricity and heat, SS: CCS) • Support for non-renewable low-carbon alternatives (PI: Fiscal/financial incentives; direct investment; Sectoral Standards, PT: Other low-carbon technologies and fuel switch, S: Electricity and heat, SS: Any)	
	• Overarching carbon pricing scheme (PI: GHG emissions allowances; GHG emission reduction crediting and offsetting mechanism; CO2 taxes, PT: Any, S: Electricity and heat, SS: Any) • Energy and other taxes (PI: Energy and other taxes, PT: Any, S: Electricity and heat, SS: Any)				
Industry	• Strategy for material efficiency (PI: Codes and standards; Other mandatory requirements, PT: Energy service demand reduction and resource efficiency, S: Industry, SS: any)	• Support for energy efficiency in industrial production (PI: Voluntary approaches; Fiscal/financial incentives; Obligation schemes; White certificates, PT: Energy efficiency, S: Industry, SS: any) • Energy reporting and audits (PI: Auditing; Monitoring, PT:	• Support scheme for renewables (PI: fiscal/Financial incentives; Green certificates; Obligation schemes, PT: Renewables, S: Industry, SS: any)	• Support scheme for CCS (PI: Fiscal/financial incentives; Infrastructure investments, PT: Other low-carbon technologies and fuel switch, S: Industry, SS: Industrial CO2) • Support scheme for fuel switch (PI: Fiscal/financial incentives;	• Landfill methane reduction (PI: any, PT: Non-energy, S: Industry; SS: Waste CH4) • Incentives to reduce CH4 from fuel exploration and production (PI: any, PT: Non-energy, S: Industry; SS: Oil and gas production CH4)

		Energy efficiency, S: Industry, SS: any) • Performance and equipment standards (PI: Codes and standards, PT: Energy efficiency, S: Industry, SS: any)		Infrastructure investments, PT: Other low-carbon technologies and fuel switch, S: Industry, SS: Industrial energy related) • Carbon dioxide removal technology development (PI: Fiscal/financial incentives; Infrastructure investments, PT: Other low-carbon technologies and fuel switch, S: Industry, SS: Negative emissions)	• Incentives to reduce N2O from industrial processes (PI: any, PT: Non-energy, S: Industry, SS: Industrial processes N2O) • Incentives to reduce fluorinated gases (PI: any, PT: Non-energy, S: Industry, SS: Fluorinated gases)
	• Overarching carbon pricing (PI: GHG emissions allowances; GHG emission reduction crediting and offsetting mechanism; CO2 taxes, PT: Any, S: Industry, SS: Any) • Energy and other taxes (PI: Energy and other taxes, PT: Any, S: Industry, SS: Any)				
Buildings	• Urban planning strategies (PI: Infrastructure investments; Strategic planning, PT: Energy service demand reduction and resource efficiency, S: Buildings, SS: any)	• Building codes and standards as well as support for highly efficient construction (PI: Codes and standards, Building codes and standards; Fiscal/financial incentives, PT: Energy efficiency, S: Buildings, SS: Any) • Performance and equipment standards as well as support for highly efficient appliances (PI: Product standards; Performance label; Fiscal/financial incentives, PT: Energy efficiency, S: Buildings, SS: Appliances)	• Support scheme for heating and cooling (PI: Fiscal/financial incentives; Obligation schemes, PT: Renewables, S: Buildings, SS: Heating and cooling) • Support scheme for hot water and cooking (PI: Fiscal/financial incentives; Obligation schemes PT: Renewables, S: Buildings, SS: Hot water and cooking)		
	• Energy and other taxes (PI: Energy and other taxes, PT: Any, S: Buildings, SS: Any)				
Land transport	• Urban planning and infrastructure investment (PI: Strategic planning; Infrastructure investments, PT: Energy service demand reduction and resource efficiency, S:	• Energy/emissions performance standards or support for energy efficient for light duty vehicles (PI: Vehicle fuel-economy and emissions standards; Fiscal/financial incentives, PT: Energy efficiency, S: Transport, SS: Light duty)	• Support for biofuels (PI: Renewable energy target; Fiscal/financial incentives; Obligation schemes, PT: Renewables, S: Transport, SS: any)	• Support for modal share switch (PI: Infrastructure investment; Strategic planning, PT: Other low-carbon technologies and fuel switch, S: Transport, SS: Any) • Support schemes for	

<table>
<tr><td rowspan="2"></td><td>Transport, SS: any)</td><td>• Energy/emissions performance standards or support for energy efficient for heavy duty vehicles (PI: Vehicle fuel-economy and emissions standards; Fiscal/financial incentives, PT: Energy efficiency, S: Transport, SS: Heavy duty)</td><td></td><td>low-emissions land transportation (PI: Any, PT: Other low-carbon technologies and fuel switch, S: Transport, SS: Low-emission mobility)</td><td rowspan="2"></td></tr>
<tr><td colspan="4">• Tax on fuel and/or emissions (PI: CO_2 taxes; Energy and other taxes, PT: Any, S: Transport, SS: Any)</td></tr>
<tr><td rowspan="2">Agriculture and forestry</td><td colspan="5">• Standards and support for sustainable agricultural practices and use of agricultural products (PI: Strategic planning; Product standards, PT: any, S: Agriculture and forestry, SS: none)
• Incentives to reduce CO_2 emissions from agriculture (PI: any, PT: any, S: Agriculture and forestry, SS: Agriculture CO_2)
• Incentives to reduce CH_4 emissions from agriculture (PI: any, PT: any, S: Agriculture and forestry, SS: Agriculture CH_4)
• Incentives to reduce N_2O emissions from agriculture (PI: any, PT: any, S: Agriculture and forestry, SS: Agriculture N_2O)
• Incentives to reduce deforestation (PI: any, PT: any, S: Agriculture and forestry, SS: Forestry)</td></tr>
<tr><td>•</td><td>•</td><td>• Sustainability standards for biomass use (PI: Product standards, PT: Renewables, S: Any, SS: any)</td><td></td><td></td></tr>
</table>

S2 Data sources

Overview of data sources. For some policies, the databases were complemented with peer reviewed articles or specific reports. Details on individual policies can be found at climatepolicydatabase.org. The general structure of the database is one entry per policy. Rollbacks are included by changing the policy status to 'ended' or 'superseded.'

Name	Coverage	Country coverage	Reference
Asia Pacific Energy Portal	Economy-wide	Asia-Pacific	link
Brown to Green report	Economy-wide	G20	link
CAIT INDC	Economy-wide	Worldwide	link
Climate Action Tracker	Economy-wide	A few countries	link
Columbia Law School Database	Economy-wide	Worldwide	link
COMMIT	Economy-wide	A few countries	link
Deutsche Bank Global Climate Policy Tracker	Economy-wide	Worldwide	link
Dieselnet	Emissions standards	A few countries	link
ECOLEX	Economy-wide	Worldwide	link
EU Climate Change Mitigation Policies and Measures	Economy-wide	EU	link
GBPN - Building Policies for a Better World	Buildings	A few countries	link
ICAP Emissions Trading Schemes	Economy-wide	Worldwide	link
IEA Clean Coal Database	Emissions standards	Worldwide	link
IEA Policy Database	Energy-related	Worldwide	link
INDCs - UNFCCC	NDCs	Worldwide	link
Climate Change Laws of the World	Economy-wide	Worldwide	link
OECD Energy taxes	Economy-wide	OECD + others	link
OECD Stat	Economy-wide (indicators)	OECD + others	link
OECD Policy Instruments for the environment	Economy-wide	OECD + others	link
PBL COP update 2016	Economy-wide	A few countries	link
PBL COP update 2017	Economy-wide	A few countries	link
PBL COP update 2018	Economy-wide	A few countries	link
PBL COP update 2019	Economy-wide	A few countries	link
PBL Spring update 2018	Economy-wide	A few countries	link
PBL Spring update 2019	Economy-wide	A few countries	link
REN21	Renewables/Efficiency	Worldwide	link
RES Legal	Renewables	EU	link
Scaling up Argentina	Economy-wide	Argentina	link
Scaling up EU	Economy-wide	EU	link
Scaling up Indonesia	Economy-wide	Indonesia	link
Scaling up South Africa	Economy-wide	South Africa	link
Scaling up Turkey	Economy-wide	Turkey	link
State Energy Efficiency Policy	Efficiency	US	link
State incentives of RE & EE	Renewables/Efficiency	US	link
Transport policy	Transport	A few countries	link
UNFCCC NatComs and BURs	Economy-wide	Worldwide	link
World Bank INDC data	NDCs	Worldwide	link
WTO Environmental Database	Economy-wide	Worldwide	link

S3 Distribution of policy instruments

Figure 20: Policy instrument types (identified by colours) in the G20. Bar charts indicate country coverage weighted using G20 members' share of total emissions in 2018.

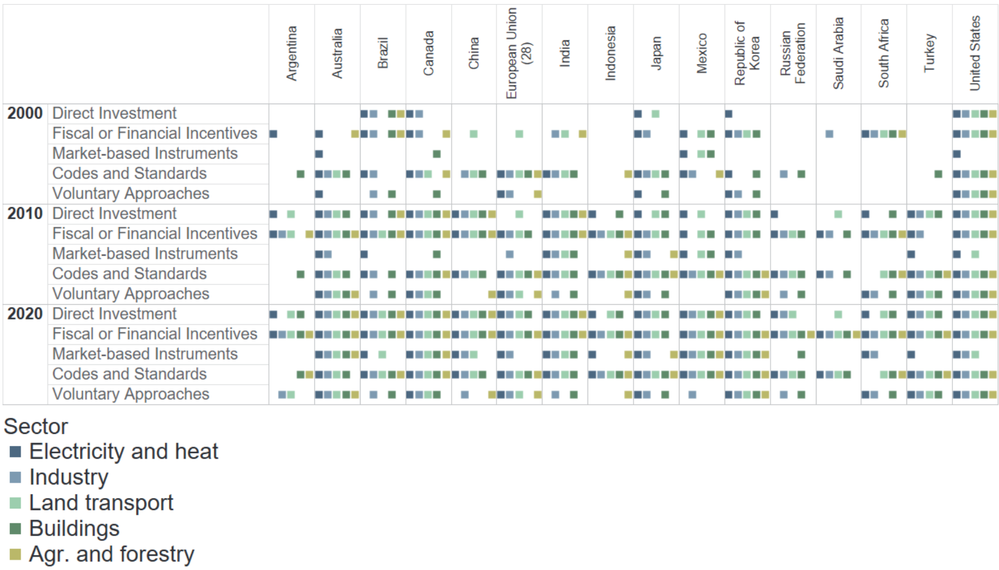

Figure 21: Distribution of policy instruments per sector and country.

S4 Cluster description

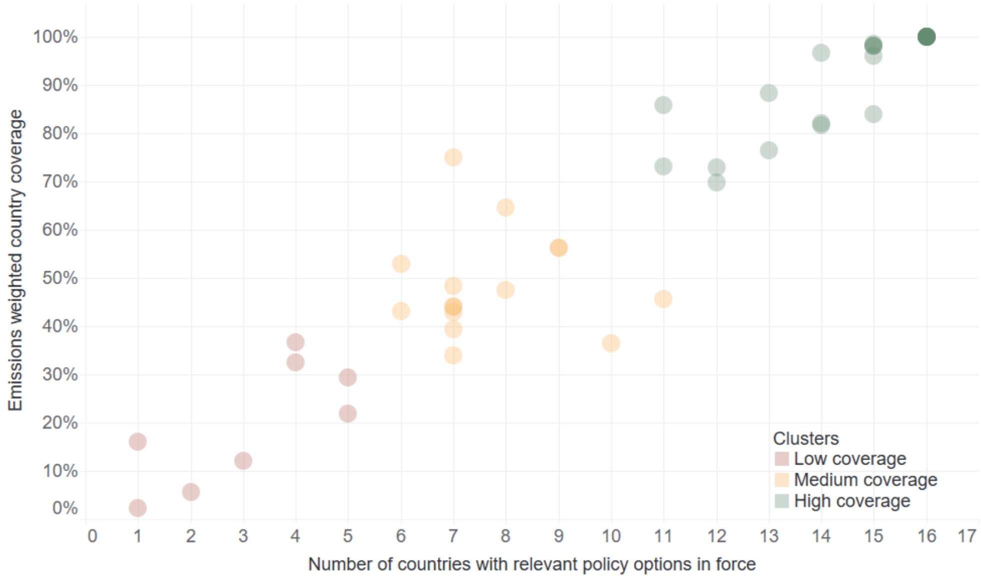

Figure 22: Cluster results, each circle represents one policy option. No G20 country has removed fossil fuel subsidies. This policy option is not used in the cluster analysis but would be categorised 'low coverage.'

Number of Clusters:	3
Number of Points:	49
Between-group Sum of Squares:	8.5516
Within-group Sum of Squares:	1.0859
Total Sum of Squares:	9.6375

		Centres	
Clusters	**Number of items**	**Emissions share**	**Count of countries**
High coverage	26	0.92323	14.615
Medium coverage	15	0.48722	7.7333
Low coverage	8	0.19544	3.125

SM5 - Supplementary material Chapter 5

Supplementary figures

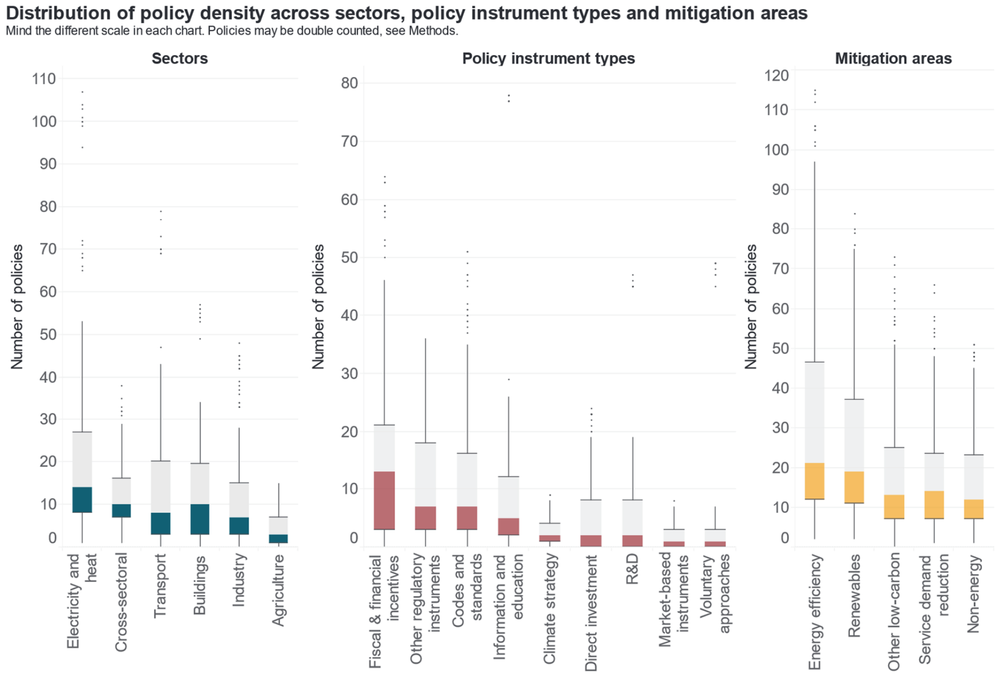

Figure 23: Distribution of policies per sector, policy instrument and mitigation area.

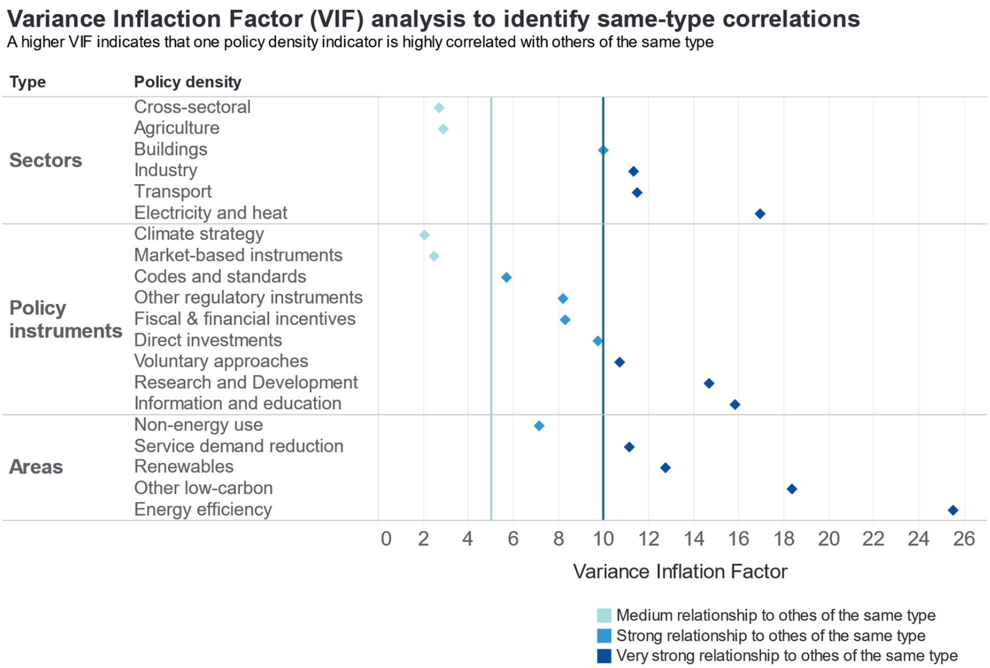

Figure 24: Variance inflation factor (VIF) of distinct policy density indicators. The figure indicates that a high number of electricity and heat policies is associated with a high number of policies in other sectors. While a correlation matrix measures one-on-one relationship between policy density indicators, the VIF measure one-to-many relationships and summarises the information in one single value. Here, we use typically-used VIF cut-off values for reference (Craney & Surles, 2002).

Supplementary methods

This section presents a summary of the typology used in the research and example of policies included. This section is adapted from Nascimento et. al (2022).

Policy instrument types

The original typology includes additional instruments since these categories could be further disaggregated. However, further disaggregation resulted in samples too small for statistical analyses.

Policy instrument type	Description
Climate strategies	Includes, for example, formal and legally binding climate strategies and climate change strategies which are not enshrined in law but are adopted through policy documents published by government agencies.
Codes and standards	Codes and standards are a very prominent sub-category of regulatory instruments. They refer to, for example, building codes and standards, industrial air pollution standards, product standards, vehicle fuel-economy and emissions standards
Direct investments	Direct investments differ from fiscal and financial incentives because they refer to direct investments by national governments. For example, they include direct transfer of funds from national to sub-national governments for activities that have a potential to reduce the region's GHG emissions. Also, infrastructure investments with a mitigation component would also be considered a direct investment.
Fiscal and financial incentives	Fiscal and financial incentives are a specific type of economic instruments that indirectly provide incentives for measures but do not establish a market-based mechanism. Some examples are feed-in tariffs, CO_2 and other taxes and subsidies.
Information and education	Refer to policies aimed are informing or educating users. Some examples include consumer-oriented labelling schemes that provide a rating of good or service against a pre-determined scale or that inform that good or products adapts to pre-defined minimum standards related to mitigation outcomes. It also includes schemes aimed at increasing access to information with potential positive mitigation outcomes, such as energy savings approaches or training programs for activities associated directly or indirectly with mitigation outcomes.
Market-based instruments	Includes multiple instruments such as: government-established emissions limits or caps on specific actors which can be traded to incentivize cost-effective emissions reductions; Scheme for the generation of tradable renewable energy certificates, or; schemes for generating tradable energy savings certificates produced by energy efficiency activities measured against a baseline.
Other regulatory approaches	Other regulatory approaches are those which do not fall into the codes and standards category, such as obligation schemes (e.g., mandatory requirement to comply with regular quotas for mitigation-

	related outcomes, such as yearly energy efficiency improvements for businesses).
Research and Development	Includes incentive schemes to accelerate the production of near-to-market technologies, nascent technologies with mitigation potential or the support for the implementation of pre-operational technologies or new uses of existing technologies.
Voluntary approaches	Voluntary approaches include partnerships between public and private actors for the implementation of mitigation-related activities or agreed voluntary commitments. It also includes several schemes to support voluntary activities by private actors, such as providing incentives to overcome split incentives (e.g., between landlord and tenant).

Sectors

Agriculture

Includes policies to increase sustainable practice in agriculture. Policies associated with sustainability standards for biomass used as a source for biofuels in other sectors are also included in this sector.

Buildings

Includes policies that target energy-use in buildings. These policies address building structure, appliances, cooking and heating/cooling devices. This sector also contains urban planning strategies.

Electricity and heat

Policies related to energy supply and enabling infrastructure, such as transmission and distribution grids, are included in this sector. However, policies related to fossil fuel exploration and production are included in the industry sector.

General

Cross-sectoral policies or policies that apply to any sector and that provide framing for or enable the implementation of other sectoral policies are included in this sector. These include, but are not limited to, national or sectoral climate strategies and Research and Development (R&D) policies.

Industry

Policies covering both energy-generation for own use and process-related emissions. This sector also includes policies related to other non-energy emissions. For example, emissions related to waste or fossil fuel exploration.

Transport

This sector includes policies related to all modes of land transportation and infrastructure programmes that might reduce transport needs (e.g., urban planning).

Mitigation areas

Energy service demand reduction and resource efficiency

Includes policies that indirectly reduce demand by supporting activity changes (e.g., reducing material use in manufacturing industries or developing urban planning strategies to minimize transport needs). These policies modify demand for goods and services by targeting choices/adoption of technology, consumption, behaviour, lifestyles, coupled production–consumption infrastructures and systems, service provision and associated socio-technical transitions" (Creutzig et al., 2022).

Energy efficiency

Includes policies to reduce national energy use. Energy efficiency policies include both framing policies with a goal to reduce energy consumption, such as energy efficiency targets, as well as policy options that support energy reductions in specific sectors, such as subsidies for energy efficient appliances or fuel consumption standards.

Renewables

Includes policies to support renewable energy technologies. This support might take a direct form, via subsidies or loans, or indirect, such as by developing grid infrastructure technology, that support the integration of high share of variable electricity generation technologies. This mitigation area includes policies that support the uptake of renewables in energy-use sectors, such as bio-energy mandates in in transport.

Other low-carbon technologies and fuel switch

Includes policies that support non-renewable, low-carbon technologies and options that impose limitations on the use of emissions-intensive technologies. Low-carbon technologies include support for nuclear electricity and fuel switch include for example coal and oil phase out policies. In this mitigation area we also include policies that support carbon dioxide removal technology development.

Non-energy

Includes policies that reduce non-energy related emissions. For example, policies to reduce emissions associated with fossil fuel exploration and production, industrial processes and the ban of fluorinated greenhouse gases.

Supplementary tables

Table 19: ISO3 of the countries analysed.

ARE	CRI	KAZ	PHL
ARG	ETH	KEN	RUS
AUS	EU27/28 (not an ISO code)	KOR	SAU
BRA	GAB	MAR	SGP
BTN	GBR	MEX	THA
CAN	GMB	NGA	TUR
CHE	IDN	NOR	UKR
CHL	IND	NPL	USA
CHN	IRN	NZL	VNM
COL	JPN	PER	ZAF

Table 20: Regression results. In all models we present the results including and excluding control variables. Considering the sample size, we focus on the total results but present the regression per cluster for transparency. The number of policies remain statistically associated with the projected emission change rates across clusters.

	Dependent variable: Mean projected emissions growth rate, 2021-2030							
	Total control	Total	Moderate decline control	Moderate decline	Moderate growth control	Moderate growth	High growth control	High growth
Number of Policies	-0.28***	-0.39***	-1.33***	-0.51***	-0.23*	-0.56***	-0.72***	-0.20**
	(0.08)	(0.05)	(0.14)	(0.15)	(0.13)	(0.09)	(0.14)	(0.08)
GDP per capita	-0.56***		-0.06		-0.36		-0.51***	
	(0.08)		(0.18)		(0.25)		(0.10)	
Emissions per capita	0.06		0.58***		0.53***		0.09	
	(0.05)		(0.19)		(0.11)		(0.10)	
Rule of law	-0.10		-0.82***		-0.14		0.02	
	(0.08)		(0.27)		(0.17)		(0.07)	
Number of high-impact policies	0.08		0.02		-0.04		0.64***	
	(0.07)		(0.18)		(0.11)		(0.14)	
Observations	263	263	35	35	72	72	156	156
R^2	0.51	0.15	0.76	0.26	0.56	0.31	0.31	0.04
Adjusted R^2	0.50	0.15	0.72	0.24	0.53	0.30	0.28	0.03
Residual Std. Error	0.71 (df=257)	0.93 (df=261)	0.54 (df=29)	0.88 (df=33)	0.69 (df=66)	0.84 (df=70)	0.85 (df=150)	0.99 (df=154)
F Statistic	72.94*** (df=5; 257)	68.17*** (df=1; 261)	43.26*** (df=5; 29)	11.23*** (df=1; 33)	16.65*** (df=5; 66)	39.12*** (df=1; 70)	24.18*** (df=5; 150)	6.34** (df=1; 154)
Note:								*p<0.1; **p<0.05; ***p<0.01

Summary

Changes in the Earth's system that are caused by climate change, threaten our current society and ecosystems. In response, most countries committed to pursue efforts to mitigate and adapt to climate change when they ratified the Paris Agreement in 2015. Limiting global average warming and reducing the impacts of climate change demands that global greenhouse emissions halve by 2030 and reach zero as soon as possible in the second half of this century.

The Paris Agreement was designed to ensure broad participation. Countries submit their own pledges, named Nationally Determined Contributions (NDCs), to reduce their greenhouse gas emissions. These pledges are expected to be updated over time but are not reviewed or approved centrally; They are collectively assessed in the "Global Stocktake" process. In this process, the aggregated level of emissions implied by NDCs is compared to the global emission pathways that are necessary to meet the goals of the Paris Agreement. However, aggregated pledges clearly remain insufficient to reach these global goals. Although pledges are likely to improve over time, this approach for reviewing and revising them hinders country comparisons and muddles accountability.

Countries also need to adopt national policies to meet their pledges. Climate policies, which are adopted by governments to reduce emissions or support the uptake of low-carbon practices, technologies and behaviours, reduced emissions in the past. They also increased in number and now cover many important areas but globally they remain insufficient to meet countries' own pledges. Although increasing the strength of policies in force is a means to improve their overall ability to reduce emissions, expanding their number helps ensuring that all relevant sectors and emissions are addressed. However, considering the increasing number of policies adopted, new methods to identify policy-adoption gaps are necessary to identify potential policy-expansion entry points.

Against this backdrop, my thesis has two main objectives. First, I assess progress in the implementation of the Paris Agreement, especially considering national-level policies and targets to reduce emissions and their change over time. Second, I develop and apply methods to identify potential climate-policy entry points building on a large dataset of adopted policies. My thesis is organised around four research chapters, which I summarise in the following paragraphs.

First, I, together with my collaborators, analysed countries' actions to mitigate climate change by comparing emission projections based on current policies to original and updated NDC emission pledges. We found that most countries need to implement additional policies to meet their NDCs. Among the 25 countries analysed, eleven are projected to meet their current NDCs. However, in several of these countries, the current NDC targes result in emissions substantially above those implied by adopted policies. This suggests that their NDCs have a limited effect on guiding further emission reductions. Additionally, many countries have not yet adopted sufficient policies to meet their original NDCs, which were set over seven years ago. Delaying this sequencing of targets and policies undermines the pledge and review mechanism of the Paris Agreement.

Second, we estimated the effect of policies adopted until 2015 on emissions projections for the G20 economies, which represent most of global emissions. We repeated the exercise with policies adopted until 2021 and compared the projected emissions level in 2030. This exercise helps to assess progress since the adoption of the Paris Agreement and clarifies whether more recent projections improve on the original ones and by how much. We find that emissions projections up to 2030 for the G20 countries have improved since 2015 and are approximately 6 $GtCO_2eq$ or 15% lower in 2021. The reasons for these reductions vary. The COVID-19 pandemic resulted in a dip in greenhouse-gas emissions and affected long-term emissions. However, the adoption of additional policies also explains lower emissions. Renewable uptake has been faster than projected before, efficiency improvements result in

lower energy demand and coal phase out policies result in substantial shifts in emissions projections of some countries. Nonetheless, the existing gap between global current policies and the goals of the Paris Agreement is still approximately three to four times larger than the improvement observed between 2015 and 2021. Countries need to substantially accelerate their efforts to meet the collective goals of the Paris Agreement.

Third, we evaluated the change in climate policies adopted in the past two decades to assess progress over time and identify policy adoption gaps in the G20 countries. We simplified the comparison of climate policies by identifying a fixed list of policy options to reduce emissions and measuring the change in their prevalence over time. We find that the number of sectoral climate policies and their coverage in G20 countries has increased. Countries with relevant policy options in force cover on average two-thirds of total G20 emissions, in comparison to only one-third twenty years ago. However, approximately half of the identified policy options are not widely adopted. The prevalence of climate policies is particularly low for policies that aim to phase out coal and oil, and mandate energy reductions in electricity and heat supply; reduce industrial process emissions and incentivise fuel switches in industry; design urban planning strategies and enable building retrofits; and support the use of renewable energy for cooking and heating/cooling purposes in buildings. Policies to remove fossil-fuel subsidies and support carbon-dioxide removal also need substantial improvement. Filling policy-adoption gaps presents a concrete strategy to improve sectoral, national and global climate policies.

Finally, we compared the number of climate policies adopted per country between different country groups using best-performing countries as a reference. We analysed the distribution of policies adopted per sector, policy instrument types and mitigation area. We also contextualised these distributions using countries' emission projections developed based on adopted policies. We find that larger and more comprehensive policy portfolios are conducive of emission reductions, regardless of whether absolute emissions are projected to increase or decline. We also find that country groups have distinct entry points to expand climate policy. Countries with fast-increasing emissions have significantly fewer policies overall, but policies are especially missing in energy-demand sectors, such as buildings and transport. Countries with plateauing emissions lack climate strategies and other cross-sectoral policies. This suggests the need for better coordination of mitigation efforts across sectors. In all country groups that fail to reduce emissions, policies to reduce energy and material demand are also substantially fewer.

In my thesis, I show that countries have progressed in their climate-change mitigation efforts both in terms of adopting policies and reducing emissions. Evaluating progress is important to highlight that climate action matters and helps shaping future emission pathways. However, my research indicates that current efforts still need to improve to limit the worse impacts of climate change. We also found that expanding climate policies in line with the findings of my thesis is an important means to improve national climate action and that international cooperation plays an important role in facilitating it.

The four research chapters of my thesis have diverse implications for the forthcoming implementation of the Paris Agreement and consequently for national and global reduction of greenhouse gas emissions. Assessing progress since the adoption of the agreement supports mapping out potential means to improve its future ambition raising cycles. Identifying areas to expand climate policies supports national implementation of the Paris Agreement goals. My research indicates that the Global Stocktake must raise the sense of urgency to reduce emissions and move towards national analyses to inform ambition raising. Also, it shows that best-performing countries can proactively support the implementation of the Paris Agreement by improving rollout of well-established mitigation options. Considering the findings of this research, strengthening international cooperation as will be fundamental to realise the collective goals of the Paris Agreement.

About the author

Leonardo Nascimento was born in Belo Horizonte, Brazil. When he was nine, his parents moved to a smaller city so he and his sisters could enjoy the freedom of growing up with fewer worries. This carried him through his physics degree at the Federal University of Minas Gerais (UFMG) between 2010 and 2013. Leonardo's undergraduate research focused on solid-state physics, but his courses and guided studies focused on classic general relativity, his favourite topic as a physicist.

After graduation, he started a career in management consulting in São Paulo, Brazil. He developed and validated methods to analyse regulatory risk for major international banks. This experience led him to a brief career as a risk consultant for a financial joint venture. In this job, Leonardo developed tools to analyse and report risk and models to assess financial performance.

In 2017, Leonardo obtained his Sustainable Energy Technology master's degree from the University of Twente, in the Netherlands. In his masters, he specialised in the relationships between energy systems and society, especially considering how data can be used to inform sustainable transitions and the role of federal governments in enabling them. For his master thesis, he created an agent-based model to explore how individual's roles and preferences affect the emergence of community-led energy projects.

Since 2018, Leonardo works at NewClimate Institute in Cologne and Berlin, Germany. Leonardo has since worked on multiple projects that evaluate climate action and analyse greenhouse-gas emission trajectories. He specialises in the analysis of national policies and their collective effects. He is a contributor of the Climate Action Tracker and Climate Change Performance Index projects, which both evaluate national climate-change commitments and policies. He is also a contributing author of the annual editions of the UNEP Emissions Gap Report. Leonardo participates in distinct European research projects that prepare and analyse future climate-change mitigation pathways. He works extensively in the policy-science interface and uses his research to provide analytical support to policymakers through policy briefs, scientific publications and direct support to ministries and the European Commission. Since 2020, Leonardo is also an associate at Wageningen University and Research.

Publication list

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