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IDENTIFYING AND TRACKING CLIMATE CHANGE MITIGATION STRATEGIES: A CLUSTER-BASED ASSESSMENT

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ABSTRACT/RÉSUMÉ

Identifying and tracking climate change mitigation strategies: A cluster-based assessment

This paper identifies different types of climate change mitigation strategies countries adopted over the last two decades and assesses the policy synergies they might generate. The analysis exploits the rich policy repository of the OECD's Climate Actions and Policies Measurement Framework (CAPMF). This is the most comprehensive and harmonised mitigation policy database to date, covering more than 120 policy instruments and 50 countries over 2000-20. Statistical cluster analysis yields four types of mitigation strategies, which differ in the variety and stringency of mitigation policies. Until the mid-2000s mitigation strategies were similar and based on few policies and low overall stringency. They started to differentiate in the mid-2000s and then in the mid-2010s as some countries enlarged the variety of policy instruments and raised stringency. Regression results indicate that emissions are negatively associated with the overall stringency of the country's mitigation strategies. Moreover, this relationship is stronger for mitigation strategies comprising a larger set of instruments, pointing to larger policy synergies.

JEL codes: Q54, Q58, C23

Keywords: Climate policy, cluster analysis, greenhouse gas emissions, cross-country analysis

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Identifier et suivre les stratégies d'atténuation du changement climatique : Une évaluation basée sur les clusters

Ce document identifie les différents types de stratégies d'atténuation du changement climatique adoptées par les pays au cours des deux dernières décennies et évalue les synergies politiques qu'elles pourraient générer. L'analyse exploite le riche référentiel politique du « OECD Climate Actions and Policies Measurement Framework » (CAPMF). Il s'agit de la base de données sur les politiques d'atténuation la plus complète et la plus harmonisée à ce jour, qui couvre plus de 120 politiques publiques et 50 pays sur la période 2000-20. L'analyse statistique par clusters permet de dégager quatre types de stratégies, qui se distinguent par la variété et la rigueur des politiques d'atténuation. Jusqu'au milieu des années 2000, les stratégies d'atténuation étaient similaires et reposaient sur un petit nombre de politiques et une faible rigueur globale. Elles ont commencé à se différencier au milieu des années 2000, puis au milieu des années 2010, lorsque certains pays ont élargi la gamme des politiques publiques et renforcé la rigueur. Les résultats de la régression indiquent que les émissions sont négativement associées à la rigueur globale des stratégies d'atténuation du pays. En outre, cette relation est plus forte pour les stratégies d'atténuation comprenant un plus grand nombre d'instruments, indiquant alors des synergies politiques plus importantes.

JEL codes: Q54, Q58, C23

Mots clés: Politique climatique, analyse en grappes, émissions de gaz à effet de serre, analyse transnationale

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Identifying and tracking climate change mitigation strategies: a cluster-based assessment

By Filippo Maria d'Arcangelo, Tobias Kruse, and Mauro Pisu[1]

1. Introduction

Limiting climate change requires drastic action to close the large gap between the ambitious mitigation goals countries have set and policy implementation (IPCC, 2021[1]).[2] Over recent years, countries have ramped-up climate action (Kruse et al., 2022[2]; Nachtigall et al., 2022[3]), but these efforts still fall short of what is needed to reach net-zero targets and reach the Paris Agreement goal of limiting global warming to well-below 2°C with respect to pre-industrial average temperatures . According to some estimates, current policies can reduce CO_2 emissions by less than 13% (to 32 giga ton) between 2021 and 2050 (IEA, 2022[4]). If this path continues, global warming is likely to significantly overshoot the Paris Agreement goal, raising the likelihood of catastrophic impacts for societies and economies (Climate Action Tracker, 2021[5]; IPCC, 2022[6]).

There is a growing international consensus that well-designed mitigation strategies need to span a variety of policy instruments tailored to country specific circumstances (D'Arcangelo et al., 2022[7]; Blanchard, Gollier and Tirole, 2022[8]; van den Bergh et al., 2021[9]). Mitigation policy instruments have multiple effects and combining them can address multiple market failures, generate complementarities and improve the cost-effectiveness of the overall mitigation policy strategy (Peñasco, Anadón and Verdolini, 2021[10]). Emission pricing creates strong economic incentives to develop and deploy low-carbon technologies. Standards and regulations are useful when firms and individuals are relatively unresponsive to prices. Subsidies can encourage innovation and the development of clean technologies that are still far from commercialization. Encouraging or mandating emission disclosures in the presence of stringent mitigation policies can reduce asymmetric information, shifting capital towards low-carbon production processes (D'Arcangelo et al., 2023[11]). Policy packages also enjoy broader social support than individual climate policies (Dechezleprêtre et al., 2022[12]).

Yet, relying on a wide range of policies can also generate trade-offs and overlaps if they are not well designed, increasing costs and blunting the overall effectiveness of the mitigation policy mix. Simply stacking multiple instruments together does not guarantee that they will generate the desired synergies and results (Smith and Sorrell, 2001[13]; Fankhauser, Hepburn and Park, 2010[14]). For instance, generous

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[2] Over 140 countries accounting for 90% of GHG emissions have so far adopted or announced climate neutrality goals.

support to the deployment of non-fossil energy sources or clean technologies that are already at or close to the commercialization stage may not be effective alongside emissions pricing (Gugler, Haxhimusa and Liebensteiner, 2021[15]; Anderson et al., 2023[16]). Combining emission quotas (such as in emission trading schemes) with renewable energy quotas in the power sector may encourage power generation by the dirtiest technologies as compared with relying on emission quotas alone (Böhringer and Rosendahl, 2010[17]; Perino, Ritz and van Benthem, 2019[18]). In federal countries, a related effect occurs with interactions between federal and state-level policies resulting in "internal" emission leakage, whereby emission reductions in one state are offset (partly or totally) by increased emissions in another state (Goulder and Stavins, 2011[19]).

This paper identifies the different types of mitigation strategies countries are adopting and describes their evolution over time. It documents mitigation strategies' similarities and differences along categories of policy instruments. The analysis also provides initial insights on the combination of mitigation policies, implemented so far, that can generate synergies rather than offsetting each other.

The analysis exploits the rich policy repository of the Climate Actions and Policies Measurement Framework (CAPMF). As detailed in Section 2, the CAPMF is the most comprehensive, structured and harmonised mitigation policy database to date, covering more than 120 sectoral, cross-sectoral and international policy instruments and 50 countries over 2000-20 (Nachtigall et al., 2022[3]).[3] The richness of the data makes it possible to consider, at the same time, the range of policy instruments in force in a given country at a given point in time and their level of stringency.

The identification of countries' mitigation policy strategies relies on statistical cluster analysis performed on the latest available year (2020). As detailed in Section 3, hierarchical cluster analysis can convey, in a concise way, key information on multidimensional and complex data, such as mitigation policy repositories, and facilitates exploring and uncovering common patterns. The types of mitigation strategies identified in this way reflect similar policy instruments and similar levels of stringency across countries within the same cluster.

The cluster analysis yields four types of distinctive mitigation strategies detailed in Section 4. Cluster 1 strategies consist of limited climate policies across most policy categories and sectors. These strategies favour non-market-based instruments, especially minimum performance standards, labelling requirements, bans and phase-outs, over market-based instruments. Cluster 2 strategies feature a heterogeneous set of interventions, including fairly high subsidies for low-carbon technologies. Cluster 2 strategies have no or low carbon- and fuel excise taxes. The use of emission trading schemes (ETS) is uneven with some countries within this cluster using ETS (with high coverage and price) while others not using it at all. Bans and phase-outs are rarely used within Cluster 2 mitigation strategies. Cluster 3 strategies cover several policy categories, including fairly stringent ETS and moderate feed-in tariffs. However, the level of stringency of some key policies (e.g. carbon taxes, energy efficiency subsidies) and sectors (e.g. transport and electricity) remains modest. Cluster 4 strategies entail the most comprehensive policy mixes to date, featuring stringent policies across a wide range of policy categories and sectors. Numerous country specific assessments suggest that despite their comparative strength, even Cluster 4 strategies might still fall short of meeting emission countries' reduction targets.[4]

Until 2005 only Cluster 1 type mitigation strategies existed, reflecting limited use of mitigation policies and low overall policy stringency around the world. From 2005 onwards, some countries evolved towards

[3] The database covers OECD members (excluding the United States), OECD accession candidates and remaining G20 countries.

[4] See, among others, example for Denmark (Barker et al., 2022[49]), France (OECD, 2021[48]), Germany (Krill, Grundke and Bickmann, 2023[50]), Canada (Conigrave, 2023[51]), as well as Switzerland, New Zealand (Climate Action Tracker, 2023[47]) among others)

Cluster 3 strategies, as a result of the emergence of emission trading schemes in some countries and the gradual increase in subsidies for low-carbon technologies. Two additional mitigation strategies emerged after 2010, as countries diversified their climate policy portfolio. The most ambitious European countries moved from Cluster 3 to Cluster 4 while some non-European countries adopted richer and more stringent policy mixes, moving from Cluster 1 to Cluster 2. Countries with currently Cluster 4 strategies have progressively increased and broadened their emission pricing scheme (through taxes or emission trading schemes) and introduced phase-outs and bans, to a larger extent than the other groups. In contrast, Cluster 1 countries have over time reinforced the use of standards but made less progress with regard to other instruments. All groups have strengthened international climate commitments (within the United Nations Framework Convention on Climate Change (UNFCCC) and other initiatives) and reinforced their national climate governance, such as by establishing emission targets and establishing climate advisory bodies. Overall, this suggests that mitigation strategies have diverged over time as countries have implemented different types of mitigation policy mixes.

Finally, regression results reported in Section 5 indicate that countries' emissions are negatively associated with the overall stringency of mitigation strategies and that this relationship is stronger for policy mixes comprising a larger set of mitigation instruments. For the same overall level of policy stringency, countries with Cluster 3 and 4 strategies see larger emission reductions than Cluster 1 and 2 strategies. While the results do not show a causal relationship, they suggest that more comprehensive policy mixes may enable countries to reduce emissions at lower levels of overall stringency than otherwise.

Overall, the wide diversity in countries' mitigation strategies and the initial evidence pointing to the different policy synergies they can generate motivate future research. Investigating in detail the interactions among specific policies and identifying specific sources of possible synergies and overlaps could help policymakers to identify and design more cost-effective mitigation strategies. The diversity in countries' mitigation strategies also raises concerns in some countries on carbon leakage and the international competitiveness of domestic industries. Assessing and managing such risks requires further work to track the evolution of the array of policies composing countries' mitigation strategies and to assess their impact on emissions and economic activity. This paper lays the groundwork for future analyses in these directions.

2. The CAPMF policy inventory: description and trends

The Climate Actions and Policies Measurement Framework (CAPMF) is to date the most comprehensive, structured and harmonised climate mitigation policy database. The raw data covers 128 policy variables across 50 countries (plus the European Union) over 2000-2020. The countries in the database account for more than 73% of global GHG emissions. Currently, the CAPMF stock-taking exercise covers 75% of the instrument types listed in the policy framework of the 2022 Intergovernmental Panel on Climate Change (IPCC) Working Group III report (IPCC, 2022[6]). It does not yet cover policy instruments for agriculture, forestry and land use (i.e. AFOLU) and the waste management sector. These will be added in future updates.

The CAPMF policy inventory covers sectoral, cross-sectoral and international climate-relevant actions and policies. It includes actions and policies that have an explicit intent of lowering emissions as well as those that have an expected effect on emissions without this being their explicit goal. Sectoral policies (covering electricity, transport, industry and buildings) are grouped into market-based instruments and non-market-based instruments, following the classification adopted in previous OECD work, including the OECD Environmental Policy Stringency index (Botta and Koźluk, 2014[20]; Kruse et al., 2022[2]; Nachtigall et al., 2022[3]). This classification framework does not affect the cluster analysis described in the next section. The complete list of policies is available in Annex A. Box 1 provides information on the data sources on which the CAPMF relies.

Box 1. The CAPMF data collection

The CAPMF sources data from within and outside the OECD. Data sources include information from policy databases such as the OECD Policy Instruments for the Environment database (OECD, 2021[21]), the IEA Policies and Measures database (IEA, 2021[22]) and the International Transport Forum's Transport Climate Action Directory (ITF, 2021[23]). The CAPMF draws on other official data, including from the United Nations Statistical Division, the United Nations Framework Convention on Climate Change and the World Bank (see Annex A for more details). In the future, the coverage of policies could expand to include adaptation policies.

Source: Nachtigall et al. (2022[3])

An overview of climate actions and policies

The CAPMF broadly follows the classification of policies and measures used in UNFCCC synthesis of countries' biennial reports (UNFCCC, 2020[24]). It aligns with other OECD policy inventories such as the OECD PINE database (OECD, 2021[21]) and the OECD Environmental Policy Stringency (EPS) Index (Botta and Koźluk, 2014[20]; Kruse et al., 2022[2]). More specifically, the CAPMF organises climate policies and actions into three building blocks: sectoral policies, cross-sectoral policies, and international policies (Nachtigall et al., 2022[3]). Sectoral policies apply to a specific source or economic sector and are divided into market-based instruments and non-market-based instruments. Cross-sectoral actions and policies cut across instead more than one emission source or sector, such as fossil fuel production policies and innovation policies. International actions and policies refer to policy commitments associated with international covenants or agreements (e.g. participation in international climate agreements, international climate public finance).

The types of policies included in the three CAPMF's building blocks broad are:

Sectoral climate actions and policies: market-based instruments

- **Emission pricing:** This instrument sets a direct price on emissions. It includes carbon taxes and emissions trading schemes (ETS) at both national and sub-national levels. The CAPMF records separately the rate of the carbon tax or the permit price (in nominal rates) and the coverage of explicit carbon price (i.e. the GHG emission base to which the carbon price applies to). It tracks carbon pricing instruments separately across sectors.
- **Fuel excise taxes:** These impose an implicit carbon tax as they set a price on units of fuel, which is proportional to the carbon content and the resulting emissions.
- **Other GHG reduction charges:** These are climate-change relevant policies applying to specific activities or in certain situations, such as congestion charges in urban areas.
- **Support policies for renewable electricity:** These include specific policies, such as feed-in-tariffs (FiTs), auctions and renewable portfolio standards with tradeable renewable certificates, aiming at fostering renewable energy sources in electricity generation. For FiTs and auctions, the level of the support price is scaled by the levelised cost of electricity (LCOE) to reflect falling technology costs.
- **Financing mechanisms for energy efficiency:** These include financing schemes that facilitate the deployment of technologies and tools to increase energy efficiency, such as preferential loans or risk guarantees in the industry and residential buildings sectors.

Sectoral climate actions and policies: non market-based instruments

- **Standards:** This category includes both voluntary and mandatory building energy codes, emission limit values, and minimum energy performance standards. These standards play an important role in promoting the adoption of low-carbon technologies, energy-efficient assets (e.g. buildings), and equipment (e.g. passenger vehicles, appliances). Where available, the CAPMF includes the level of the emission limit and the performance requirements of the minimum energy performance standards.

- **Bans and phase-outs:** These consist of time limits to the purchase or use of carbon-intensive technologies or energy sources (e.g. new coal power plants, internal combustion engine cars)**.** Bans refer to the prohibition on the purchase of or investment in new assets whereas phase-outs refer to the prohibition of using already existing assets. The CAPMF includes information on the year in which the ban or phase out of carbon-intensive technologies becomes effective and the legal status (e.g. announcement, in law, achieved).
- **Information instruments:** These include instruments, such as energy efficiency labels, that provide consumers with information on the environmental or emission performance of specific products or services.
- **Non-climate Instruments:** These cover non-climate instruments that however contribute to GHG emission reduction. Examples include motorway speed limits, public investment in rail infrastructure, and air pollution standards,

Cross-sectoral climate actions and policies

- **GHG emissions targets:** These cover the scope (e.g. coverage of sectors and GHGs) or the type of target (e.g. absolute reduction target or emission intensity target) for Nationally Determined Contributions (NDCs); and the institutional arrangement (e.g. in law or in policy document) and the year for net-zero targets.
- **Public Research Development & Demonstration (RD&D) expenditure:** These include six areas of public RD&D budget: energy efficiency, renewable energy, nuclear, carbon capture and storage (CCS), hydrogen and fuel cells, and power and storage technologies.
- **Fossil fuel production policies:** These include the amount of support for fossil fuel production following the OECD Inventory of Support Measures for Fossil Fuels (OECD, 2015[25]): bans and phase outs of fossil fuel extraction, where these exist; the number of policies to reduce fugitive methane emissions in the energy sector such as technology standards and regulations related to leak detection and repair as well as flaring and venting.
- **Climate governance:** This covers information on independent advisory bodies, such as their legal status and staff size.

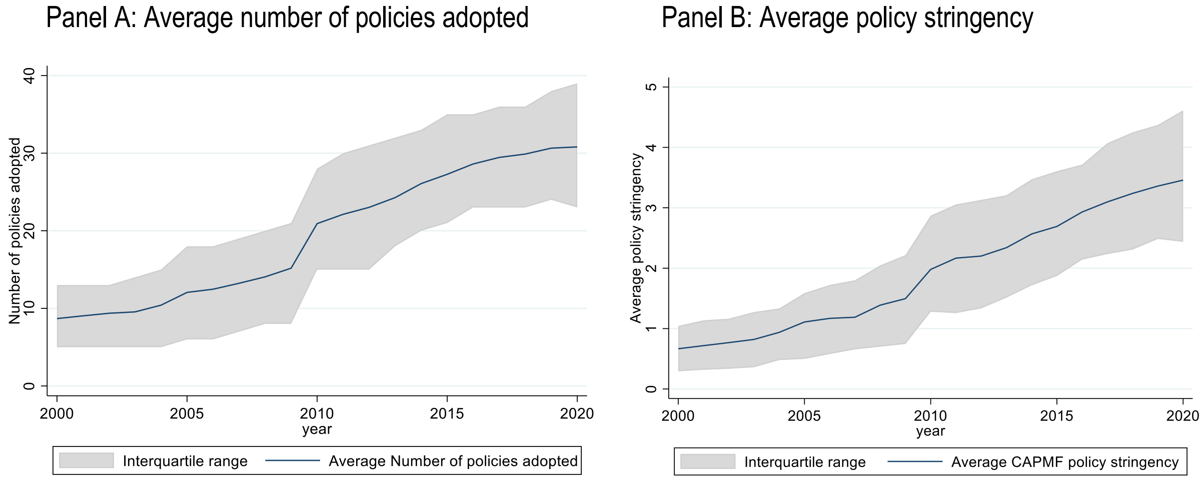
International actions and policies

- **GHG emissions data and reporting:** The CAPMF uses information provided in the reports of the respective UNFCCC Technical Expert Groups to assess the transparency of countries' emission reporting. In addition, it includes the timeliness of mandatory UNFCCC submissions, (Baettig, Brander and Imboden, 2008[26]; Bernauer and Böhmelt, 2013[27]) information of whether or not countries compile GHG emissions accounts, following the System of Environmental-Economic Accounting (SEEA)
- **International climate co-operation:** The CAPMF measures countries' participation in major international climate agreements, such as the Montreal Protocol and Paris Agreement. Furthermore, it covers participation in selected international co-operative initiatives (e.g. Climate and Clean Air Coalition) as a proxy for countries' efforts towards multilateral climate cooperation. This block also includes emissions pricing from international aviation and maritime transport along with participation in the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which is voluntary in the first phase from 2021-2023.
- **International public finance:** This block includes commitments such as banning export credit support for new unabated coal power plants and public finance for unabated fossil fuel infrastructure abroad.

Trends in climate actions and policies

Between 2000 and 2020, all countries increased the number of climate policies (as covered by the CAPMF). Countries adopted mitigation policies at different speeds, as suggested by the increasing dispersion in the number of adopted policies (Figure 1, Panel A). In 2020, the average country in the database had 31 policies in place (out of a total of 56). No country has adopted all policies tracked by the CAPMF. The number of policies adopted in 2020 varies from 13 in Peru to 45 in France. Policy stringency (measured by the CAPMF and averaged across policies, as discussed in Section 5) rose steadily over time but at a difference pace across countries (Figure 1, Panel B).

Figure 1. Countries have ramped up climate action between 2000 and 2020



Note: The jump in 2010 is due to some data becoming available only from 2010 (e.g. data on fossil fuel subsidy reform, data from the World Bank Regulatory Indicators for Sustainable Energy (RISE) database). The overall level of stringency is the average stringency of policies included in the CAPMF repository computed for each country and year as in Nachtigall et al. (2022[3]) and Nachtigall et al. (forthcoming[28]). Computing the average level of policy stringency is based on the scores, ranking from 0 (no policy) to 10 (strict policy). Using the scores makes it possible to aggregate policies measured in different units into a single metric.
Source: Authors based on Nachtigall (2022[3])

Policy adoption of sector-specific instruments varies across countries, as illustrated by the transport sector (Table 1). Only four countries have adopted (city-level) congestion charges and included the transport sector in ETS. A few countries (18) have adopted carbon taxes while some others (14 countries) have announced or legislated bans or phase outs of passenger cars with internal combustion engines (ICE). The adoption of these policies is more common across OECD than non-OECD countries. Most countries have adopted fuel economy standards, energy labels for passenger cars, fuel excise taxes and speed limits on motorways.

Table 1. Example from the transport sector: adoption of policy instruments varies across countries

Transport sector policy	Number of countries with policy	Share of countries in CAPMF inventory
Congestion charges	4	8%
Emissions trading scheme	3	6%
Ban and phase out of passenger cars with ICE	14	27%
Carbon tax	18	35%
Public investment in rail infrastructure	31	61%
Fossil fuels subsidies reform	33	65%
Fuel economy standards	39	77%

Energy labels for passenger cars	40	78%
Fossil fuels excise taxes	43	84%
Speed limits on motorways	44	86%

Note: The table provides an example of policy adoption in the transport sector for policies and countries included in the CAPMF data repository. The reference year is 2020.
Source: Nachtigall et al. (2022[3]).

3. Data and methods for cluster analysis

Data and policy dissimilarity measures

The cluster analysis relies on the CAPMF data for the year 2020 across 50 countries (Nachtigall et al., 2022[3]; Nachtigall et al., forthcoming[28]).[5] For the data analysis, the original CAPMF data has been cleaned as follows. The European Union is excluded as an individual jurisdiction as all EU countries are included separately. Variables related to policies that are equal across countries in 2020 (such as participation in the Montreal Protocol) are excluded, as they provide no useful information for the cluster analysis. Four variables concerning reforms of fossil fuel subsidies are also excluded because information is missing for some countries and cannot be imputed.

For the remaining variables, the CAPMF might record a missing value in 2020 if information is not available. These were imputed as follows. The latest available data is used for ten variables whose value is missing in 2020 but is available in recent years.[6] Data for Japan, Luxembourg and New Zealand refers to 2019. In the remaining cases (about one quarter of the observations), a missing value can be reasonably attributed to the absence of the policy in the country. Therefore, the value of zero is used when this has economic meaning (e.g. a carbon price equal to zero) or a large value (implying low stringency) is imputed, when a ban date has not yet been set or a performance standard is not defined, following a simple rule (e.g. the year 2077 is imputed for countries without a net-zero target date).[7] This assumption could lead to underestimate stringency in case a policy exists but there is no available information regarding its stringency (i.e. the value is missing).

The final dataset used for the cluster analysis consists of 108 policy variables, of which 54 are standardised continuous variables, 31 are standardised ordinal variables and 23 are dummy variables. Cluster analysis is then applied on the matrix of dissimilarity measure in climate policy variables calculated for each pair of countries. The dissimilarity measure reflects differences in policy adoption and stringency between two countries' mitigation strategies in 2020. Two countries' mitigation strategies that are dissimilar along one policy variable have different values for that policy variable, either because one country has adopted the policy and the other has not or because both have adopted it but with different stringency levels. Because of the nature of the data, this dissimilarity measure does not differentiate between differences in adoption

[5] The data used for the analysis is based on information updated in February 2023. At the time of writing, the CAPMF is being updated in preparation for publication. The published version may therefore slightly differ from the one used in this paper.

[6] Data for "Planning for renewables expansion", "Financing mechanisms for energy efficiency" (Industry and Buildings), "Energy efficiency mandates ", "Minimum energy performance standards for heavy duty vehicles", "Submission of BUR by non-Annex I countries" are imputed with 2019 data. Feed-in tariffs (price and duration) for solar photovoltaic and wind data are imputed using 2015 data, because the series presents missing data in the following years that cannot be imputed reasonably assuming absence of policy.

[7] The imputed value is equal to the least stringent value observed plus (or minus where appropriate) half the difference between this value and the observed mean. This simple rule ensures that imputed (extreme) values still conform with the observed values for ban dates and performance standards.

and differences in stringency of policies.[8] The sum of the pairwise differences across the 108 policy variables is the overall policy dissimilarity measure between two countries' mitigation strategies.

More in detail, Gower's (1971[29]) general dissimilarity coefficient is used to calculate the dissimilarity measure between mitigation strategies. This coefficient produces pairwise distances between the mitigation strategies of country i and country j, based on the sum of differences in each policy. Distances take values between zero (least dissimilar/most similar) and one (most dissimilar/least similar) since variables are normalised. Gower's coefficient of dissimilarity allows for mixed data, which includes continuous, ordinal and binary variables and is based on different types of distance, depending on variable types.

Gower's dissimilarity coefficient is the sum of two distances, $d_L(i,j) + d_J(i,j)$ depending on variable types. For the p continuous and ordinal variables, the distance between the mitigation strategies of country i and country j is the L_1 distance:

$$d_L(i,j) = |x_{i1} - x_{j1}| + |x_{i2} - x_{j2}| + \cdots + |x_{ip} - x_{jp}| \qquad (1),$$

where x_{kn} are standardised variables.[9] That is, $d_L(i,j)$ is the sum of the (absolute value) of the differences in each p variable between country i and country j.

For the q binary variables, the distance between mitigation strategy i and j is the Jaccard distance:

$$d_J(i,j) = \frac{M_{11}}{M_{01} + M_{10} + M_{11}} \qquad (2),$$

where M_{11} is the number of variables with value of 1 in country i and j, M_{01} is the number of variables with value of 0 in i and 1 in j and M_{10} is the number of variables with value of 1 in i and 0 in j.

Gower's dissimilarity coefficient is the sum of the two distances above: $d_L(i,j) + d_J(i,j)$. The Gower's dissimilarity measure takes values between 0 (least dissimilar/most similar) and 1 (most dissimilar/least similar) since variables are normalised.

A diagonally-symmetric distance matrix can help to visualise dissimilarities of mitigation strategies among countries (Figure 2). Romania and Bulgaria, at the centre of the matrix, have the most similar mitigation strategies: they share several market-based and non market-based instruments, mostly adopted at the European Union level. They also have comparable fuel taxation in most sectors, cross-sectoral policies, climate governance and involvement in international agreements. In contrast, France and India have the most dissimilar strategies, differing along many dimensions such as most market-based instruments, the use of targets and bans, support for renewable energy sources and standards for air pollutants. Visual inspection of the distance matrix suggests the potential presence of at least three distinct groups of countries with similar policies, a large one in the south-west portion of the graph, one in the north-east portion of the graph and one in the centre.

[8] For example, assuming stringency varies from 0 to 10, this dissimilarity measure would be the same in the two following cases. One country has not adopted the policy (i.e. stringency value of zero) while the other adopted it with stringency value of two; both countries adopted the policy, one with stringency value of ten and the other of eight. In both cases the difference in stringency is two.

[9] Additionally, for ordinal variables, in case of a tie (two equal values) Podani's (1999[46]) generalisation is applied.

Figure 2. Policy dissimilarity matrix

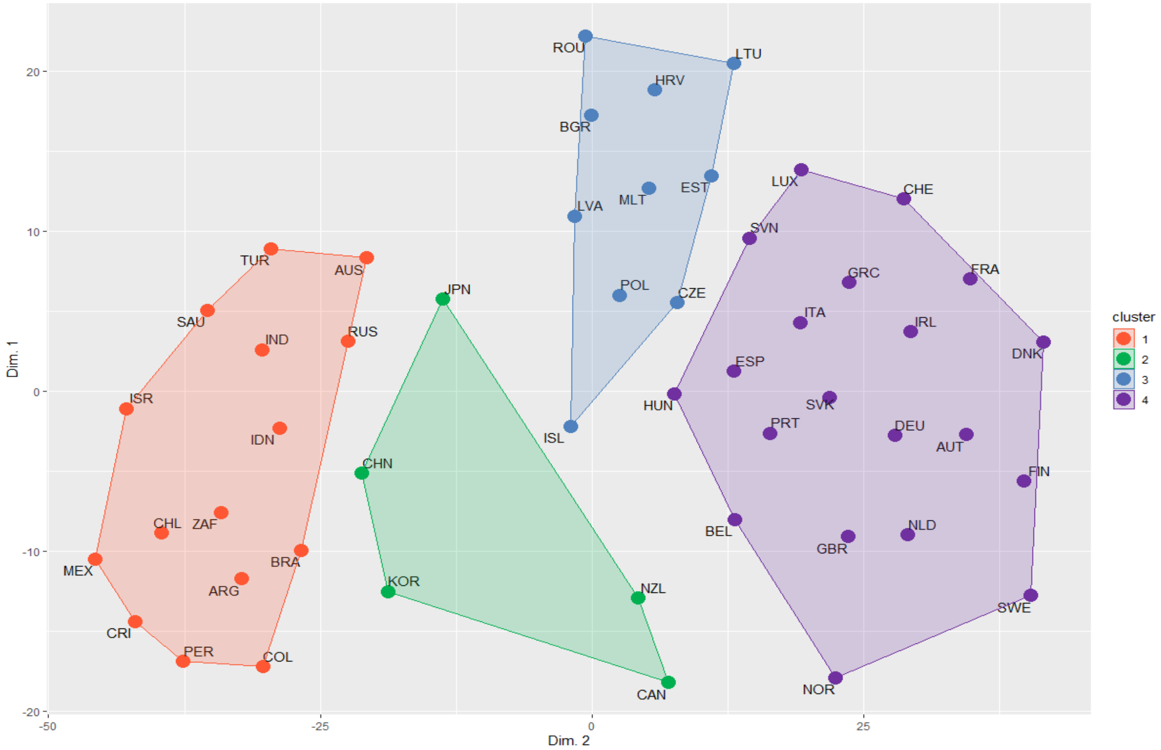
Note: Gower's dissimilarity coefficient based on 2020 data. Values between zero (least dissimilar/most similar) and one (most dissimilar/least similar). The matrix is diagonally symmetric and it is approximately ordered to group countries with low dissimilarity together.
Source: OECD.

Clustering results

Applying cluster analysis to the pairwise matrix of dissimilarities in mitigation strategies computed on CAPMF data makes it possible to identify broad types of mitigation strategies. The analysis employs agglomerative hierarchical clustering with Ward's minimum variance method. Details about the methodology and robustness checks are in Annex B.

The analysis considers four clusters, striking a balance between interpretability of results and stable and clearly separated (in statistical terms) clusters. The four clusters can be represented in a two-dimensional chart that preserves as much as possible the distances between the clusters (Figure 3). There is a clear divide between Cluster 1 and Cluster 2, on the one hand, and Cluster 3 and 4, on the other, which is also supported by statistical tests. Cluster 2 is the less compact of the four, and further dividing clusters would separate Japan, Korea and China on one side and Canada and New Zealand on the other, as also suggested by the dendrogram in Annex B. No information is lost in pursuing the analysis with four clusters instead of two and the discussion and conclusions that follow can be aggregated up to the two large clusters.

Figure 3. Standardised distances between countries across clusters



Note: The n-dimensional Gower's distances (where $n = 50 \times 50$ pairwise distances) are embedded in a 2-dimensional space using Barnes-Hut t-Distributed Stochastic Neighbour Embedding (tSNE). The 2 dimensions of the graph are unitless and are not interpretable in terms of the variables used for the cluster analysis (i.e. mitigation polices in this case). The clusters are based on 2020 data.
Source: OECD.

There is a clear relationship between the geographical area of countries and the types of mitigation policies they adopted as of 2020. All European countries adopt a Cluster 3 or Cluster 4 mitigation strategy. Most Central and Eastern Europe countries adopt Cluster 3 mitigation strategies, while Western European countries adopt Cluster 4 type. Most European countries in these clusters may have adopted similar mitigation policies, ostensibly because of EU policy reforms. Latin American countries have all adopted Cluster 1 mitigation strategy, along with Australia, India, Indonesia, Israel, Russia, Saudi Arabia, South Africa and Türkiye. A geographically heterogeneous group of countries follow Cluster 2 type strategies, which includes three Asian countries (China, Japan and Korea), New Zealand and Canada. A description of the four clusters follows in the next section.

4. Documenting mitigation strategy types

Qualitative and quantitative approaches can be used to uncover commonalities and differences among the mitigation strategy clusters identified above. A policy instrument that is adopted with similar level of stringency by all countries within a cluster (i.e. low within-cluster variance) but having large differences in stringency across clusters (i.e. high between-cluster variance) contributes the most to the cluster structure. Furthermore, comparing mean values of policy stringency along common policy categories, such as market and non market-based instruments, sectoral versus cross-sectoral and international policies, also helps to uncover commonalities and differences among mitigation strategies. These quantitative criteria combined with qualitative ones make it possible to identify which policy categories are most commonly employed across countries within each cluster and which ones differentiate clusters the most.

This analysis leads to the following observations:

- Cluster 1 strategies exhibit comparatively weak stringency across most policy instruments. These strategies focus on few policies, such as minimum performance standards and energy-efficiency financing mechanisms. Policy intervention is concentrated in few sectors, usually industry;
- Cluster 2 strategies feature a more diverse use of instruments, albeit in few policy categories. These strategies include relatively generous subsidies, specifically feed-in tariffs and energy efficiency subsidies. Cluster 2 strategies have no or low carbon and fuel excise taxes while the use of emission trading schemes (ETS) is uneven.[10]
- Cluster 3 strategies cover several policy categories, including fairly stringent emission trading schemes and moderate feed-in tariffs. However, the stringency across some key policies (e.g. carbon taxes and energy efficiency subsidies) and sectors (e.g. transport and electricity) remains modest;
- Cluster 4 exhibit the most varied policy mix and most stringent policies (compared to the other clusters).

Differences in policy categories across mitigation strategies

To describe the variety of policies of the different mitigation strategies, the 108 policy variables used in the cluster analysis were grouped into seven policy categories (Table 2). These policy categories are based on those used in the CAPMF (section 2) with few differences. These are the following: the market-based instrument category is divided in two (taxes and ETS) as the non market-based instruments (standards or phaseouts and bans);[11] the category ‘subsidies and other public expenditures’ (not used in the CAPMF) collects a mix of market-based (such as FiTs) and other instruments (such as public subsidies to RD&D). These differences from the CAPM classification allow for better characterising and differentiating clusters.

Overall, the policy instruments that differentiate countries' mitigation strategies the most are emission pricing (carbon taxes and emission trading schemes), fuel excise taxes, public expenditure to support innovation, and the use of bans and phase-outs.

Mitigation strategies in Cluster 1 are narrow in terms of policy range and have lower level of stringency than the other types of mitigation strategies. They do not rely - or rely only to a limited extent - on market-based instruments and feature low levels of subsidies, mostly limited to energy efficiency. Cluster 1 strategies often include financing mechanisms (e.g. preferential loans) for improving energy efficiency; they also favour standards, especially minimum performance standards, labelling requirements, bans and phase-outs but these are often loosely binding relative to other strategies. Although strategies in this cluster have strengthened commitments to international initiatives, they remain low, compared to the other mitigation strategies type, and most still lack clear GHG reporting.

Cluster 2 mitigation strategies concentrate interventions in some policy categories. These strategies feature fairly generous subsidies, specifically via feed-in tariffs and energy efficiency subsidies. They also employ standards (at moderate level of stringency), focussing on minimum energy performance standards (MEPS) and energy efficiency mandates, but include only few bans on fossil fuel extractions. These strategies have no or low carbon and fuel excise taxes. However, some strategies within Cluster 2 use

[10] Within cluster 2 some strategies employ ETS with relatively high stringency, while other strategies within Cluster 2 do not use ETS. Bans and phase-outs are rarely used within these mitigation strategies

[11] Standards are instruments that require the use of specific technologies, or that limit the maximum amount of energy or emissions from an activity or technology. Bans and phase-outs are regulatory instruments that mandate the cessation of the purchase (ban) or the usage (phase out) of certain activities.

emissions trading schemes (with high stringency), while others do not use them at all. Strategies in this cluster tend also to have weaker climate governance, nationally determined contributions and net-zero targets than other clusters. Overall, cluster 2 strategies have scope to expand and broaden their policy mix, by for instance strengthening carbon taxes, introducing bans and phase-outs, and reinforcing climate governance.

Table 2. Mitigation strategies by policy category

Policy category	Policy variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Market based instruments: Taxes	Carbon taxes and excise taxes on fossil fuels	Mixed carbon taxes and low fuel excise taxes	Low carbon taxes and low fuel excise taxes	Low carbon taxes and mixed excise taxes	High carbon and fuel excise taxes
Market based instruments: ETS	ETS permit price and coverage by sector	Almost no ETS	Heterogeneous use of ETS with some high and some moderate coverage and price	Fairly high coverage of ETS and high prices	High coverage of ETS and high prices
Subsidies and other public expenditures	Energy efficiency (EE) subsidies, feed in tariffs (FiT) for solar/wind, public RD&D expenditure	No use of FiT High EE subsidies No RD&D expenditure	Fairly high FiT High EE subsidies No RD&D expenditure	Moderate FiT Low EE subsidies Low RD&D expenditure	High FiT Moderate EE subsidies High RD&D expenditure
Non market-based instruments: Bans and Phase-outs	Date and legal status of bans and phase-outs of fossil fuel uses, fossil-fuel extraction, internal combustion engine (ICE) sales	Few (e.g. ban on unabated coal power plants[12])	Few (e.g. ban on fossil fuel extraction)	Few (e.g. phaseout of fossil fuel use)	Many, although sometimes without concrete date
Non market-based instruments: Standards	Air Emission Standards, Building Energy Codes, Vehicles performance standards (MEPS), Energy Efficiency Mandates, Fugitive Emissions, Speed Limits	Low overall standards, concentrated in policies for fugitive emissions and emission limit values	Moderate overall standards, concentrated in MEPS and energy efficiency mandates	Mixed overall standards, concentrated in Emission Limit values and MEPS	High overall standards, concentrated in Building Energy Codes and MEPS
Climate Institutions	Climate Governance and GHG Targets (NDC and Net Zero Targets)	Moderate climate governance, weak NDCs and Net Zero Targets	Moderate climate governance and moderate NDCs and Net Zero Targets	Weak climate governance Strong NDC and moderate Net Zero Targets	Strong climate governance Strong NDC and Net Zero Targes
International Commitments	International Climate Coordination and GHG Reporting	Low participation in international Initiatives low GHG reporting	Medium participation in International Initiatives and GHG reporting	High participation in International treaties and GHG reporting, but low participation in international initiative	High participation in International Initiatives and GHG reporting

Note: Darker colours indicate more stringent climate policies.
Source: OECD.

[12] Unabated coal power plants refer to power plants that are not equipped with carbon capture utilisation and storage (CCUS) technologies or non-CCUS emission abatement technologies, which may be developed in the future (OECD, 2021[52]).

Cluster 3 mitigation strategies employ market-based policy instruments, focusing more on fuel excise taxes and emission trading schemes than other strategies, and some non-market-based policies, including mandatory energy labelling for appliances and phase-outs of internal combustion engine vehicles. Mitigation strategies in Cluster 3 employ relatively low levels of subsidies. Overall, Cluster 3 mitigation strategies include a richer mix of instruments than Cluster 1, though the scope and strength of their policy mix is lower than Cluster 4. Cluster 3 and Cluster 2 have similar level of overall stringency but employ a different mix of policy instruments.

Cluster 4 mitigation strategies present a more diverse set of policies and higher stringency than the other mitigation strategies. The strategies in this cluster make a more extensive use of market-based instruments (especially carbon taxes, emission trading schemes and fuel excise taxes) than other strategies. These are accompanied by a mix of other instruments, such as subsidies, bans and phase-outs, standards and good climate governance. These strategies stand out for relatively stringent phase-outs of internal combustion engine cars and coal power plants and strong policy support to innovation. All European Union countries adopt either Cluster 3 or 4 strategy.

Differences in sectoral policy instruments across mitigation strategies

Climate strategies differ in their sectoral focus, especially regarding the buildings and transport sectors (Table 3). This subsection compares mitigation strategies focusing only on differences in the stringency of sectoral climate action and policies.

In the buildings sector, Cluster 4 strategies include the phase-out of fossil fuel heating systems, generally absent in other strategies, as well as stringent building energy codes, some carbon taxes and excise taxes on residential fuels. Cluster 2 and 3 strategies encompass stringent building energy codes and moderate to high pricing policies, including carbon pricing and excise taxes. Cluster 1 strategies have very limited intervention in the buildings sector, with the sole exception of financing mechanisms (e.g. providing preferential loans, risk guarantees) for energy efficiency.

In the transport sector, Cluster 4 mitigation strategies stand out for the most varied policy mix, with highest reliance on market-based policies (mostly through high carbon- and fuel taxes) and the phase-outs of internal combustion engine vehicles. The other strategies encompass fewer policy instruments and demand lower stringency, with Cluster 3 strategies favouring excise taxes and public investments in rail transport and Cluster 2 strategies featuring moderate levels of internal combustion engine phase-outs and speed limits, but limited investments in rail infrastructure. Cluster 1 strategies have low levels of market-based policies and only few internal combustion engine phase-outs.

In the electricity sector, both Cluster 2 and 4 strategies have high levels of stringency, although the choice of instruments generally differs. Cluster 2 strategies have low levels of carbon pricing but generous renewable energy support policies. The opposite is true for Cluster 4 strategies, which have a significantly higher share of renewable energy in the energy mix (as discussed below). Both have stringent air quality standards. Cluster 1 and 3 strategies encompass a variety of policy instruments in the electricity sector. Cluster 3 has ample scope to increase their stringency.

Industry is the sector with the most homogenous level of ambition across clusters 2, 3 and 4, though specific policy instruments differ. Cluster 1 strategies have low carbon pricing, low minimum energy performance standards (MEPS), but fairly high levels of energy efficiency mandates and financing. Cluster 2 and 3 strategies have similar levels of policy ambition for this sector, with the former featuring higher energy efficiency mandates. Both clusters employ relatively stringent carbon pricing in the sector and fairly high MEPS. Cluster 4 has an overall high level of stringency, due to relatively stringent carbon pricing, the most stringent MEPS, and the use of some energy efficiency mandates.

Table 3. Mitigation strategies by sectoral focus

Sector	Policy variables	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Buildings	Carbon pricing and excise taxes, Bans and phase-outs, Energy codes	No or low CO_2 pricing and moderate excise taxes Few Bans Low energy codes	High CO_2 pricing but low excise taxes Few Bans High energy codes	Moderate excise taxes Few Bans High energy codes	Moderate to high CO_2 pricing and excise taxes Stringent Bans High energy codes
Transport	Market-based policies (Carbon pricing, excise taxes and congestion charges), Internal combustion engine phase-outs, Other (rail investment, speed limits)	Low market-based policies Some ICE phase-outs Moderate Other	Mixed market-based policies Moderate Internal combustion engine phase-outs Mixed Other	Mixed market-based policies Some Internal combustion engine phase-outs Mixed Other	High MBIs Some Internal combustion engine phase-outs High Other
Electricity	Carbon pricing and excise taxes, RES support and planning, Standards	MixedCO_2 pricing Mixed RES support and planning Low standards	Low CO_2 pricing High RES support and planning Fairly high standards	Mixed CO_2 pricing Mixed RES support and planning Moderate standards	High CO_2 pricing Moderate RES support and planning High standards
Industry	Carbon pricing and excise taxes, MEPS on industrial motors, energy efficiency mandates and financing	Low CO_2 pricing Low MEPS High energy efficiency mandates and financing	Moderate CO_2 pricing Fairly high MEPS High energy mandates and financing	Mixed CO_2 pricing Fairly high MEPS Low energy efficiency mandates and financing	High CO_2 pricing High MEPS Mixed energy efficiency mandates and financing

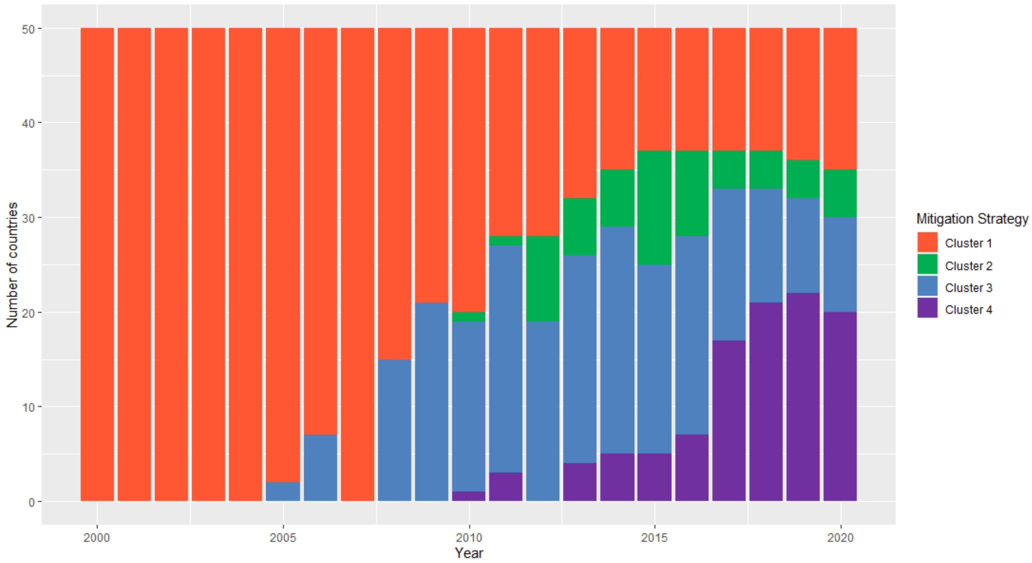
Note: Darker colours indicate more stringent climate policies.
Source: OECD.

The evolution of mitigation strategies

To assess the temporal evolution of mitigation strategies over time, a country was assigned in each year of the 2000-19 period to one of the clusters identified above using 2020 data. The assignment is based on the minimum squared distance between the country’s mitigation strategy in a specific year and the centre of each cluster (i.e. the cluster’s medoid). Each cluster’s medoid is the country’s mitigation strategy with the lowest sum of dissimilarities to all other countries within the same cluster. As such, it can be interpreted as the centre of the cluster or the representative mitigation strategy of that cluster. This methodology then allocates in each year a given country to the mitigation strategy type that most resembles its mitigation strategy in that year.

Up to 2005, all countries were pursuing mitigation strategies that were most similar to Cluster 1, reflecting lower ambition in fighting climate change, lower stringency and limited policy implementation. While differences across countries’ climate policies existed prior to 2005, these were not large enough to form a separate cluster. From 2005 onwards, some countries gradually started moving to Cluster 3, largely as a result of the implementation of emission trading schemes. From 2010, countries’ mitigation strategies diverged further, with the introduction of emission pricing and other market-based policies, as well as more stringent standards, e.g. air quality standards, forming Cluster 2 and Cluster 4. The most ambitious European countries separated from Cluster 3 into Cluster 4. Non-European countries that adopted a different policy mix and strengthened their climate policies formed Cluster 2.

Figure 4. The evolution of mitigation strategy adoption over time



Note: The figure shows the evolution of mitigation policies strategies between 2000 and 2020, countries were assigned to clusters established in the year 2020. The assignment of countries to clusters was based on minimizing the squared distance between a country, and the medoid country within each cluster.
Source: OECD.

Additional detail on the evolution of the different policy categories underscores commonalities and differences across the four types of mitigation strategies identified above (Figure 5). Overall, policies have become more stringent. Some trends are common across mitigation strategy types, such as the raising in standards and the improvement of climate change institutions starting from 2015. Yet, policies evolved differently within each cluster. The evolution of stringency by policy category for each country is depicted in Annex C.2. (Figure A C.2). Annex C (Figure A C.1) also shows the evolution of the average stringency of policy categories by clusters.

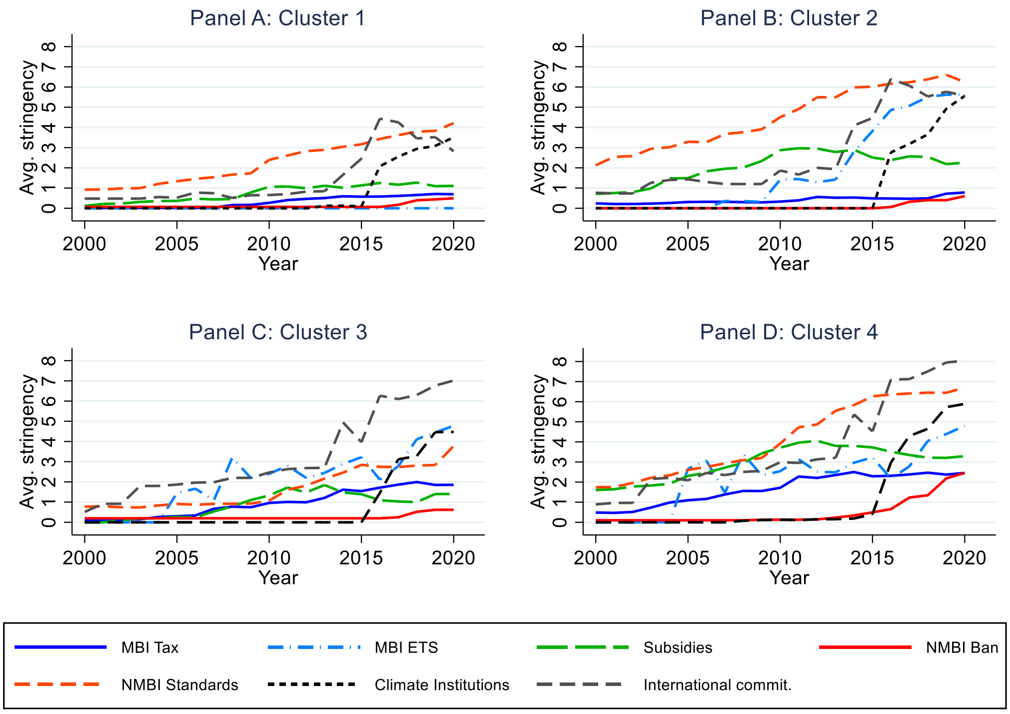
Countries with Cluster 1 mitigation strategies in 2020 have increased to moderate levels the use and stringency of non-market-based instruments (specifically standards) from 2010 onwards. The stringency of market-based instruments and the level of subsidies has remained relatively flat (Figure 5 panel A). Some bans and phase-outs of carbon-intensive technologies have also been introduced since 2017.

Countries with Cluster 2 strategies in 2020 have increased the stringency of standards to high levels. Subsidies reached generous level in the 2000s but have declined somewhat since 2010. Cluster 2 strategies have seen the introduction of emissions trading schemes in 2010, with a steep acceleration since 2013. The stringency of bans and carbon taxes has remained low. Cluster 2 is the smallest cluster, which means that changes in the mitigation strategy of individual countries may have a large impact on the cluster average (Figure 5 panel B).

Countries with Cluster 3 and 4 mitigation strategies in 2020 have complemented these trends with a marked increase in the use of market-base instruments (either taxes or ETS or both). Subsidies have increased noticeably though they retrenched from 2012, following reductions in the level of feed-in-tariffs and subsidies for renewable energy deployment. Bans and phase-outs of coal power plants and internal combustion engine vehicles have been expanded rapidly since 2015 (Figure 5 panel C and D).

Figure 5. The evolution of different types of mitigation strategies

Average stringency, scale 0 (least stringent) to 10 (most stringent)



Note: The figure shows the evolution of policy stringency by mitigation strategy adopted in 2020 (Table 2). The dark blue line shows the average stringency for carbon taxes (MBI stands for market-based instruments). The dashed light blue line shows the average stringency for Emissions Trading Schemes. The dashed green line shows the average stringency for subsidies (feed-in-tariffs, auctions, research and development support). The red line shows the average stringency for bans and phase-outs of coal power plants and combustion engine vehicles (NMBI stands for non-market based instruments). The dashed orange line shows the averages stringency of standards. The dashed black line shows the quality of climate institutions. The dashed grey line shows the stringency of countries' internationally commitments including their NDCs.
Source: OECD.

5. Assessing the relationship between mitigation policy strategies and emission changes

This section analyses the relationship between mitigation policy strategies and emission changes, first descriptively and then in a regression framework. Policy mixes reflect choices based on factors that may go well beyond the actual or perceived effectiveness of mitigation policies in reducing emissions. These choices may trade off climate-change mitigation considerations with other country specific economic and social priorities, political and social constraints, and the social acceptability of different policy measures or combinations thereof (Dechezleprêtre et al., 2022[12]). Moreover, countries have different starting positions and face specific circumstances, such as abatement potential depending on industrial structure. For example, a moderate carbon price could trigger large reductions in GHG emissions in countries with vast low-cost abatement potential. Conversely, a high carbon price may result in only marginal emission reductions in countries specializing in sectors (such as agriculture) with a paucity of viable low-carbon technologies.

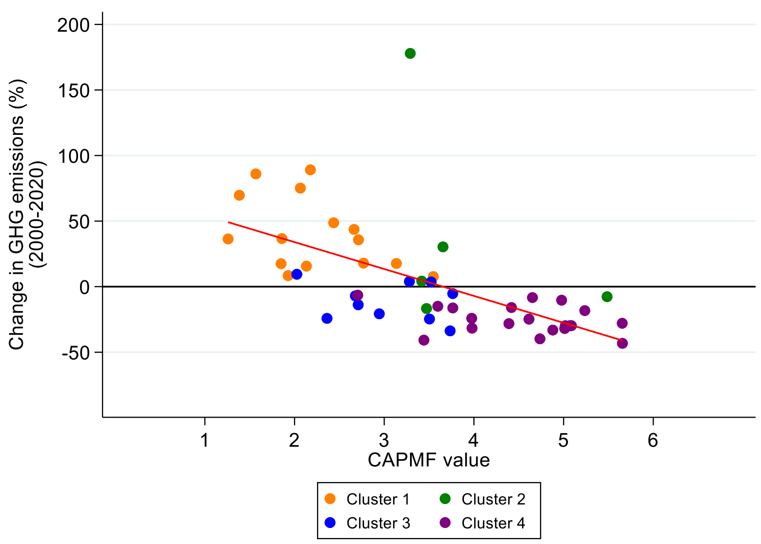
The effectiveness and cost-effectiveness of mitigation strategies depend on synergies and trade-offs across policies given specific national circumstances. A policy mix consisting of few policy instruments may be highly effective in reducing GHG emissions if these complement each other well. Conversely, a country with many policies in place might achieve only limited success in reducing GHG emissions if these policies generate “internal" carbon leakage (so that emissions shift from one regulated sector to a less regulated sector) or multiple policy instruments address the same market failures. For instance, new climate policies may have a reduced or no effect on a country’s emissions if there is already a cap on emission (e.g. an emission trading system), i.e. water bed effects (Böhringer and Rosendahl, 2010[17]; Rosendahl, 2019[30]).

The relationship between overall stringency and emission changes varies across mitigation strategy types (Figure 6). Average stringency varies across mitigation strategies and more stringent policy combinations are associated with larger reductions in emissions (panel A) and emission intensities (panel B)[13]. Cluster 3 and 4 mitigation strategies are associated with higher emission reductions than Cluster 1, whose emissions often increased between 2000 and 2020 (panel A). Cluster 2 has heterogeneous levels of policy stringency and changes in emissions, with some countries having increased emissions while some others having decreased them over the past two decades.

Emission reductions are associated with more stringent mitigation policies, but the composition of the policy mix appears to matter as well. The colour-coding tentatively suggests that this relationship is stronger for some mitigation strategies than for others. Cluster 1 (orange points) strategies are usually above the linear interpolation lines (Figure 6, panel A and B) whereas Cluster 3 (blue points) and Cluster 4 (purple points) strategies are generally below those lines. This means that for the same average level of mitigation policy stringency (measured on the x-axis), countries with Cluster 3 and 4 strategies experience a larger decrease in emissions (measured on the y-axis).

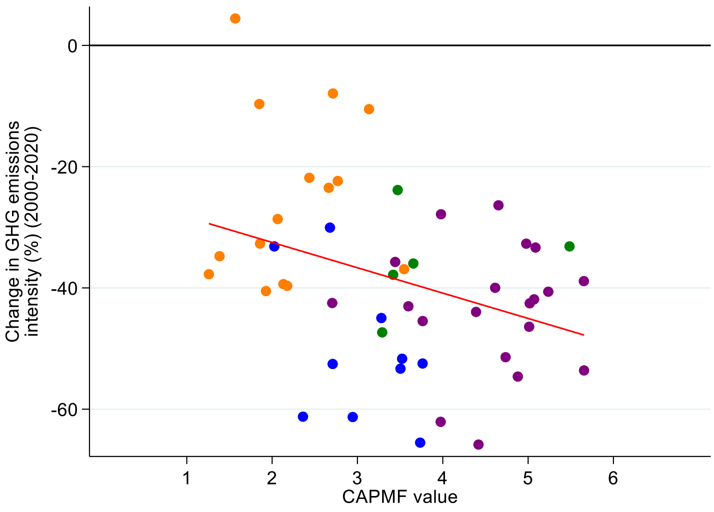
Figure 6. Relationship between clusters, overall policy stringency and emissions

Panel A: Change in GHG emissions (%) by cluster



13 Average stringency is defined as the average CAPMF score across all policies in a country-year, setting all missing values to zero.

Panel B: Change in GHG emissions intensity (%) (2000-2020)



Note: Panel A shows the change in CO2 emissions (in %) between 2000 and 2020 versus countries' CAPMF value in 2020. Panel B shows the change in CO2 emissions intensity (in %) between 2000 and 2020 versus the CAPMF value in 2020. Emission intensity is measured as CO2 emissions divided by GDP (measured in constant PPP 2017 international USD).
Source: Emissions data is from (Gütschow et al., 2016[31]). GDP data is from (WDI, 2021[32]) The CAPMF data is from (Nachtigall et al., 2022[3]) and based on authors' calculations.

Regression analysis on the effectiveness of climate change mitigation strategies

Socio-economic factors, including countries' economic structures, level of development and population, and policies' design may affect the negative correlation between overall stringency and emission reductions. A regression analysis can control for these confounders.

The regression analysis covers 48 countries (Peru and Romania were excluded because of missing data) and 20 years from 2001 to 2021. The overall level of stringency is the average stringency of policies included in the CAPMF repository computed for each country and year based on the CAPMF policy scores, ranking from 0 (no policy) to 10 (strict policy), as in Nachtigall et al. (2022[3]) and Nachtigall et al. (forthcoming[28]). This approach relates to prior works that have used a composite index to capture overall policy stringency. These cover for instance the OECD EPS index - to assess the effects of climate policies on emissions (Frohm et al., forthcoming[33]), employment (Dechezleprêtre, Nachtigall and Stadler, 2020[34]) and innovation in clean technologies (Dechezleprêtre and Kruse, 2022[35]) – and the OECD Effective Carbon Rates – to estimate the effect of carbon pricing on CO_2 emissions and government tax revenues (D'Arcangelo et al., 2022[36]).

The baseline empirical specification is the following:

$$GHG_{ct} = \beta \, \mathrm{CAPMF}_{ct-1} * Cluster_{c,2020} + X'_{ct}\gamma + \delta_c + \delta_t + \varepsilon_{ct}$$

where GHG_{ct} is the logarithm of the GHG emissions (excluding emissions from land use, land use change and forestry) in country *c* and year *t*. $CAPMF_{ct-1}$ is the overall policy stringency (computed as described above) and is standardised to have mean 0 and standard deviation 1. The use of a year-lagged CAPMF reduces concerns of simultaneity problems. $Cluster_{c,2020}$ is a categorical variable indicating one of the four mitigation strategies adopted by a country in 2020, as identified with the cluster analysis. The choice of control variables follows closely the existing literature (Best, Burke and Jotzo, 2020[37]; Eskander and Fankhauser, 2020[38]) These include several economic variables (all in 2017 constant USD and in PPP) to account for time-varying confounders, including (log) GDP, as well as (log) GDP squared to accommodate any nonlinear relationship emerging from an environmental Kuznet's curve (Andreoni and Levinson, 2001[39]), the Hodrick-Prescott decomposition to separate long term growth from cyclical fluctuations in GDP; the import share of GDP and the service share of GDP control for varying economic structure. Moreover, we include (log) population and a measure of Rule of Law sourced from the Worldwide Governance Indicators to control for enforcement of policies following Best, Burke and Jotzo (2020[37]).[14] Furthermore, the model includes both country fixed effects, δ_c, controlling for all time-invariant difference across countries, and year fixed effects, δ_t, controlling for time-specific shocks common across countries. As country fixed effects are present and the outcome is in logs, the estimated coefficients can be interpreted as percent variation from the country average.

Because the specification controls for output and population, this approach is tantamount to estimating the effect of policies on emission intensities (i.e. emissions per GDP unit and per capita). Adding output and population as a control is important because emissions are strongly associated with these variables.[15] On the other hand, including GDP as a control variable 'shuts down' a potential emission reduction channel as mitigation policies might reduce emissions by lowering GDP.

Emission data come from PRIMAP's national historical emissions time series (Gütschow et al., 2016[31]), which offers comprehensive country coverage and a transparent methodology. The results of the analysis do not vary when using data provided by Climate Watch (2022[40]) (see Table C.2. in Annex C). We use energy data from the IEA's World Energy Statistics and Balances to calculate energy intensity, which we include in one specification as a 'mediator' variable.

Higher overall stringency of the policy mix is associated with lower emissions, as suggested by the negative and statistically significant coefficients on CAPMF (Table 4, columns 1 and 2). A standard deviation increase in CAPMF is associated with a reduction of 13% in GHG emissions. The results are also robust to using CO_2 emissions (Table A C.1. in Annex C) or GHG emission intensity (Table A C.2. in Annex C). The point estimate indicates that the 2.3 points rise in CAPMF over the 2001-21 period was associated with a 30% reduction in emissions on average over the same period.

While it is difficult to establish causality at the country-level, the results suggest that the different types of mitigation strategies as identified by the cluster analysis have different effects on emissions for the same level of policy stringency. The coefficient estimates of CAPMF is largest for Cluster 3 and 4 strategies (Table 4, columns 2 and 3). A one standard deviation increase in the average policy stringency is associated with a 12.6% reduction in emissions for countries in Cluster 4 and a 9.2% reduction for those in Cluster 3 (both are significant at the 1% level). With regard to Clusters 1 and 2 strategies, changes in the average mitigation policy stringency are lower and not statistically significantly at the 10% level. While for mitigation strategies in Cluster 2, the coefficient is negative (-4.5% for a one standard deviation increase in average stringency), the number of observations in Cluster 2 is small, which may explain the large standard error for the estimated coefficient.

Thus, this regression analysis tentatively indicates that policy synergies are larger in Cluster 3 and 4 mitigation strategies than in Cluster 1 and 2. Cluster 3 and 4 mitigation strategies feature a variety of policies including market-based instruments, non-market-based approaches, and technology support policies. Overall, the results suggest that these policies are being designed and implemented in such a way to help to address a host of market failures, thus complementing each other and resulting in lower emissions for the same level of stringencies compared to Cluster 1 and 2 mitigation strategies.

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[14] Data on GDP is obtained from the OECD National Accounts and complemented with the World Bank's World Development Indicators (WDI). Population data is from WDI. The import share data is calculated from WDI based on OECD National Accounts. The data on services share of GDP is from the OECD Trade in goods and services database.

[15] Failing to control for these variables could confound the estimates if GDP (or population) and CAPMF correlate.

Mitigation policies can affect economy-wide emission intensities (i.e. emissions per unit of GDP) by reducing the emission intensity of the energy mix (emissions over energy consumption) and the energy intensity of the economy (energy consumption per unit of GDP). These are two channels of the so called Kaya decomposition, which relates emissions to population, GDP per capita, emission intensity of the energy mix and energy intensity. Keeping constant the (log of) energy intensity of the economy (i.e. energy consumption per unit of GDP) by including it as a regressor (Table 4, column 3) isolates the effect of mitigation strategies on the emission intensity of the energy mix (i.e. emissions over energy consumption). A schematic in Annex D synthesizes the conceptual framework for this regression.

Table 4. The effects of mitigation strategies on GHG emissions across countries

	(1)	(2)	(3)
	Log-GHG	Log-GHG	Log-GHG
L.CAPMF	-0.130***		
	(0.030)		
Cluster 1 * L.CAPMF		0.026	0.047
		(0.043)	(0.032)
Cluster 2 * L.CAPMF		-0.045	-0.013
		(0.028)	(0.022)
Cluster 3 * L.CAPMF		-0.092***	-0.070**
		(0.032)	(0.030)
Cluster 4 * L.CAPMF		-0.126***	-0.075***
		(0.027)	(0.022)
GDP	-1.501**	-1.113**	-0.599
	(0.564)	(0.484)	(0.479)
GDP2	0.080***	0.061***	0.050***
	(0.020)	(0.017)	(0.016)
HP Filter	-0.021**	-0.011**	-0.012***
	(0.008)	(0.005)	(0.004)
Population	0.286*	0.088	-0.060
	(0.149)	(0.213)	(0.120)
Service % of GDP	-0.001	-0.001	-0.003
	(0.003)	(0.002)	(0.002)
Import % of GDP	0.003	0.007**	0.003
	(0.006)	(0.003)	(0.002)
Rule of law	0.084	0.067	0.096*
	(0.055)	(0.052)	(0.049)
Energy/GDP			0.493***
			(0.063)
Constant	12.802**	14.502***	16.806***
	(4.963)	(4.942)	(4.064)
Observations	993	993	952
Year f.e.	Yes	Yes	Yes
Country f.e.	Yes	Yes	Yes
Within R2	.63	.7	.75

Note: The table shows the results of an OLS regression assessing the effects of mitigation strategies on emissions; standard errors clustered at the country and year level in parenthesis. Column 1 shows the effects of the CAPMF average level of stringency on emissions. Column 2 shows the effects of different mitigation strategies on emissions. Column 3 shows the effects of mitigation strategies on emissions, while in addition controlling for the energy intensity of GDP.
Source: OECD.

With regard to the CAPMF coefficient estimates, they are smaller in the specification with energy intensity of the economy as control variable (column 3) than without (column 2), with the exception of Cluster 1 strategies. The difference between the two sets of coefficients in column 2 and 3 (which are not statistically significant at standard confidence levels, however) can be attributed to the effect of mitigation strategies on energy intensity. This is because the coefficients in column 2 take into account the effects of mitigation strategies on emissions due to changes in the energy intensity of the economy and on the emission intensity of the energy mix, whereas those in column 3 take into account only the effects due to changes in the emission intensity of the energy mix. Comparing the point estimates of the two sets of coefficients suggest that, for Cluster 2 strategies, lower emissions from more stringent mitigation strategies come predominantly from lower energy intensity (70%) rather than lower emission intensity of the energy mix. The opposite is true for Cluster 3 and 4 strategies, where energy intensity explains respectively 25% and 40% of lower emissions. Emissions increase with stringency in Cluster 1 strategies, as the emission intensity of the energy mix increases, but the effect is not statistically significant at 10%.

Across all the specifications, the coefficients of the control variables have the expected sign, although they should not be interpreted causally. GHG emissions and GDP are positively related, as a higher economic activity is associated with higher emissions.[16] This relationship is convex, in contrast with the environmental Kuznet's curve hypothesis, which predicts an inverted U-shaped relationship between GDP and emissions. This difference between the literature on the environmental Kuznet's curve and the analysis here could be attributed to two reasons. First, the scope of analysis differs: the environmental Kuznet's curve literature considers a large number of countries at different stage of development whereas this analysis focuses mostly on developed economies; second, the environmental Kuznet's curve literature looks at levels while this analysis considers percentage variations from the mean (as the variables are in log and the model contains country fixed effects). Population and GHG emissions are positively related, although the coefficient is not statistically significant in some specifications. Interestingly, the GDP share of imports is positive and statistically significant in some specification, suggesting that trade-exposed countries also emit more.

6. Conclusions and next steps

This paper describes and classifies the climate-change mitigation strategies of 50 countries, exploiting the rich policy inventory of the OECD's Climate Actions and Policies Measurement Framework (CAPMF). The CAPMF contains comprehensive, structured and harmonised information on mitigation policies and actions. Cluster analysis helps to describe and rationalise the complex and multi-dimensional approaches to mitigation efforts that countries have taken. The analysis identifies four types of mitigation strategies, which differ in the variety and stringency of policies they comprise.

The temporal analysis shows how some countries progressively differentiated from others since 2005, as some countries started to adopt new policies and increase their stringency more than others. At this time, some countries began introducing market-based policies, and raised the stringency of standards and of

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[16] The marginal effect of GDP on GHG emissions (D_{yx}) can be calculated from the coefficient of the linear term (β^1_{GDP}) and the coefficient of the quadratic term (β^2_{GDP}) and is equal to $D_{yx} = {\beta_{GDP}}^1 + 2(\beta^2_{GDP} \times GDP)$.This implies that $D_{yx} > 0 \iff GDP > 9.1$. The minimum observed (log) GDP value in the dataset is 9.3, so that the correlation of GDP and GHG emissions is always positive. In the model in column 3, energy intensity enters log of Energy/GDP, in line with Kaya's decomposition and to help interpretation of the coefficient as an elasticity. Because GDP enters in logs at the denominator and logarithms are an additively separable function, this changes the coefficient on the linear term of the regression. The coefficient on the linear term of GDP is thus -1.092 (obtained summing -0.599 and -0.493), while the marginal effect is always positive and can be computed as follows: $D_{yx} = {\beta_{GDP}}^1 + 2(\beta^2_{GDP} \times GDP) - \beta_{EI}$, where β_{EI} is the coefficient of the log of Energy/GDP.

the level of subsidies for low-carbon technologies. From the 2010s onwards, two further clusters emerge. One cluster (Cluster 4) includes countries in Europe, that adopted more comprehensive and stringent policies, such as market-based policies (emission pricing, emission trading schemes) and non-market-based policies (air quality standards, bans and phase-out announcements). Another cluster of non-European countries (Cluster 2) adopted a different policy mix, containing relatively generous subsidies (via feed-in tariffs) and energy efficiency subsidies. The use of emissions pricing is heterogeneous within this Cluster 2, with only some strategies relying on emission trading schemes. Cluster 2 is smaller than the others and as a result one or few individual countries within the cluster may be driving its characterisation and results.

The findings from the analysis indicate that mitigation strategies encompassing a broad range of instruments – such as market-based instruments, non-market-based approaches, and technology support policies – are associated with lower emissions for the same level of overall stringency. This points to the importance of adopting comprehensive and diversified policy approaches to lower emissions. A diverse set of policy instruments can harness synergies and amplify the effectiveness of the overall mitigation strategy in terms of emission reduction.

Some limitations of the analysis are worth mentioning. The CAPMF measures de jure climate actions and policies but does not account for their degree of implementation or enforcement. Second, the CAPMF policy inventory is limited to certain sectors and policies, which though large and comprehensive are not exhaustive. For example, policies concerning agriculture are not yet included. In countries where agricultural production accounts for a relatively large share of total GHG emissions, the inventory may capture a small share of the overall climate policy mix and not the most important policies in place to reduce emissions. Furthermore, as countries expand their policy toolkits to innovative policies, the relevant policies might expand beyond those considered by the CAPMF so far.

Future work could analyse synergies and complementarities of specific policy combinations and assess their effects on emissions and economic outcomes, including by using micro-data. Using firm- level data could enable the identification of potential causal effects and allow for exploring policy synergies between and within sectors in addition to uncovering sectoral heterogeneities. Making strides in this direction would help to identify the sources - and extent - of synergies that different mitigation strategies may yield and aid policy makers in designing and implementing cost-effective mitigation strategies. Moreover, as countries might raise mitigation policies' stringency at different paces and rely on different policies to suit their specific circumstances and starting points, mitigation policy asymmetries may increase, fomenting concerns over carbon leakage and international competitiveness losses. Tracking the broad array of policies countries have been adopting and most probably will continue to adopt to reduce emissions, evaluating them and identifying possible sources of synergies are key to quantifying these risks and proposing solutions to manage them.

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Annex A. Detailed list of policies in the CAPMF

List of sectoral climate policies in the CAPMF policy repository

Table A A.1. Sectoral climate policies: Market-based instruments

Policy	Policy variables/Measurement	Rationale	Source
		For each sector	
Emissions trading schemes	Average annual price level of emissions trading scheme Number of GHG covered by ETS weighted by contribution to global GHG emissions	Carbon pricing is the most cost-effective mitigation policy to reduce CO_2 emissions. Pricing of GHG emissions provides incentives to reduce GHG emissions, including short-lived climate pollutants and other non-CO_2 GHG emissions	OECD, ICAP
Carbon tax	Nominal tax rate of carbon tax in USD/tCO_2	Carbon pricing is the most cost-effective mitigation policy to reduce CO_2 emissions	OECD
Fossil fuel excise taxes	Level of nominal diesel tax in USD/tCO_2e Level of gasoline tax Level of coal tax Level of natural gas tax Level of kerosene tax	Fossil fuel excise taxes indirectly put a price on energy-related carbon emissions which helps reduce fossil fuel consumption and, thus, CO_2 emissions in a cost-effective way. The CAPMF only takes into account a fuel in a sector if the fuel accounts for more than 5% of energy consumption.	IEA/OECD
Governments' reform of fossil fuel support	Fossil fuel support for oil, natural gas, and coal in % of total tax revenue	Fossil fuel support (e.g. tax exemptions) encourages consumption of fossil fuels, leading to an increase of CO_2 emissions. Removing those incentives would reduce consumption of fossil fuels.	OECD
		Electricity	
Feed-in-tariffs for solar PV and wind	Ratio between the level of feed-in-tariff (FiT) and its levelised cost of electricity (LCOE) for solar PV and wind Duration of support in years for solar PV and wind	Financial support for renewables is necessary to accelerate renewables deployment. FiT provide certainty for investors, channeling private funds into renewables. Scaling by LCOE ensures that the level of policy support takes falling technology costs into account	OECD
Auctions for solar PV and wind	Ratio between the level of bid price and its LCOE for solar PV and wind Duration of support in years	Financial support for renewables is necessary to accelerate renewables deployment. Auctions provide certainty for investors, channeling private funds into renewables.	IEA
RPS with tradeable renewable energy certificates	Share of renewable electricity obligation on total electricity generation	Renewable energy portfolio standards and tradeable certificates provide an extra revenue source for renewable energy developers, which can accelerate the deployment of renewables.	OECD
		Transport	
Congestion charges	Price of a city's congestion charge	Congestion charges for passenger cars in urban areas reduce incentives for car use and, thus, car dependency while promoting the shift towards more sustainable modes of transport such as public transport or cycling.	OECD
		Industry	
Financing mechanisms for energy efficiency	Number of financing mechanisms for energy efficiency investments of large consumers (e.g. preferential loans, risk guarantees).	Financing mechanisms reduce the upfront investments costs, one of the key barriers for technology adoption, for companies, driving investments into more energy efficient technologies. Improving energy efficiency is one of the key channels to reduce industrial GHG emissions.	World Bank (RISE)

Source: Nachtigall et al., (2022[3])

Table A A.2. Sectoral climate policies: Non market-based instruments

Policy	Policy variables/ Measurement	Rationale	Source
Electricity			
Ban on the construction of new and phase out of existing unabated coal power plants	Target year and legal status of phase out Target year and legal status of ban	Coal power plants are the single most important contributor to global GHG emissions. According to IEA's net-zero 2050 scenario, all unabated coal power plants need to be phased out by 2040 globally and much earlier in developed economies. In addition, the last unabated coal power plant would be completed in 2025 and no unabated coal power plant will go online in developed economies from 2020	IPAC CAPMF data collection
Planning for renewables expansion	Existence of integrated transmission and generation planning and renewable siting	Integrated transmission and (renewable) generation planning in combination with resource data and siting is the foundation to expand generation from renewable energy sources such as wind and solar PV.	World Bank (RISE)
Air pollution standards for coal power plants	Emission limit value for nitrous oxide sulphur oxide particulate matter and sulphur emissions	Emissions limit values on air pollutants increase the operating costs of coal power plants, reducing the operating hours and accelerating market exit of inefficient plants. Although the effect of emission limit values on GHG emissions is highly non-linear (e.g. because standards typically incentivise the installation of pollution abatement equipment, which could increase energy consumption and, thus, GHG emissions), the market exit effect is found to clearly dominate.	OECD EPS
Transport			
Fuel economy standards	Emission limit value in place (yes/no) for light duty vehicles heavy duty vehicles	Emission limit values or minimum energy performance standards for light and heavy-duty vehicles can improve the fuel efficiency of cars, leading to lower GHG emissions.	IEA and World Bank (RISE)
Mandatory fuel economy labels for light duty vehicles	Existence of mandatory fuel economy label for light duty vehicles	Information about prospective fuel consumption supports consumers to make better informed purchasing decisions, increasing demand for more fuel-efficient cars.	IEA
Ban on the sales of new and phase out of conventional passenger cars	Target year and legal status of phase out Target year and legal status of ban	Fossil-based passenger cars are the major source of transport-related GHG emissions. According to IEA's net-zero 2050 scenario sales of new conventional passenger cars is required to halt in 2035 globally	IPAC CAPMF data collection
Share of rail on total surface transport public expenditure	Share of central government's expenditure on new investments in rail infrastructure on total surface transport expenditure	Public investments in rail infrastructure provides alternatives to private car journeys. Rail transport has substantially lower GHG emissions per passenger kilometre compared to cars, notably in non-urban areas (IEA, 2020[41]).	ITF
Speed limits on motorways	National speed limit on motorways	Speed limits on motorway are one of the most effective ways to reduce road transport emissions immediately. According to the European Environmental Agency, reducing the speed limit from 120 km/h to 110 km/h would reduce fuel consumption and GHG emissions of passenger cars by 12-18% (EEA, 2020[42]).	ITF
Industry			
Minimum energy performance standards for electric motors	Level of the minimum energy performance standards of industrial motors	Minimum energy performance standards for electric motors are key to limit industry's energy demand. According to IEA's net-zero 2050 scenario, all new electric motors need to be best in class from 2035.	IEA
Energy efficiency mandates	Existence of mandates for large energy consumers	Mandates such as mandatory energy audits, certified energy management systems or energy managers can play a vital part in reducing energy consumption, and thus, CO2 emissions in industrial facilities.	World Bank (RISE)

Buildings			
Building energy codes	Mandatory or voluntary building energy code for new buildings in place (yes/no)	Mandatory or voluntary building energy codes are key to curb energy demand by mainstreaming energy efficient buildings. According to IEA's net-zero 2050 scenario, all new buildings need to be zero-carbon ready from 2030.	IEA
Minimum energy performance standards of appliances	MEPS in place for new domestic appliances: lighting, refrigerator, freezer, air conditioner	Minimum energy performance standards in the buildings sectors are key to curb energy demand by mainstreaming energy efficient electrical equipment. According to IEA's net-zero 2050 scenario most new appliances and cooling systems need to be best in class from 2035.	IEA
Mandatory energy labels for appliances	Mandatory energy label in place for new domestic appliances	Energy labels provide information on appliances' energy performance, enabling consumers to make better-informed decisions. This helps mainstream more energy efficient products.	IEA
Ban and phase out of fossil fuel heating systems	Target year and legal status of phase out Target year and legal status of ban	Using fossil fuels for heating substantially contributes to building-related GHG emissions. Banning fossil fuel use (oil and natural gas) for heating in new buildings and phasing out fossil fuel use in existing ones would accelerate the uptake of alternative heating technologies (e.g. heat pumps, district heating with non-fossil fuel where available).	IPAC CAPMF data collection

Source: Nachtigall et al., (2022[3])

List of cross-sectoral climate actions and policies in the CAPMF policy repository

Table A A.3. Cross-sectoral climate actions and policies

Policy	Policy variables/ measurement	Rationale	Source
GHG emissions targets			
NDCs	Coverage of NDCs (sectors, GHGs) of NDCs Type (e.g. absolute reduction target)	NDCs are key short-term targets to support the goals of the Paris agreement. Yet, NDCs differ in terms of coverage and type. The NDC is more demanding and more transparent the broader the coverage of NDCs and the more stringent the type.	UNFCCC
Net-zero target	Year in which country plans to achieve net-zero Institutional arrangement of the net-zero target (categorical). Coverage of net-zero target (e.g. all GHG, all domestic sectors)	To limit global warming to 1.5°C, global GHG emissions must reach net-zero by 2050. The earlier countries are planning to reach net-zero, the higher the chance to limit global warming in line with the 1.5°C target. The institutional arrangement of net-zero targets has implications on the credibility and on potential litigation actions from civil society if countries are not on track in meeting their targets. The scope of net-zero targets is key for its effectiveness.	IPAC CAPMF data collection
Public RD&D expenditure			
Public Research, Development and Demonstration expenditure	Spending on public RD&D related to energy efficiency in % of national GDP RD&D for renewables RD&D for nuclear RD&D for hydrogen RD&D for power and storage RD&D for CCS	Public RD&D expenditure in low-carbon technologies (e.g. renewables, nuclear, CCS) is crucial for innovation and adoption of new technologies to limit global warming to 1.5°C. Other non-fossil energy technologies (e.g. energy efficiency, hydrogen, fuel cells, smart grids) are key technologies to decarbonise hard-to-abate sectors (e.g. steel, cement) or key enablers for the shift towards zero-carbon energy systems.	IEA
Fossil fuel production policies			
Reform of governments'	Governments' support for fossil fuel production in % of	Governments' fossil fuel support encourages the use of fossil fuels, contributing to the lock-in of carbon-intensive	OECD

support for fossil fuel production	total government expenditure.	production and consumption styles. The volume of government support for fossil fuels remains substantial. Reforming or removing fossil fuel support would increase fossil fuel prices, providing incentives to shift away from fossil fuels.	
Bans and phase outs of fossil fuel extraction	Target year and legal status of phase out Target year and legal status of ban	Fossil fuels are the major contributor to GHG emissions. According to IEA's net zero 2050 scenario, from 2021 there is no need for new oil and gas fields for development as well as for new coal mines or mine extensions. To limit global warming to 1.5°C, it is estimated that 90% of proven coal reserves and around 60% of proven gas and oil reserves must not be extracted (Welsby et al., 2021[43]).	IPAC CAPMF data collection
Policies to reduce fugitive methane emissions	Score of IEA's methane reduction policy indicator	Methane is a very potent, though short-lived greenhouse gas. Methane policies, including robust measurement and reporting requirements, technology standards and economic incentives for abatement have successfully reduced energy-related methane emissions (IEA, 2022[44])	IEA
		Climate governance	
Independent climate advisory body	Climate advisory body in law Annual budget Size of the Secretariat Number of staff	The existence of an independent advisory body on climate change has proved effective to monitor governments' progress towards climate targets, to propose policy instruments to reach targets or to propose short-term, mid-term and long-term targets (Averchenkova and Lazaro, 2020[45])	IPAC CAPMF data collection

Source: Nachtigall et al., (2022[3])

International Policies in the CAPMF policy repository

Table A A.4. International climate policy: Detailed description of components

Policy	Policy variables/measurement	Rationale	Source
		GHG emissions data and reporting	
UNFCCC evaluation of Biennial Reports and Biennial Update Reports	Evaluation of the UNFCCC technical expert review's assessment on the transparency and completeness of BRs and BURs (replaced by BTRs post-2024)	Transparency and completeness of Biennial (Update) Reports is a prerequisite for climate action because it ensures that relevant data is available to measure progress and to identify the drivers of emissions.	UNFCCC
Submission of key UNFCCC documents	Timely submission of key mandatory and voluntary documents to the UNFCCC (e.g. BR, BUR, BTR post 2024, NIR, NC, LT-LEDS)	Submission of documents to the UNFCCC is a prerequisite for climate action because it fills information gaps and helps identify drivers of emissions as well as strategies to climate mitigation.	UNFCCC
GHG emissions reporting and accounting	UNFCCC evaluation of the submission of GHG Inventories based on UNFCCC Technical Expert reviews. Existence of Air emissions accounts under the System of Environmental Economic Accounting (SEEA)	Tracking GHG emissions is key for enhancing transparency and addressing climate change effectively. Environmental accounting enables countries to analyse and track total emissions, emissions sources, and emission removals, all of which are key to inform policy and track progress towards targets.	UNFCCC, OECD, Eurostat
		International climate co-operation	
Participation in international	Being Party to major international climate	Major international agreements are key to tackling climate change as they provide a common understanding	UNFCCC, UNTC

climate agreements	agreements (yes/no, year of adhesion or ratification), including the Montreal Protocol (+amendments), the UNFCCC convention, the Kyoto Protocol, the Paris Agreement.	of the problem, and its solutions while laying out common targets. Participation in those agreements shows commitment to the stated goals.	
Participation in international climate initiatives	Number of memberships in international climate initiatives listed in the Global climate action portal of the UNFCCC	Participation in international climate activities is a good proxy for international co-operation, which is needed to reach climate goals.	UNFCCC
Participation in international emissions pricing from aviation and shipping	Carbon price on CO2 emissions from international aviation (e.g. through ETS) Carbon price on CO2 emissions from international maritime transport Participation in CORSIA	Emissions from international aviation and maritime transport cannot easily be attributed to specific countries and, thus, require international co-operation. Pricing those emissions is a cost-effective means to reduce emissions.	IPAC CAPMF data collection
International public finance			
Banning governments' export credits for new unabated coal power plants	Ban on export credits for new unabated coal power plants (yes/no).	Banning governments' export credit for new unabated coal power plants is expected to increase coal plants' financing costs, discouraging investments in new unabated coal plants.	IPAC CAPMF data collection
Banning public finance for unabated fossil fuel infrastructure abroad	Ban on public finance for unabated fossil fuel infrastructure abroad (yes/no).	Banning public finance for unabated fossil fuel infrastructure abroad is expected to reduce investments in this kind of infrastructure.	IPAC CAPMF data collection

Source: Nachtigall et al., (2022[3])

Table A A.5. International climate policy: Detailed description of components

Policy	Policy variables/measurement	Rationale	Source
GHG emissions data and reporting			
UNFCCC evaluation of Biennial Reports and Biennial Update Reports	Evaluation of the UNFCCC technical expert review's assessment on the transparency and completeness of BRs and BURs (replaced by BTRs post-2024)	Transparency and completeness of Biennial (Update) Reports is a prerequisite for climate action because it ensures that relevant data is available to measure progress and to identify the drivers of emissions.	UNFCCC
Submission of key UNFCCC documents	Timely submission of key mandatory and voluntary documents to the UNFCCC (e.g. BR, BUR, BTR post 2024, NIR, NC, LT-LEDS)	Submission of documents to the UNFCCC is a prerequisite for climate action because it fills information gaps and helps identify drivers of emissions as well as strategies to climate mitigation.	UNFCCC
GHG emissions reporting and accounting	UNFCCC evaluation of the submission of GHG Inventories based on UNFCCC Technical Expert reviews Existence of Air emissions accounts under the System of Environmental Economic Accounting (SEEA)	Tracking GHG emissions is key for enhancing transparency and addressing climate change effectively. Environmental accounting enables countries to analyse and track total emissions, emissions sources, and emission removals, all of which are key to inform policy and track progress towards targets.	UNFCCC, OECD, Eurostat
International climate co-operation			
Participation in international climate agreements	Being Party to major international climate agreements (yes/no, year of adhesion or ratification), including the Montreal Protocol (+amendments), the UNFCCC convention, the Kyoto Protocol, the Paris Agreement.	Major international agreements are key to tackling climate change as they provide a common understanding of the problem, and its solutions while laying out common targets. Participation in those agreements shows commitment to the stated goals.	UNFCCC, UNTC

Participation in international climate initiatives	Number of memberships in international climate initiatives listed in the Global climate action portal of the UNFCCC	Participation in international climate activities is a good proxy for international co-operation, which is needed to reach climate goals.	UNFCCC
Participation in international emissions pricing from aviation and shipping	Carbon price on CO2 emissions from international aviation (e.g. through ETS) Carbon price on CO2 emissions from international maritime transport Participation in CORSIA	Emissions from international aviation and maritime transport cannot easily be attributed to specific countries and, thus, require international co-operation. Pricing those emissions is a cost-effective means to reduce emissions.	IPAC CAPMF data collection
International public finance			
Banning governments' export credits for new unabated coal power plants	Ban on export credits for new unabated coal power plants (yes/no).	Banning governments' export credit for new unabated coal power plants is expected to increase coal plants' financing costs, discouraging investments in new unabated coal plants.	IPAC CAPMF data collection
Banning public finance for unabated fossil fuel infrastructure abroad	Ban on public finance for unabated fossil fuel infrastructure abroad (yes/no).	Banning public finance for unabated fossil fuel infrastructure abroad is expected to reduce investments in this kind of infrastructure.	IPAC CAPMF data collection

Source: Nachtigall et al., (2022[3])

Annex B. Methodology and robustness checks

Agglomerative hierarchical clustering starts with clusters consisting of a single country and progressively merges them based on a dissimilarity measure i.e., the Gower's dissimilarity coefficient in this case. Ward's method is employed to minimise total within-cluster variance, thus merging at each step the pair of clusters with the minimum between-variance dissimilarity.

When considering the choice between hierarchical clustering and non-hierarchical alternatives, several factors motivate the preference for the hierarchical approach in this study. In contrast with other clustering techniques, agglomerative hierarchical clustering provides easy-to-interpret graphical visualization of the results and makes the cluster-formation process explicit through a dendrogram (Figure 7). Another significant advantage of hierarchical clustering is that it does not require an arbitrary selection of the number of clusters.

The algorithm progressively aggregates country strategies into clusters based on their mitigation policy dissimilarities and the Ward's method (Figure 7). The height of the dendrogram represents the degree of similarity of two clusters that merge (i.e. cophenetic distance). The number of clusters increases if the dendrogram is cut at lower heights (i.e. lower similarity among clusters).

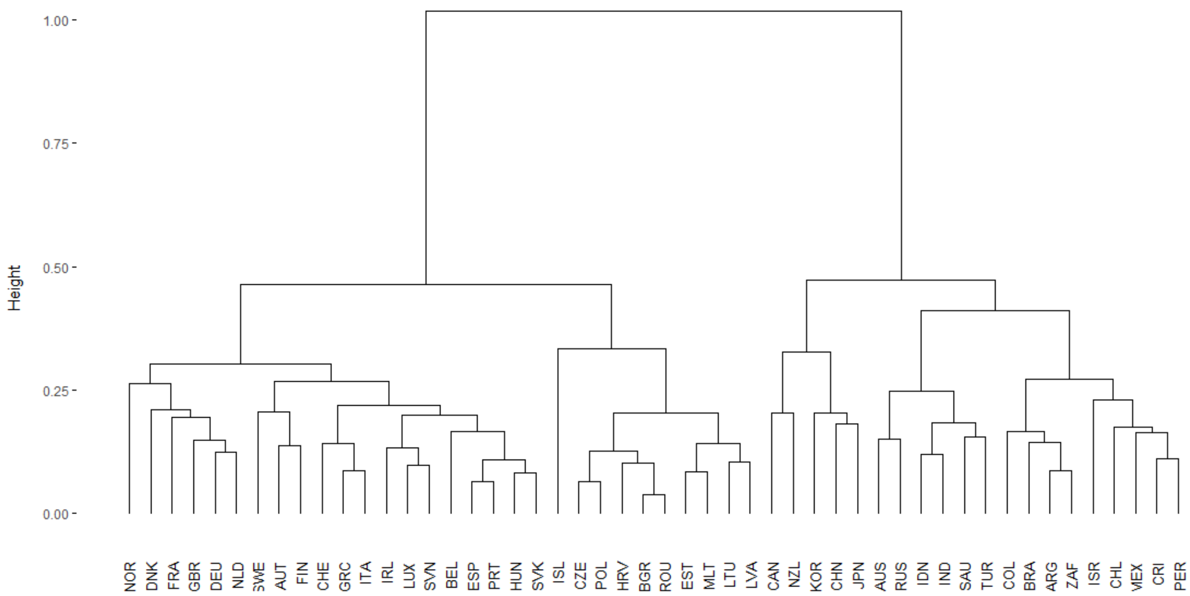
At a high cut, the dendrogram identifies two large clusters. The first cluster, depicted on the left side of the dendrogram, includes European countries. The second cluster consists of Latin American countries, along with Australia, India, Indonesia, Israel, Russia, Saudi Arabia, South Africa and Türkiye.

Each of these large clusters splits into two when the dendrogram is cut at a lower height. The first cluster divides into: Central and Eastern Europe plus Iceland and Malta (Cluster 3); the rest of Europe (Cluster 4). The second cluster divides into Latin American countries plus Australia, India, Indonesia, Israel, Russia, Saudi Arabia, South Africa and Türkiye (Cluster 1); and Asian countries plus New Zealand and Canada (Cluster 2).

Cutting the dendrogram at even lower heights results in more clusters. For example, in Cluster 1, Argentina, Brazil, Colombia, and South Africa detach and form a separate cluster from Chile, Costa Rica, Israel, Mexico, and Peru. In Cluster 2, China, Korea, and Japan are grouped together, indicating greater similarity in their mitigation policies compared to the rest of Cluster 2 countries, Canada and New Zealand. In Cluster 3, Iceland forms a sub-cluster on its own. In Cluster 4, Denmark, France, Germany, Netherlands, Norway and the United Kingdom exhibit more similar features to one another in comparison to other European countries.

Several robustness checks point to the reliability of the clustering results. The high correlation coefficient (0.69) between the cophenetic distance and Gower's dissimilarity measures indicates a valid cluster structure. Results are robust to the use of non-hierarchical clustering: k-medoid clustering, employing the Partitioning Around Medoids (PAM) method, provides similar outcomes. The so called "elbow" test favour a four or seven clusters partition, while tests based on the silhouette favour two clusters. When working with four clusters, PAM selects similar ones to those obtained with hierarchical clustering. About three quarter of countries used in this study were assigned to comparable clusters. The main difference is that k-medoid clustering combines Japan, Korea, and Australia with Eastern European countries in one cluster and separates Cluster 1 to form a cluster with China, Indonesia, Indonesia, Saudi Arabia and Türkiye.[17] The Frey test, McClain test, silhouette test, and Dunn test all favoured the two large clusters described above.

Figure 7. Dendrogram based on countries' climate change mitigation policies



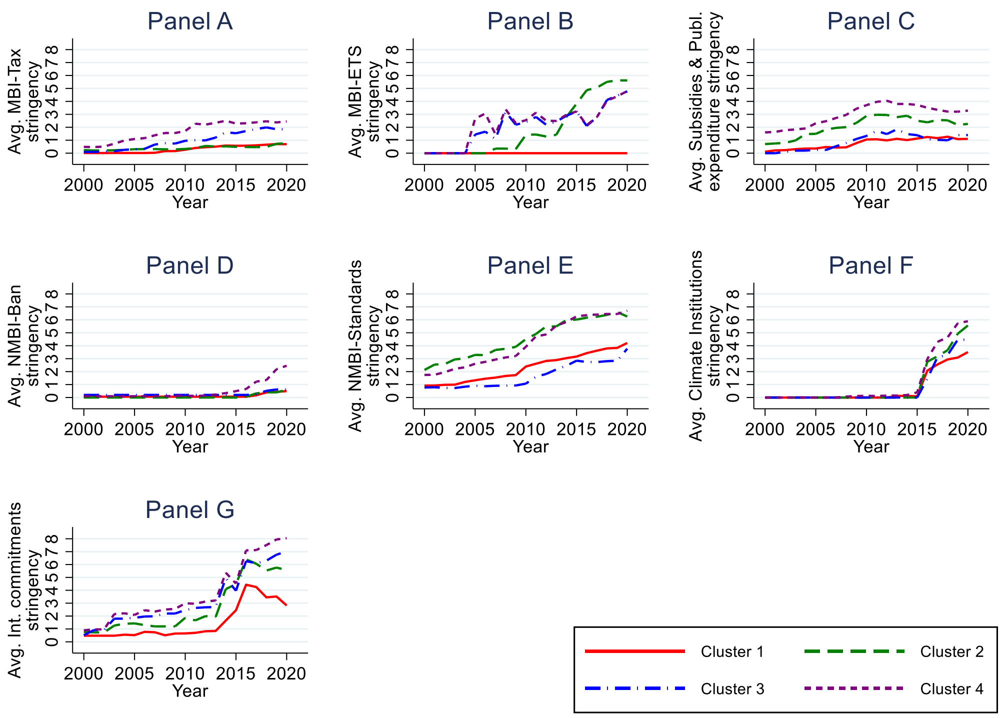
Note: The figure shows the Dendrogram that visualises the result of the agglomerative clustering, which begins with clusters consisting of singletons and progressively merges them based on a dissimilarity criterion, using Ward's minimum variance method.
Source: OECD.

[17] To further assess the validity of the clustering results, several tests were conducted, including a silhouette analysis, tests based on the sum of dissimilarities to the closest medoid, and the Duda-Hart test. These tests provided strong support for the existence of at least two clusters but yielded inconclusive evidence regarding the optimal number of clusters, with a slight preference for three or four clusters.

Annex C. Cluster evolution over time

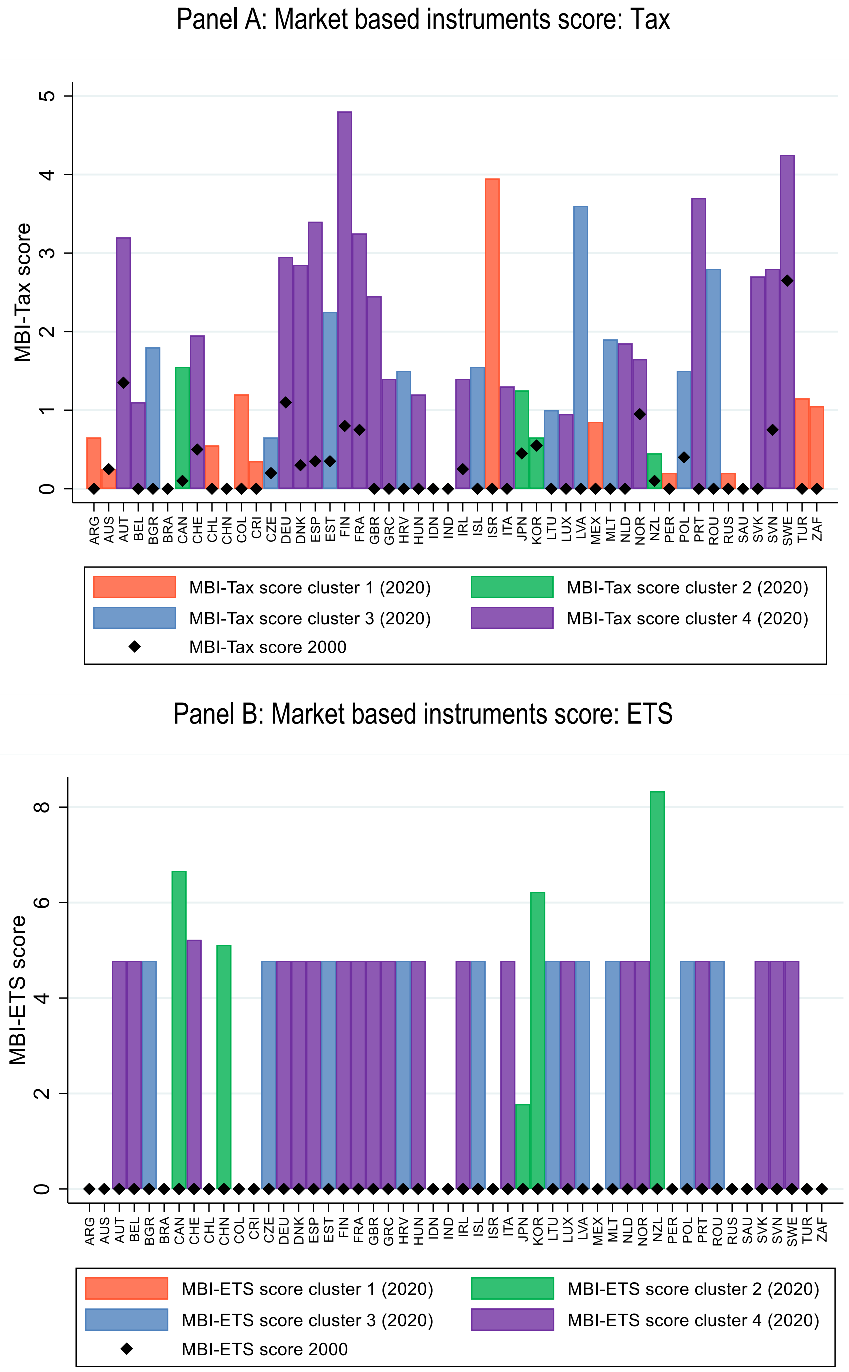
Figure A C.1. The evolution of average policy stringency by cluster across policy groups

Average stringency, scale 0 (least stringent) to 10 (most stringent)



Note: The figure shows the evolution of average policy stringency by cluster across policy groups. Panel A: Taxes; Panel B: ETS; Panel C: Subsidies and public expenditures; Panel D: Bans and phase-outs; Panel E: Standards; Panel F: Climate institutions; Panel G: International commitments. The red line shows the evolution for cluster 1, the dashed green line shows the evolution for cluster 2, the dashed blue line shows the evolution for cluster 3, and the dashed purple line shows the evolution for cluster 4.

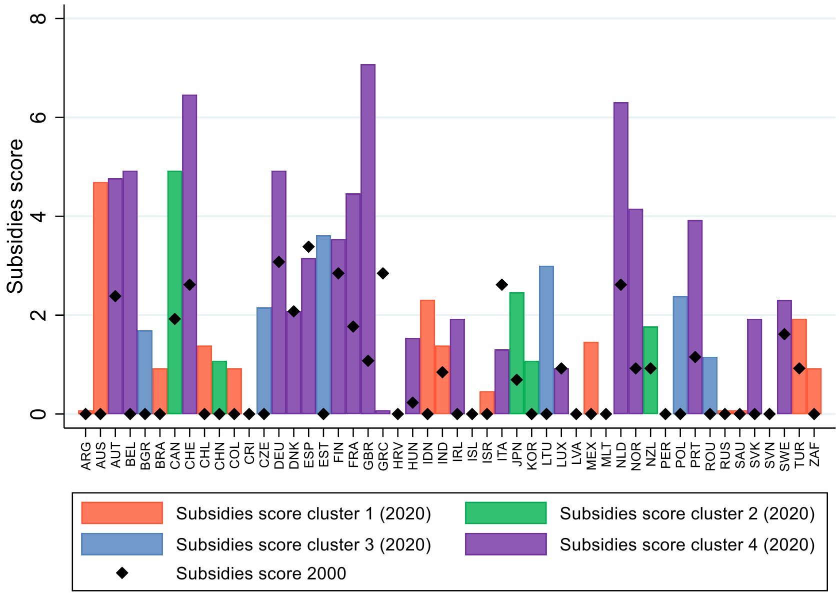
Figure A C.2. The evolution of market based instruments over time by country



Note: The figure shows the evolution of market based instruments over time by country for the year 2000 (diamonds) and 2020 (bars). Orange bars show the score for cluster 1, green for cluster 2, blue for cluster 3 and purple for cluster 4. Panel A shows the score for taxes and panel B for ETS. MBI stands for market based instruments.

Figure A C.3. The evolution of the subsidies score over time by country

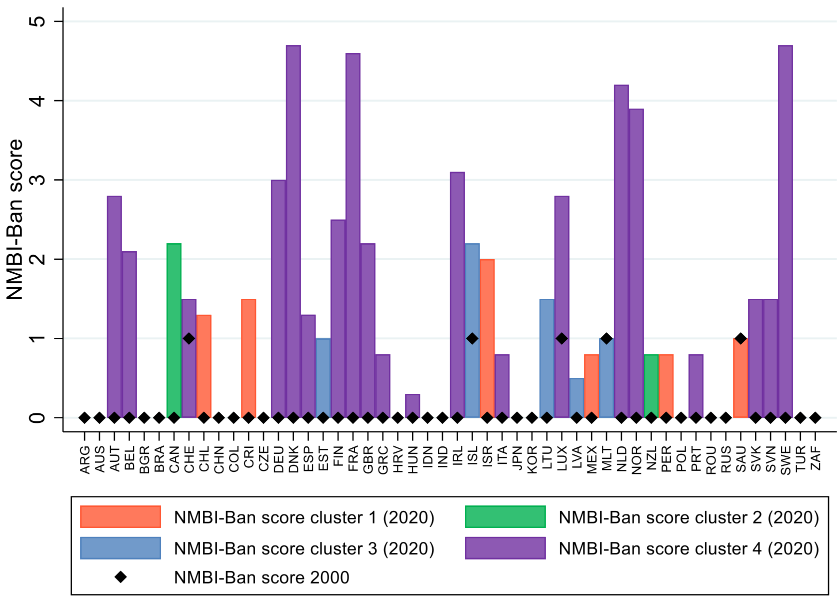
Panel A: Subsidies and other public expenditures score



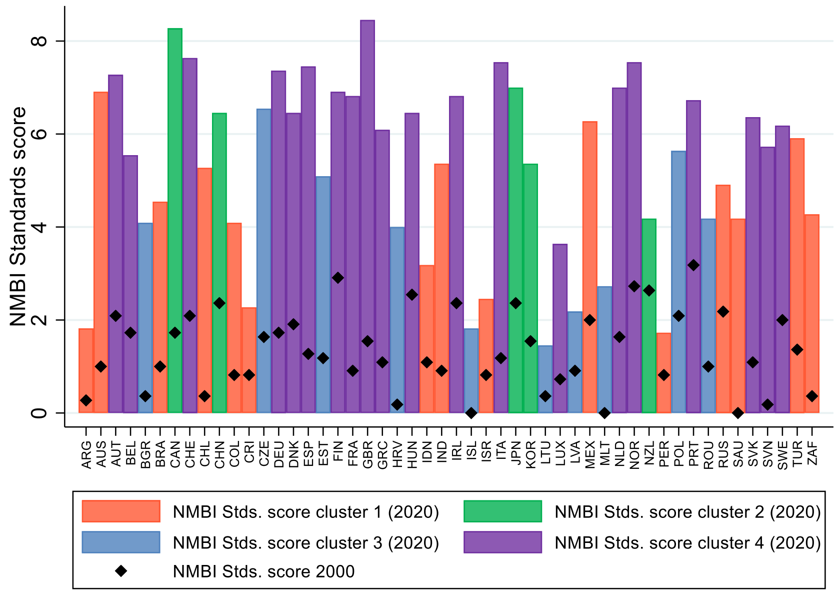
Note: The figure shows the evolution of subsidies scores over time by country for the year 2000 (diamonds) and 2020 (bars). Orange bars show the score for cluster 1, green for cluster 2, blue for cluster 3 and purple for cluster 4.

Figure A C.4. The evolution of non-market based instruments over time by country

Panel A: Non-market based instruments score: Bans and Phase-outs



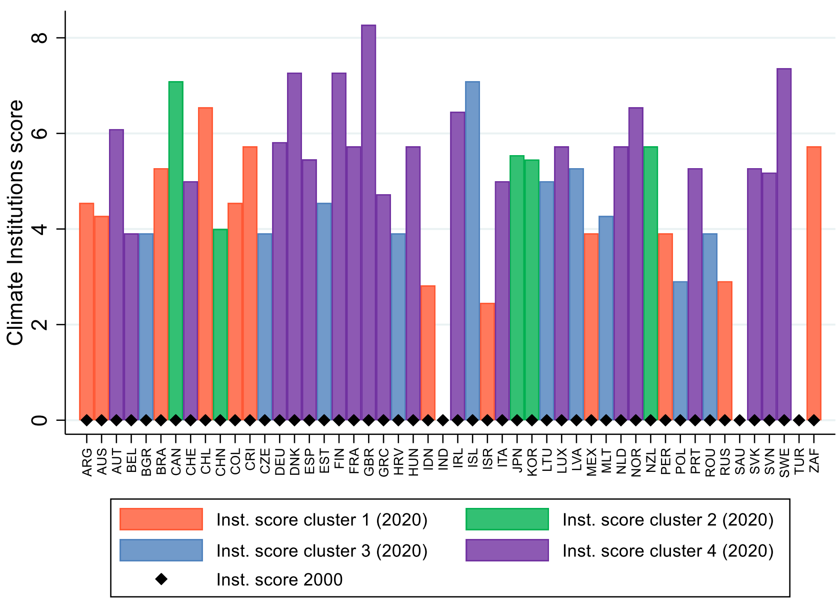
Panel B: Non-market based instruments score: Standards



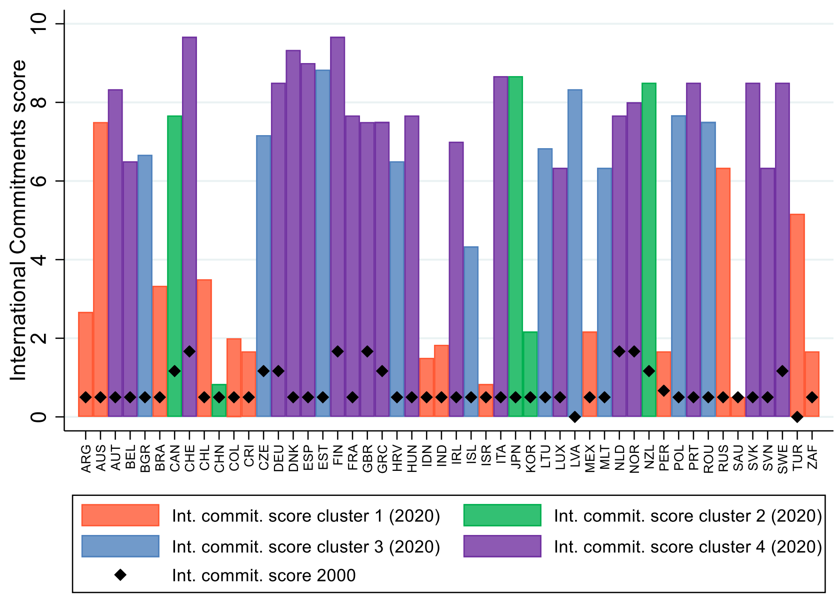
Note: The figure shows the evolution of non-market based instruments over time by country for the year 2000 (diamonds) and 2020 (bars). Orange bars show the score for cluster 1, green for cluster 2, blue for cluster 3 and purple for cluster 4. Panel A shows the score for bans and panel B the score for standards. NMBI stands for non-market based instruments.

Figure A C.5. Evolution of international initiatives over time by country

Panel A: Climate institutions score



Panel B: International commitments



Note: The figure shows the evolution of international initiatives over time by country for the year 2000 (diamonds) and 2020 (bars). Orange bars show the score for cluster 1, green for cluster 2, blue for cluster 3 and purple for cluster 4. Panel A shows the climate institutions score. Panel B shows the international commitments score.

Annex D. Robustness checks

Table A D.1. The effects of climate policies and policy clusters on CO_2 emissions across countries

	(1)	(2)	(3)
	CO2	CO2	CO2
L.CAPMF	-0.132***		
	(0.036)		
Cluster 1 * L.CAPMF		0.033	0.064*
		(0.052)	(0.036)
Cluster 2 * L.CAPMF		-0.049	-0.007
		(0.033)	(0.026)
Cluster 3 * L.CAPMF		-0.100**	-0.073**
		(0.036)	(0.032)
Cluster 4 * L.CAPMF		-0.126***	-0.059**
		(0.034)	(0.026)
GDP	-1.938**	-1.496**	-0.808
	(0.702)	(0.600)	(0.592)
GDP^2	0.099***	0.078***	0.064***
	(0.025)	(0.021)	(0.020)
HP Filter	-0.022**	-0.013*	-0.013**
	(0.009)	(0.006)	(0.005)
Population	0.302	0.065	-0.148
	(0.178)	(0.258)	(0.136)
Service (% of GDP)	-0.002	-0.002	-0.004
	(0.004)	(0.003)	(0.003)
Import (% of GDP)	0.009	0.013***	0.009*
	(0.008)	(0.004)	(0.005)
Rule of law	0.124*	0.111	0.146**
	(0.068)	(0.066)	(0.060)
Energy/GDP			0.640***
			(0.080)
Constant	14.620**	16.576**	19.762***
	(6.258)	(6.337)	(5.084)
Observations	993	993	952
Year f.e.	Yes	Yes	Yes
Country f.e.	Yes	Yes	Yes
Within R2	.59	.65	.71

Table A D.2 Robustness checks to the main specification

	(1)	(2)	(3)	(4)	(5)
	GHG (2015-20)	**Emission intensity (GHG/GDP)**	**Emission intensity (CO2/GDP)**	**GHG (WRI data)**	**GHG (pre-COVID-19)**
Cluster 1 * L.CAPMF	0.053	0.026	0.033	0.034	0.011
	(0.037)	(0.043)	(0.052)	(0.052)	(0.044)
Cluster 2 * L.CAPMF	-0.024	-0.045	-0.049	-0.007	-0.043
	(0.014)	(0.028)	(0.033)	(0.036)	(0.028)
Cluster 3 * L.CAPMF	-0.025	-0.092***	-0.100**	-0.083**	-0.080*
	(0.041)	(0.032)	(0.036)	(0.036)	(0.039)
Cluster 4 * L.CAPMF	-0.076***	-0.126***	-0.126***	-0.107***	-0.127***
	(0.016)	(0.027)	(0.034)	(0.031)	(0.027)
GDP	-0.946	-2.113***	-2.496***	-1.052**	-1.066*
	(0.932)	(0.484)	(0.600)	(0.480)	(0.514)
GDP^2	0.053	0.061***	0.078***	0.059***	0.059***
	(0.033)	(0.017)	(0.021)	(0.017)	(0.018)
HP Filter	-0.010	-0.011**	-0.013*	-0.012**	-0.011*
	(0.006)	(0.005)	(0.006)	(0.005)	(0.006)
Population	0.452	0.088	0.065	0.210	0.174
	(0.408)	(0.213)	(0.258)	(0.289)	(0.213)
Service % of GDP	-0.005	-0.001	-0.002	0.000	-0.001
	(0.006)	(0.002)	(0.003)	(0.002)	(0.002)
Import % of GDP	-0.010	0.007**	0.013***	0.007**	0.008**
	(0.011)	(0.003)	(0.004)	(0.003)	(0.003)
Rule of law	0.001	0.067	0.111	0.056	0.056
	(0.045)	(0.052)	(0.066)	(0.049)	(0.054)
Constant	7.714	14.502***	16.576**	4.971	12.709**
	(4.485)	(4.942)	(6.337)	(5.066)	(5.301)
Observations	283	993	993	908	908
Year f.e.	Yes	Yes	Yes	Yes	Yes
Country f.e.	Yes	Yes	Yes	Yes	Yes
Within R2	.23	.48	.4	.74	.7

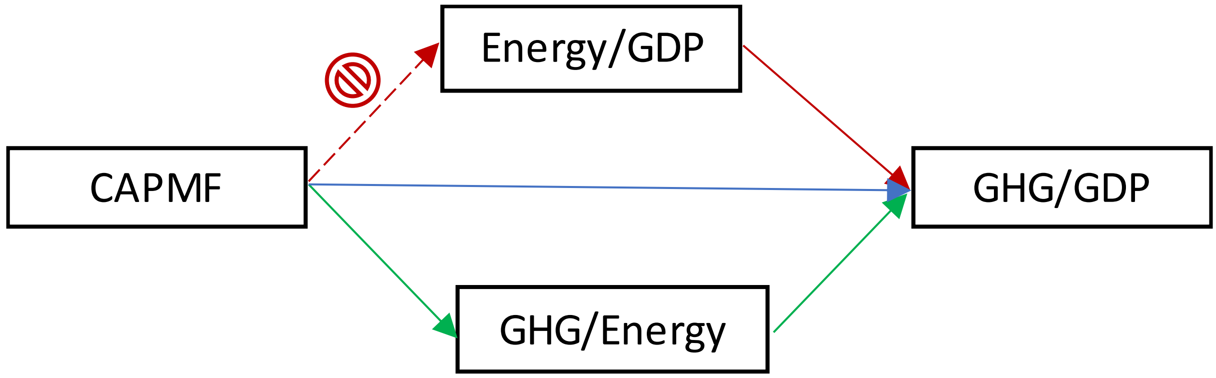
Note: The table shows the results of an OLS regression assessing the effects of mitigation strategies on different dependent variables; standard errors clustered at the country and year level in parenthesis. Column 1: GHG emissions, restricted to the years 2015 to 2020; Column 2: GHG emission intensity of GDP; Column 3: CO_2 emission intensity of GDP; Column 4: GHG emissions from a different data source (WRI, World Resource Institute); Column 5: GHG emissions, restricted to the years 2000 to 2018, to exclude years confounded by COVID-19.
Source: OECD.

Conceptual framework

The direct effect of mitigation policies on emission intensities can be estimated in model 1 and 2 (blue and green lines in Figure A D.1) corresponding to column 2 and 3 in Table 4. The effect of mitigation policies on emission intensities can be decomposed in two channels, following Kaya's decomposition: the effect of mitigation policies on the energy intensity of the economy (Energy/GDP) and on the emission intensity of the energy mix (GHG/Energy).

Model 1 (blue line in Figure A D.1, Table 4 column 2) considers both channels. Adding Energy/GDP as a control variable (green line in Figure A D.1, Table 4 column 3) 'shuts down' the energy-intensity channel (red dashed line). The resulting coefficient of the CAPMF is thus the sole effect of mitigation policies on emission intensities of the energy mix (green line).

Figure A D.1. Conceptual Framework



Source: OECD