Climate Policy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcpo20

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To cite this article: Leonardo Nascimento, Takeshi Kuramochi, Gabriela Iacobuta, Michel den Elzen, Hanna Fekete, Marie Weishaupt, Heleen Laura van Soest, Mark Roelfsema, Gustavo De Vivero-Serrano, Swithin Lui, Frederic Hans, Maria Jose de Villafranca Casas & Niklas Höhne (2022) Twenty years of climate policy: G20 coverage and gaps, Climate Policy, 22:2, 158-174, DOI: 10.1080/14693062.2021.1993776

To link to this article: https://doi.org/10.1080/14693062.2021.1993776

CLIMATE POLICY
2022, VOL. 22, NO. 2, 158–174
https://doi.org/10.1080/14693062.2021.1993776

Twenty years of climate policy: G20 coverage and gaps

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ABSTRACT

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 realize the full mitigation potential of existing policy options and to advance the transition towards global net zero greenhouse gas emissions.

Key policy insights:

- Mitigation-related policy options can be presented as a matrix by sector to shed light on what constitutes a comprehensive climate policy package; looking across sectoral climate policies helps to unpack and clarify the status of adoption.
- Policy adoption gaps exist in all sectors. Increasing the sectoral coverage of climate policies will help to ensure that all relevant sectoral emissions and mitigation areas are considered in national mitigation efforts.
- Even if an increase in policy coverage alone does not ensure emission reductions, the absence of policy coverage indicates that emissions can still be further reduced and that a portion of global emissions remain uncovered by policies.
- Despite the observed increase in the number and coverage of climate policies, 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.

ARTICLE HISTORY
Received 18 September 2020
Accepted 11 October 2021

KEYWORDS
Policy coverage; policy instruments; G20; sectoral policy; climate change mitigation; policy database

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Supplemental data for this article can be accessed at https://doi.org/10.1080/14693062.2021.1993776.

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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, 2015). 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 twenty-first century (Rogelj 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 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 broadly 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., 2019). 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 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)').[1] 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 decarbonization 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).

2. Data and methods

An overview of the analytical approach taken in this analysis is shown in Figure 1. We then explain how we systematically collect and categorize policies (Section 2.1), define a comprehensive matrix of policy options (Section 2.2), and finally how we investigate policy coverage to identify adoption gaps (Section 2.3). Our analysis focuses on policies in force between 2000 and 2019.

2.1. Step 1: Data collection and categorization

Several data sources exist that cover certain subsets of policies, sectors, countries or timeframes (Supplementary Material S1 summarizes 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 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.

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 (S2). The six sectors used in our analysis cover most G20 emissions (Table 1). We added the collected policies and categorization used in this research to an open source, online database.[2]

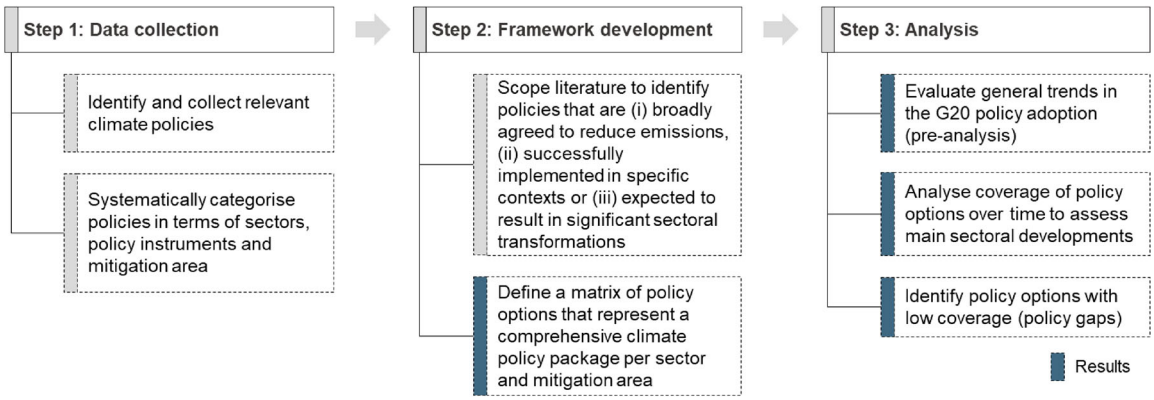

Figure 1. Overview of analytical approach.

Table 1. 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.

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 2 and Supplementary Material 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, 2018), 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.

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 so as 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

Table 2. Matrix of key policy options by sector (rows) and mitigation area (columns); each bullet represents one policy option.

	Energy service demand reduction and resource efficiency	Energy efficiency	Renewables	Other low-carbon technologies and fuel switch	Non-energy emissions
General	• Climate strategy • Emissions reduction target • Coordinating body for climate strategy • Support for low-emission or negative emissions R&D • No fossil fuel subsidies				
		• Economy-wide efficiency target	• Renewable target for primary energy		
Electricity and heat		• Support for highly efficient power plant stock • Energy reduction obligation schemes	• Renewable energy target for electricity sector • Support scheme for renewables • Grid infrastructure development and electricity storage	• Coal and oil phase-out policies • Support scheme for CCS • Support scheme for non-renewable low-carbon alternatives	
	• Overarching carbon pricing • Energy and other taxes				
Industry	• Strategy for material efficiency	• Support for energy efficiency in industrial production • Energy reporting and audits • Performance and equipment standards	• Support scheme for renewables	• Support scheme for CCS • Support scheme for fuel switch • Carbon dioxide removal development	• 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
	• Overarching carbon pricing scheme or emissions limit • Energy and other taxes				
Buildings	• Urban planning strategies	• Building codes and standards as well as support for highly efficient construction • Performance and equipment standards as well as support for highly efficient appliances	• Support scheme for heating and cooling • Support schemes for hot water and cooking		
	• Energy and other taxes				
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	
	• 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

Notes: Grey cells indicate not-applicable mitigation areas, or that no relevant policy option has been identified.

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.

3. Results

3.1. Overview of policy adoption in the G20

Jointly, the G20 countries have over 1600 national climate policies in force as of December 2019 (Table 3). 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 liberalization 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.

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 2). 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).

Table 3. Number of policies in force as of December 2019 per sector.

Sector	Number of policies in force	Year difference to first policy - median (5th to 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)

Notes: 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.

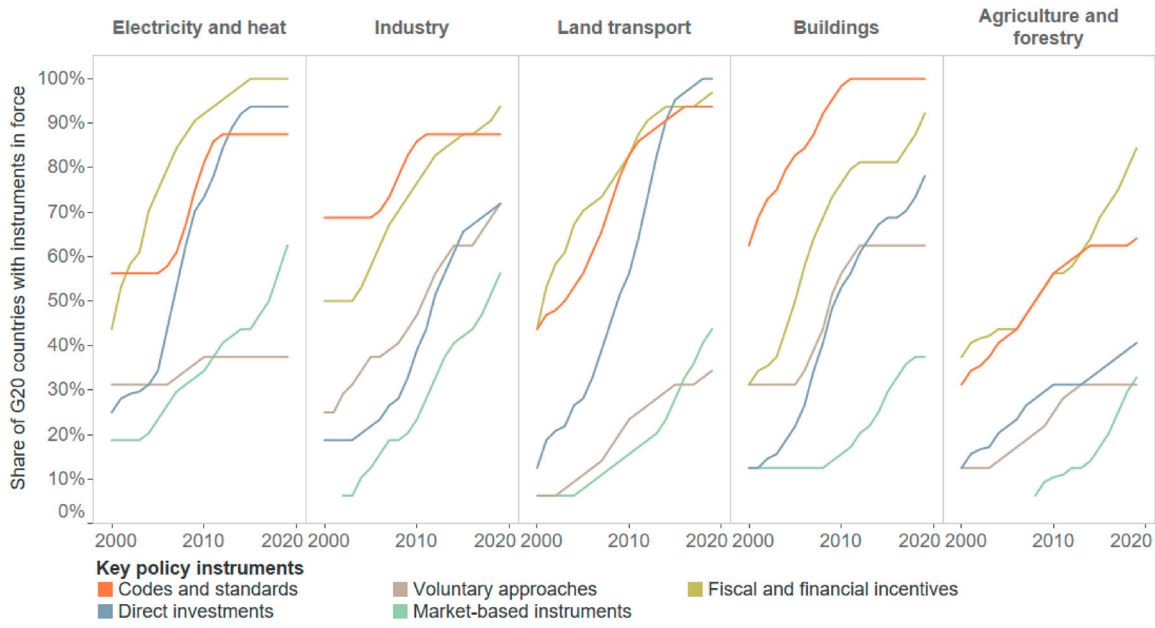

Figure 2. Time evolution (three-year moving average) of share of countries that adopted key policy instrument types by sector in the G20.

These trends support the existence of a multi-sector and multi-instrument approach to climate policies across countries (Averchenkova et al., 2017). They 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 (Supplementary Material 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.

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 2.1. 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 3). 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

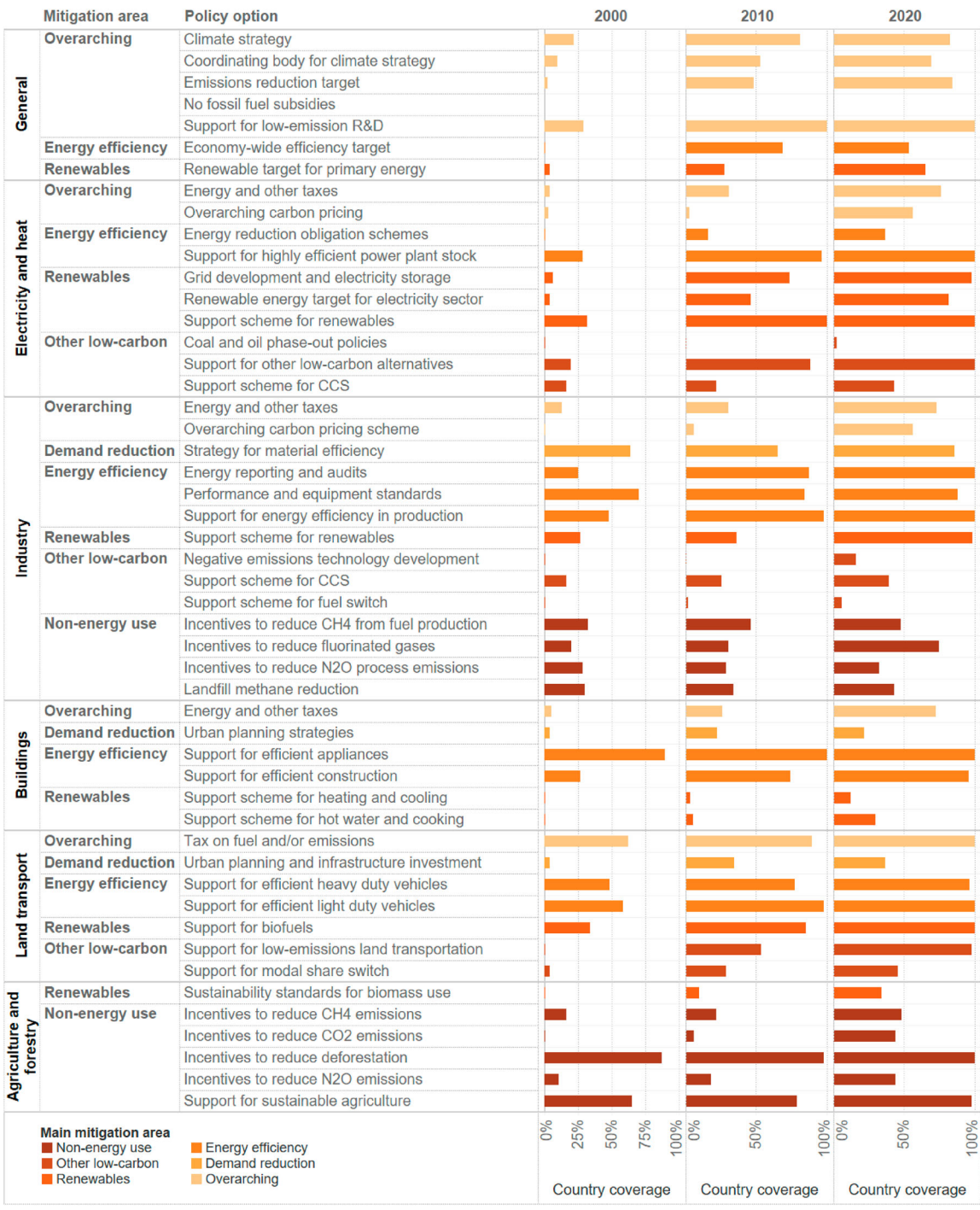

Figure 3. G20 country coverage of key policy options by sector. Bar charts indicate country coverage weighted using G20 members' share of total emissions in 2018. For visualization purposes, the names of some policy options were shortened.

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 subsidize 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 decarbonization 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 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.

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 minimize 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.

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 4). 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' (Supplementary Material 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 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 less than 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 (Supplementary Material 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 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

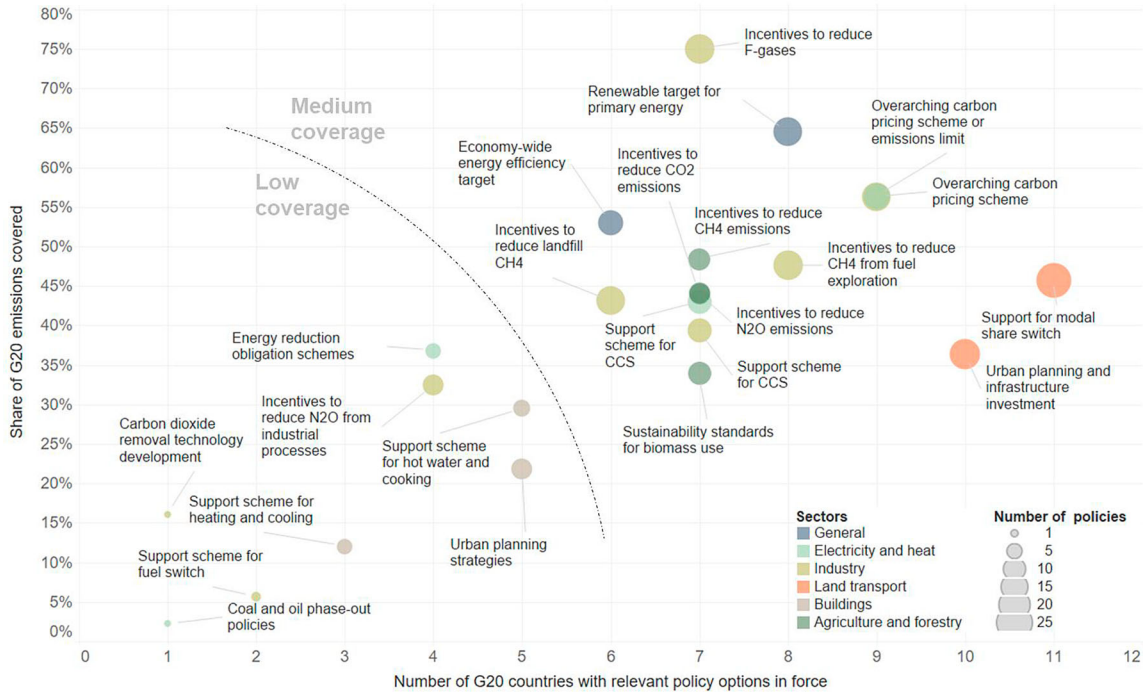

Figure 4. Low and medium coverage policy options (emissions weighted country coverage vs number of countries covered). High coverage options are excluded for visualization purposes, but included in Supplementary Material S4. The curve represents an illustrative, not actual, boundary.

(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).

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. 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 recognized 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 broadly 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 realize 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 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 subnational 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.

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, so as 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 realize 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 shows 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 subsidize 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 realize 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 minimize 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 realize the full potential of sectoral climate policy.

Notes

1. We use the term 'country' to refer to both the EU and the fifteen non-EU G20 economies.
2. www.climatepolicydatabase.org.

Acknowledgements

The authors would like to thank Rik Leemans (Wageningen University) for the valuable comments. We would also like to thank the following people supporting the review of the policy database: Chenmin He (Energy Research Institute, China), Zbigniew Klimont, Nicklas Forsell, Jessica Chalmers and Olga Turkovska (IIASA), Amit Garg (Indian Institute of Management Ahmedabad), Roberta Pierfederici (IDDRI), Ucok WR Siagian (Bandung Institute of Technology, Indonesia), Jiyong Eom and Cheolhung Cho (Korea Advanced Institute of Science and Technology), Junichiro Oda (RITE, Japan), Aayushi Awasthy and Swapnil Shekhar (TERI, India), Hongjun Zhang (Tsinghua University), Nick Macaluso (Environment and Climate Change, Canada), Michael Boulle and Hilton Trollipp (Energy Research Centre, South Africa) and Daniel Buira (IDDRI and Tempus Analitica), Vladimir Potachnikov from (Higher School of Economics, Russia), Masahiro Suzuki (Central European University), and Ioannis Dafnomilis (PBL Netherlands Environmental Assessment Agency).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work is supported by H2020 European Institute of Innovation and Technology [grant agreement No. 821471 (ENGAGE)] and builds on work developed [grant number 642147 (CD-LINKS)].

Data and code availability

The source code and data used to produce the results and analyses presented in this manuscript are available at https://doi.org/10.4121/12962288.v1.

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