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Three Decades of Climate Mitigation Policy: What Has It Delivered?

Janna Hoppe,[1] Ben Hinder,[2] Ryan Rafaty,[3,4]
Anthony Patt,[1] and Michael Grubb[2]

[1]Climate Policy Group, Institute for Environmental Decisions, ETH Zürich, Zürich, Switzerland

[2]The Bartlett School of Environment, Energy and Resources, Institute for Sustainable Resources, University College London, London, United Kingdom; email: b.hinder@ucl.ac.uk

[3]Climate Econometrics, Nuffield College, University of Oxford, Oxford, United Kingdom

[4]World Bank Group, Washington, DC, USA

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Abstract

After tentative efforts during the 1990s, the past two decades have seen a rapid increase in the number of greenhouse gas (GHG) emissions mitigation policies, initially in a few frontrunner countries and more recently spreading globally. Over the same period, GHG emissions have continued to rise, but the rate of growth has recently slowed. Are mitigation policies having an effect? To explore this question, we review and synthesize the empirical literature on the impact of mitigation policies on three key outcomes: GHG emissions, proximate emission drivers like energy intensity and land use, and low-carbon technologies. Our key contribution to the available literature lies in establishing an empirically based track record of climate action, focusing on methodologically sound ex post studies. We find that mitigation policies have had a discernible impact on emissions and multiple emission drivers. Most notably, they have led to reductions in energy use, declines in deforestation rates, as well as cost reductions and capacity expansions of low-carbon technologies in many instances. Furthermore, implemented policies to date are likely to have reduced global emissions by several billion tons of CO_2eq per year compared to a world without mitigation policies. In the light of current ambitions on climate action falling short of what is required to limit global warming to the Paris temperature goals, we conclude that there is ample evidence of policy instruments with demonstrable impacts, but that efforts need to be hugely strengthened and expanded. Also, far more attention is required to policy monitoring, evaluation, and learning so as to strengthen the basis for future policy and the attribution of its impacts.

Contents

1. INTRODUCTION

After the Intergovernmental Panel on Climate Change (IPCC) in 1990 confirmed the basic science behind climate change, the Second Assessment in 1995 identified “discernible evidence” of human impact—an attribution of cause and effect, which has grown with each assessment to the most recent stating that the link is “unequivocal” (1, 2). In response, the number of international climate frameworks and domestic mitigation measures has increased, first slowly, then more rapidly since the mid-2000s, initially mainly in countries of the Global North and more recently across the world (3–5). In 2017, climate policies covered approximately 70% of global greenhouse gas (GHG) emissions, compared to less than 20% in 2005 (3). These developments have been spurred by international climate treaties such as the Kyoto Protocol and the Paris Agreement (3, 4, 6) and more general global policy diffusion (7–9). Unlike climate change itself, there remains skepticism about what—if anything—these mitigation policies have achieved.

Mitigation: efforts to reduce the amount of CO_2 entering the atmosphere in order to constrain the effects of climate change

NDC: nationally determined contribution

Global GHG emissions continued to grow, at least to 2022, and it is widely acknowledged that countries’ nationally determined contributions (NDCs), even if fully implemented, are not sufficient to limit the increase in global average temperatures to 1.5° (6, 10–12). Economic activity and population growth have been major drivers of the continuous increase in CO_2 emissions (13–15), contributing to the all-time high of energy-related CO_2 emissions of 36.8 $GtCO_2$ in 2022 (16). As Stoddard et al. (17) rightly pointed out, we have not “bent the global emissions curve"—despite three decades of climate mitigation. Although the underlying facts have not changed, we offer a more bottom-up and fine-grained perspective on efforts undertaken toward combatting climate change. This review takes a first step toward evaluating and quantifying, ceteris paribus, the impacts of climate protection efforts to date.

Ex ante: analysis that looks at the potential effects of an intervention before it has been applied through modeling

Ex post: analysis that looks at an intervention after the intervention has been applied

Most world regions have experienced a sustained decline in energy intensity [energy per unit of gross domestic product (GDP)] over the past two decades, and several regions have also reduced carbon intensity (CO_2 per unit of energy) (14, 15, 18–26). At least 24 countries have reduced their CO_2 and overall greenhouse gas emissions for more than a decade (27, 28), on the basis of consumption as well as territorial boundaries. The rate of global annual emission growth has slowed; compared to 2.3% between 2000 and 2010, the average over the subsequent decade was 1.3%/year, dropping to 0.8%/year since 2014 (29). New analyses based on revised land-use emissions suggest that global CO_2 emissions were almost flat over the past decade (30). Collectively, these developments suggest that the mitigation policies that have been implemented to date may have had a demonstrable effect on global emission trends. Indeed, the slowdown in emission growth has been associated with technological innovation, regulation, or climate policies more generally (18, 23, 25, 31, 32).

Studies have often projected the impact of policies ex ante using models. However, quantifying the effects of mitigation policies and determining the extent to which observed changes in emission trends can be attributed to these policies remain a challenge. Numerous factors confound the establishment of robust causal inference, such as the impact of fossil fuel prices, other nonclimate policies, spillovers from other sectors, or broader socioeconomic trends. As a result, many studies only assess the impact of a particular policy instrument in a particular setting (33–37), and even these sometimes provide contradictory results (38). Comparatively few studies examine impacts that span multiple jurisdictions and sectors (39–42), and even fewer investigate the effect of mitigation policies on global GHG emissions (43).

Several (systematic) reviews derive both case-specific and generalizable conclusions on the impacts of particular policy instruments, such as carbon prices (44–47) and incentives for the uptake of electric vehicles (EVs) (48, 49); renewable energy support policies (50, 51); and information strategies (52, 53). To date, there has been no review of the literature to explore the extent to which mitigation policies, in general, have (or have not) cut global emissions. Common sense and a substantial number of scientific studies suggest that they do, but the evidence has not yet been brought together in an instrument- and sector-spanning review. Our review works toward closing this gap in the literature, focusing specifically on robust, ex post studies assessing mitigation policy impacts on emissions and emission drivers.

We identified and grouped these studies according to three outcome areas:

- GHG emissions: impacts quantified directly in terms of emission abatement (absolute/relative)
- Proximate emission drivers: trends in the component drivers of emissions, most notably energy/GDP intensity and carbon/energy intensity (for energy-related emissions), and deforestation rates [for the agriculture, forestry, and other land-use (AFOLU) sectors], as well as more sector-specific component drivers
- Technological change: developments in key low-carbon technologies, especially in terms of investments, capacity expansions, and technology costs, that are projected to have a strong influence on future emissions

Although presented separately in the results section, the three outcomes are inherently interlinked (**Figure 1**). Emission reductions are the result of policies that directly aim to reduce emissions, such as climate laws with emission reduction obligations. They also arise from policies

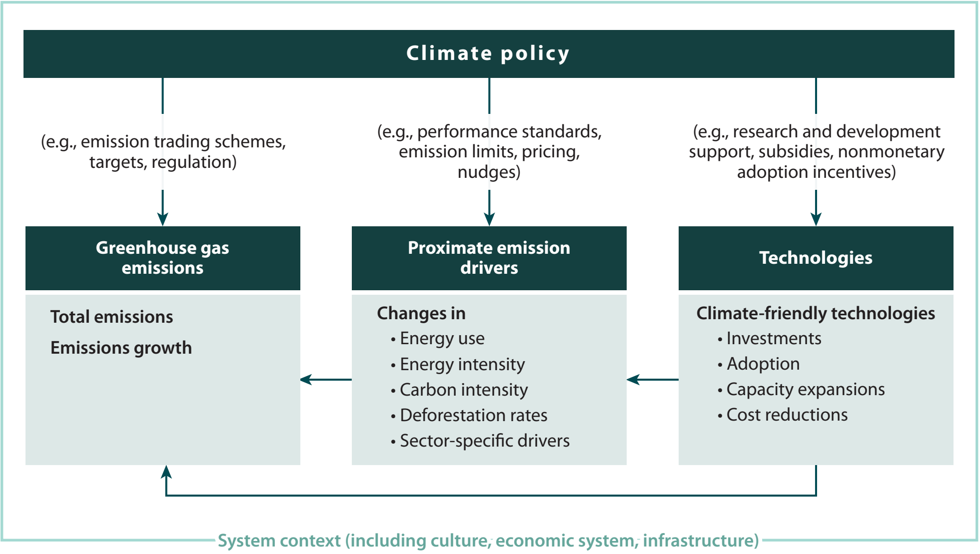


Figure 1

Conceptualizing the direct and indirect effects of mitigation policies on technologies, proximate emission drivers, and greenhouse gas emissions.

such as regulation or voluntary agreements, which impact proximate emission drivers. Finally, changes in technologies, which may be brought about by research and development (R&D) support or monetary adoption incentives, affect GHG emissions both directly and indirectly through inducing changes in proximate emission drivers. All of these factors exist within the context of the broad social, economic, and infrastructural system, which contextualizes and influences both the character of the factors and the flow of influence between them.

This review aims to examine the causal relationship between mitigation policies and each of the above-mentioned outcomes by presenting empirical, ex post evidence on a range of mitigation policies across sectors. Such a comprehensive, policy-, and sector-spanning effort as conducted in this review has not been done before. Inevitably, this comes at the cost of limited in-depth insights on specific policies and other issues noted below. Nonetheless, our comprehensive bibliography, drawing from an extremely broad and robust evidence base, provides policymakers with a wide range of insights needed to design and implement effective policies.

The influence of other policies or contextual factors lies beyond the scope of this review. The evaluation of mitigation policies apart from their effectiveness in reducing emissions, such as on the grounds of ethics, justice, and efficiency, is also beyond our scope. These matters are paramount in the context of uncertain purposive transitions, and although these issues lie beyond the scope of our review, any application of this review's findings will need to take account of them.

Nevertheless, our results unambiguously demonstrate that mitigation policies have had a discernible impact on emissions and emission drivers. Most notably, they have led to reductions in energy use, declines in deforestation rates, as well as cost reductions and capacity expansions of low-carbon technologies. Overall, implemented policies are likely to have led to global avoided emissions of several billion tons of CO_2 annually in recent years compared to a world without mitigation policies, and have helped set the stage for a Paris-aligned <2°C world.

2. METHODS

2.1. Literature Selection Criteria

The literature we assessed generally considers mitigation policies to be those adopted with either a primary or a secondary objective to reduce GHG emissions or influence key drivers thereof. This definition of mitigation policies spans higher-level goals such as GHG emission reduction targets or climate frameworks, as well as medium-term strategies and more sector-specific measures. The latter include regulatory (e.g., energy efficiency standards, building codes, renewable portfolio standards), economic (e.g., carbon taxes and trading schemes, renewable energy subsidies), and other (e.g., informational and infrastructural measures, voluntary agreements or government procurement) instruments. We sought to include studies from all jurisdictions, including at the national, sub-, and supranational level, as well as studies that explored effects within and across sectors.

We focus on papers that deployed robust, ex post methods. The majority of these deploy statistical attribution methodologies, including experimental and quasi-experimental design, instrumental variable approaches, and simpler correlational methods. Those studies typically use the relevant mitigation metric as the outcome variable, and policies and other potentially influential factors act as explanatory variables. Other types of studies base their analysis on aggregations and extrapolations from microlevel data and on inference from combining multiple lines of analysis, including various calculations. Some studies deploy mixed methods that include qualitative evidence that stems from public opinion surveys, expert interviews, document analysis, or other in-depth case study methodologies. Finally, we also included several (systematic) reviews that assess and aggregate the findings of numerous empirical studies on a particular topic, usually a specific mitigation instrument.

Finally, we selected only papers that reported findings on at least one of our three key outcome categories (emissions, proximate emission drivers, and technologies). As many studies use an outcome metric that is specific to the respective case (e.g., per capita energy use, percent increase in patents), the grouping into one of the three outcome categories was done following insights from decomposition analyses, which differentiate between the different drivers of emissions (13–15, 18–26, 31, 32, 54–57). We report outcomes in the units that were used in the original papers.

2.2. Process of Literature Collection and Analysis

We identified studies assessing the impact of mitigation policies for review using several steps. First, our primary source of literature was the literature we reviewed as part of the IPCC's latest assessment, *Climate Change 2022: Mitigation of Climate Change* (29). The literature included in IPCC reports is characterized by high methodological rigor and, to the extent possible, representativeness in terms of geographical coverage, technologies, policies, and sectors. Literature from all 17 chapters was considered, with a particular focus on Chapter 2 ("Emissions Trends and Drivers"), Chapter 13 ("National and Sub-national Policies and Institutions"), and the sectoral chapters (Chapters 6–7 and 9–11), with some additional papers recommended to us by chapter authors.

In the case of policy impacts that were highlighted by the IPCC report but not substantiated with ex post evidence, we conducted an additional literature search via the search engine Google Scholar and the citation database Web of Science. We used various search strings, including permutations of the following example: [outcome OR impact OR effect] AND [policy OR measure OR instrument] AND [climate OR mitigation OR decarbonisation].

After this selection procedure, ~1,500 studies were screened on the basis of their abstracts, leading to a selection of 500 studies that were subjected to more detailed review. These studies included a cross section of ex post analyses of policy impacts, contextual papers (e.g., papers on mediators of policy impacts, such as carbon leakage), and a limited number of modeling and ex ante studies in cases where no ex post evidence was available. After a final round of assessment, we had collected more than 320 papers that met our standard with regard to methodological rigor, scope, and relevance and, most importantly, addressed our key research question: Are mitigation policies having an effect?

All papers were carefully read by at least two authors and categorized according to several dimensions [e.g., type of policy instrument(s), outcome variable(s), geographical scope, sectoral coverage]. Studies were then clustered, following the structure of our conceptual model (see **Figure 1**) and summarized with regard to the research question before condensing the results further for this article. In designing and conducting the review, we followed methodological best-practice guidelines (58). The **Supplemental Appendix** provides further detail on selected papers.

Supplemental Material >

3. RESULTS

3.1. Overview of Literature

Categorizing papers according to their geographical and sectoral scope as well as types of instruments and outcome categories reveals that the literature is imbalanced. Many studies either focus on European countries (30%) or are global in scope or compare cases from different regions (26%); fewer studies focus on North America, other Organisation for Economic Co-operation and Development (OECD) countries, and China; whilst all other countries account for less than 10%. Many articles focus on particular sectors (transport, buildings, energy, industry, and the AFOLU sector), whilst 28% either assess impacts across several sectors or do not address one specifically. In terms of policy types, studies on economic and mixed instruments dominate, with fewer articles investigating the impact of regulatory or other instruments. Interestingly, there appears to be a relationship between the type of policy instrument and the outcome category, with the impacts of regulatory policies most often reported in terms of emission drivers and those of economic instruments in terms of emission abatement. Similar relationships exist in the case of countries and sectors.

3.2. International Treaties on Climate Change

The Kyoto Protocol, which was adopted in 1997 and entered into force in 2005, marks a key milestone in climate policy. We are reviewing its effectiveness separately from the three outcome metrics for two reasons: First, the Kyoto Protocol is a climate framework and thus follows a different logic than specific and targeted mitigation instruments. Second, the available literature is significant and can be represented comprehensively.

The Kyoto Protocol set binding emission reduction targets for 37 industrialized countries and economies in transition. On aggregate, these amounted to 5% emission reductions over the first commitment period (2008–2012) compared to 1990. Despite early criticisms, most scholars concluded that emission reduction obligations under the Kyoto Protocol had a positive, statistically significant impact on CO_2/GHG emission reductions in the Annex B countries that ratified with targets under the treaty (i.e., industrialized countries, minus the United States and Canada), or globally (59–69).

Maamoun (41), in a recent and particularly robust study that covers the entire commitment period, found that the Kyoto Protocol reduced the GHG emissions of Annex B countries by 7% on average compared to a no-Kyoto synthetic scenario over 2005 to 2012, resulting in abatement of approximately 1 Gt in 2012. Kim et al. (42) estimated that CO_2 emissions of Annex I countries in

2008 would have been 14% higher (per 2005 base year model) had these countries not committed to reducing their emissions, which is equivalent to approximately 3,000 metric tons CO_2 per year. Aichele & Felbermayr (70) concluded that Kyoto ratification reduced CO_2 and GHG emissions by 10% (2002–2007) compared to the counterfactual no-Kyoto world. According to Kuriyama & Abe (71), Kyoto led to 951 $MtCO_2eq$ of real emission reductions globally (2005–2012) compared to a synthetic counterfactual constructed using US states as comparisons for Annex B countries, the majority stemming from nonenergy GHG emissions in non-Annex B countries.

CO_2eq: the unit used to measure the impact of emissions referring to the global warming potential of one tonne of a gas in comparison to one tonne of CO_2

The environmental efficacy of the Kyoto Protocol has been qualitatively questioned based on its institutional design (71–73), as well as on shortfalls in the implementation of Clean Development Mechanism (71, 74, 75) or Joint Implementation (76) projects, although the latter have also been found to have yielded positive outcomes (69, 77–80). There are a few studies that failed to detect a statistically significant effect of the Kyoto Protocol (76, 81). Others find a considerable amount of Kyoto-induced carbon leakage (82–84), which have, however, been criticized for using country-level data, not taking into account other macroeconomic trends, covering up to only 2007 or 2009, and failing to pinpoint the mechanisms through which any estimated leakage occurred (85, 86). Overall, the complete range of abatement estimates starts from no statistically detectable effect (81) to emission avoidance of up to 50% compared to a case in which countries had not taken on emission reduction obligations (87, 88). For a full overview of abatement estimates, see **Supplemental Table 1**.

Supplemental Material >

Besides emission reductions, the Kyoto Protocol has been found to increase international patent applications for renewable energy technologies, especially in countries with more stringent emission reduction targets, but it has also led to an increase in patent applications in countries without emission reduction obligations (89). Kyoto also had a positive and statistically significant impact on the cost-effectiveness of renewable energy projects (90), as well as on renewable energy capacity development, as it stimulated the introduction of domestic renewable energy policies (91). Finally, it also had a positive impact on forest carbon sinks in the LULUCF (land use, land-use change and forestry) sector, especially after it entered into force in 2005 (92).

To date, little empirical evidence exists on the immediate emission reduction effect of the 2015 Paris Agreement. One paper, using panel data up to 2019, suggests that the Paris Agreement reduces emissions by approximately 0.01% in Germany, Spain, and France compared to the period before ratification (93). Another paper found that comparatively stringent NDCs have a positive impact on green bond finance for renewable energy projects (94). Importantly, the treaty stimulated national policy development, both before and after the agreement (3, 4), and was followed by a wave of net zero target announcements (95). As of July 2023, 150 countries, including major emitters, have announced or are considering net zero targets, covering almost 90% of global emissions (96). Most qualitative assessments conclude that despite several limitations, it is the best agreement that reasonably could have been reached at the time (97–101). Its built-in ratcheting-up mechanism is expected to contribute toward closing the prevailing ambition and implementation gap (11, 100–107), and more than 150 parties submitted new or updated mitigation targets for 2030 ahead of the Glasgow Climate Pact. These renewed pledges, if fully implemented (conditional and unconditional pledges inclusive), could result in an average temperature increase of approximately 1.9°C, which was outside the realm of possibility for the previous pledges (108, 109).

3.3. Global Greenhouse Gas Emissions

Specific mitigation policies (i.e., beyond emission targets) have demonstrably led to emission reductions in several jurisdictions and sectors, although their aggregate global impact has only been assessed by one study to date. Eskander & Fankhauser (43), using panel data on climate mitigation legislation in 133 countries, found that each new climate law was on average associated with an annual reduction of CO_2 emissions per unit of GDP by 0.78% in the short term (up to 3 years) and by 1.79% in the long term (beyond 3 years). They estimated emissions reductions building up to 5.9 $GtCO_2$ in 2016 (i.e., −15%), with cumulative emission savings amounting to 37.7 $GtCO_2$ from 1999 to 2016, although some methodological challenges have been noted (110).

Supplemental Material >

3.3.1. Carbon pricing.

By 2022, 70 carbon pricing initiatives have been implemented worldwide, covering 47 national jurisdictions and representing 23.17% of global GHG emissions (111). This makes carbon prices (either in the form of carbon taxes or emissions trading schemes) one of the most frequently implemented mitigation policies. Our review identified 43 papers that have conducted formal empirical evaluations of emissions savings associated with different carbon pricing systems (see **Supplemental Table 2**), which provide mixed but largely positive results. Indeed, most studies conclude that carbon prices have had a discernible diminishing effect on CO_2 emissions in the energy, industry, transport, and buildings sectors (33, 39, 40, 44–47, 112–151).

Among these, perhaps the most significant are Best et al. (117), who observed a 2% reduction in the annual growth of emissions from fossil fuel combustion in countries with carbon pricing compared to countries without carbon pricing. Similarly, Rafaty et al. (118) found that the introduction of carbon prices in 39 countries reduced the growth in CO_2 emissions by 1–2.5% per year, with marginal effects varying across sectors. These two studies find that global carbon pricing schemes led to average annual avoided emissions of 130–200 $MtCO_2$/year, which is in line with the aggregate impact of all carbon pricing schemes as detailed in the **Supplemental Appendix**.

In the case of the European Union Emissions Trading System (EU ETS), the world's oldest GHG emission trading scheme, abatement estimates span a wide range of 1–50% of total emissions or total emissions covered by the EU ETS compared to a no-policy world over the different trading periods. This is partly due to differences in model baselines, regions and time periods studied, and reporting units (annual versus cumulative effects, and relative versus absolute reductions). Having taken this into account, we estimate the likely range of directly attributable avoided emissions from the EU ETS to be 3–9% of the emissions governed by its rules over the historic periods studied (typically up to 2012 or 2016) compared to a business-as-usual path (39, 40, 113–116), acknowledging that the studies underpinning this estimated range covered the period before prices rose substantially in 2021. The evidence on the EU ETS also highlights that the overall effectiveness of carbon pricing is ultimately a matter of design (46). Emission reductions varied between the trading phases in response to instrument reconfigurations (114, 120) such as changes to the share of emission certificates that were auctioned, or the implementation of scarcity-inducing mechanisms like the market stability reserve. Essentially, the carbon price is determined by the demand for and availability of (surplus) certificates on the market, which can be real or anticipated.

Most of the emissions reductions attributed to carbon pricing schemes appear to be the result of low-cost operational measures that are relatively easy to implement and thus produce immediate emission reductions. These include fuel switching (44, 47, 115, 119, 132, 152) or reductions in fossil fuel consumption (122, 127, 153, 154), which may stem from energy efficiency improvements (120) or industrial restructuring (133, 155). As a result, carbon prices also led to a notable decline in the carbon intensity of many countries' electricity mixes (116, 120, 155–158). Despite widespread concerns, the estimated extent of carbon leakage, i.e., the relocation of utilities and businesses to regions not subject to a carbon price and the resulting increase in emissions in these regions, is rather small, or nonexistent in many (85, 86, 122, 159, 160) but not all (161) cases.

Finally, a few studies fail to detect a statistically significant effect of carbon pricing on emissions, at least for some jurisdictions and sectors, particularly industry and in countries with tax exemptions for energy intensive industries or low carbon prices (124, 138, 146, 153, 158). Above all, there is broad consensus that the impact of other (climate and nonclimate) policies as well as broader socioeconomic trends on emissions (such as the 2008 recession or nuclear shut down in Japan following the 2011 earthquake) in jurisdictions with carbon prices are substantial and tend to account for a larger share of observed emission reductions, implying that carbon prices in some cases remain at too low a level to drive mitigation, and in other cases fail to address other systemic barriers to change (33, 46, 114, 121, 123).

3.3.2. Other mitigation policies. Numerous additional mitigation policies have demonstrably reduced GHG emissions. Although many of them are primarily directed at influencing emission drivers (see Sections 3.4 and 3.5), several studies also report their immediate or lagged effects on emissions. Considerable emission reductions in energy, for example, were realized through the policy-driven expansion of renewable energy technologies that led to a displacement of fossil fuel combustion (135). These policies most notably include (market-based) regulation and governmental subsidies (162). When attributing 70% of global wind and solar deployment to date to mitigation policies, policies led to emission avoidance of at least 1.3–2.5 $GtCO_2eq$ in 2021 (163). According to the International Energy Agency (IEA), the expansion of renewables and EVs in 2022 alone led to avoidance of almost 1 $GtCO_2eq$ (164).

In the buildings sector, observed emission reductions are mainly attributed to building sector regulation, especially building energy standards (38, 165–167). In India, energy efficiency policies, including energy standards, labels, subsidies, and a trading scheme for energy savings, have led to substantial emission reductions (~172 $MtCO_2$ in 2020) (168). In industry, loans and subsidies incentivizing renewable energy adoption as well as legal requirements mandating energy audits have been effective in lowering firms' GHG emissions (169). Voluntary programs may also yield firm-level emission reductions, but the literature suggests that regulation, or the threat thereof, is likely more effective (170).

For land transport, regulatory instruments, such as vehicle fuel economy or emission standards, have been found to reduce fuel use and emissions (171–179). Both monetary disincentives of car use (e.g., fuel taxes, road tolls, congestion pricing, parking fees, or the abolishment of car-use-related benefits) (180–186) and nonmonetary disincentives (e.g., driving restrictions) (187, 188) have been shown to reduce overall car use and passenger transport-related GHG emissions. An analysis of the EU road transport sector identified 10 effective policy interventions that reduced emissions between 1995 and 2018 by between 8 and 26% per case and, taken together, by 35.9 $MtCO_2$ in total in the EU15 relative to the estimated counterfactual (147). The replacement of internal combustion engine vehicles by EVs holds a substantial mitigation potential, although empirical, ex post evidence is not yet substantive, given the early phase of the substitution process (see Section 3.5) (49, 189–191). Empirical literature on the emission reduction effect of policies that promote alternative modes of transport is scarce, but the available evidence suggests that investments in or the provision of public transport and cycling infrastructure reduces air pollution and congestion, and thereby GHG emissions (192–203). Measures that have been empirically demonstrated to reduce demand and emissions from aviation include fuel and passenger taxes (204–206) and the construction of high-speed rail (207–209). Aviation taxes have been shown to lead to cross-border substitution (206), making the overall effectiveness of the instrument contingent on geographical conditions. In China, the construction of high-speed rail is estimated to have led to a cumulative net abatement of 1.76–2.76 $MtCO_2$ from 2012 to 2015, which is equivalent to 3–5% of 2015's domestic aviation emissions (207).

In the AFOLU sector, emissions have mainly been abated as a result of decreasing rates of deforestation (see Section 3.4.2). In agriculture, certain management practices and technologies (e.g., improved grazing, fertilization management, legume sowing, or irrigation) can lead to substantial GHG emission reductions (210–213), the adoption of which has been facilitated by public policy such as R&D funding (210). Educational measures and infrastructural support can also incentivize the adoption of mitigation measures in agriculture (214). Yet overall, the application of mitigation policies in the agricultural sector has been limited. Additional and sector-spanning factors that were found to be correlated with emissions reductions include energy taxes, fuel prices, and patenting activities surrounding environmentally friendly technologies, all of which may have a strong steering effect on GHG emissions (13, 128, 135, 153).

3.4. Proximate Emission Drivers

Mitigation policies have had a discernible effect on the proximate drivers of emissions. Although most research on proximate emission drivers points to trends in energy intensity, carbon intensity, and deforestation rates, results are commonly expressed by numerous outcome metrics, such as per capita electricity consumption or the share of fossil fuels in the energy mix. The following two sections present the results of our literature review separately for energy-related and AFOLU-related drivers.

3.4.1. Energy-related drivers. Several studies demonstrate that mitigation policies have had a significant impact on energy consumption in all energy end-use sectors. Bertoldi & Mosconi (215), for example, estimated that the EU28's final energy consumption in 2013 would have been 12% (4.9 million Terajoules) higher in the absence of energy efficiency policies. The largest energy savings were achieved in the industry sector (20% compared to a simulated counterfactual case), followed by transport (12%), and households (9%), with no significant effect in the services sector. Another study found that energy efficiency policies have led to electricity and natural gas savings of 807 Petajoules in the EU's household and manufacturing sector since 2006, which is equivalent to 5.6% of the EU's combined electricity and natural gas usage in 2011 (216). In India, three energy efficiency programs resulted in energy savings of almost 27 Mtoe in 2020 (168), including electricity savings of 8% of final electricity consumption. In a meta-regression of the impact of energy efficiency policies, Labandeira et al. (217) found that they typically reduce energy demand by 8–10% compared to a business-as-usual scenario.

Improvements in energy efficiency have been attributed to various instruments, including R&D investments (31, 218), governmental subsidies (162), standards and regulation (162), and market-based approaches (162). White certificate schemes, which require utilities to assist their customers in implementing energy efficiency measures at homes for which the utilities receive tradable certificates, have led to an increase in energy efficiency in several European economies (38, 219–221). Urban planning policies have a considerable impact on energy use in buildings and transport (190, 222–225). McIntosh et al. (200), for example, demonstrated that each 1% increase in investments in public transit is associated with a 0.16% reduction in private vehicle kilometers traveled per capita on average across 26 cities in Europe, North America, and Australia.

In Europe, residential energy consumption per unit floor area declined by 52% between 1995 and 2017 when controlling for effects of climate, income, and population, implying a strong impact of energy efficiency policies (167). Regulatory policies, most notably building energy codes and standards, have enabled these substantial improvements in energy efficiency in both commercial and residential buildings (165, 226–232). In recent years, the adoption of minimum energy performance standards for the existing buildings stock has risen sharply, leading to an increase in the rate and depth of renovations (233). Other impactful instruments include Top Runner Programs for energy-efficient appliances (234) (such as, famously, in Japan), city-level benchmarking programs, and best-practice standards and labeling (228, 235–238).

While regulatory policies in buildings are generally assessed to be more effective than carbon prices or informational instruments, especially in the case of space heating, the latter have also demonstrably reduced building sector energy use (61, 231, 239). This includes feedbacks (52, 53, 62–65, 235) and nudges (66, 67). In a meta-level review on informational policies, Delmas et al. (52) found that in experiments individuals reduced their electricity consumption by approximately 7% on average across experiments. Similarly, Zangheri et al. (53) concluded that informational feedbacks reduce household energy consumption by 5–10%. However, short study periods and publication biases have raised concerns about the persistence of behavioral effects (52, 68) and the generalizability of results (61, 239, 240).

Finally, carbon prices (131, 154, 231, 239) and energy prices (64, 131) have also been found to reduce overall energy and fossil fuel use in buildings. Measures promoting sufficiency (i.e., the deliberate reduction of energy, typically not measured per unit of output) may result in energy savings (241, 242), but there is little experience with sufficiency-oriented instruments. Importantly, energy efficiency improvements in the buildings, transport, and industry sector are often at least partly offset by two factors: a rebound effect as a direct response to (policy-induced) energy savings, as well as non-mitigation policies that increase the production and consumption of more energy-intensive goods or services (234, 243–246).

To date, few mandatory mitigation policies have been implemented in the industry sector; simultaneously, few scientific studies on mitigation policy impacts on proximate emission drivers in industry exist. Carbon prices have demonstrably led to energy efficiency improvements in firms (247). Exempting industry from carbon prices or other climate-related levies on energy, on the other hand, has led to a notable increase in electricity consumption among German firms (248). Voluntary agreements (e.g., between industry and governments) have been successful in generating energy savings (249, 250) but are only rarely strictly voluntary, as they typically involve penalties or threats of sanctions (250). Case studies from South Korea and China indicate that the establishment of eco-industrial development zones (i.e., industrial symbiosis) has lowered energy use and CO_2 emissions compared to the national industry average (251–254). Lastly, end-user energy saving obligations may be effective in the industrial and commercial sector (255).

Mitigation policies have also had a discernible impact on carbon intensity (emissions per unit of energy consumption). Since reductions in carbon intensity have been mainly brought about by supply-side changes toward low-carbon technologies, such as the increased deployment of renewables for electricity generation, results are mostly reported in Section 3.5. Likewise, Section 3.3.1 on carbon pricing highlights that carbon prices led to reductions in both energy and carbon intensity, thereby ultimately reducing emissions. Using a decomposition analysis for 18 developed economies, Le Quéré et al. (23) more generally found that the number of policies on renewables and the share of fossil fuel–based energy are negatively correlated.

3.4.2. Agriculture, forestry, and other land use–related drivers. Mitigation policies have had a discernible impact on rates of deforestation, the dominant source of AFOLU sector emissions. Since policies targeting forest cover retention tend to be applied to confined, subnational geographical areas, it is infeasible to derive conclusions about the impact of mitigation policies on global land-use change. Additionally, there are multiple driving forces behind (avoided) deforestation (256), and the attribution of observed effects to policies remains challenging. Global deforestation is estimated to have peaked in the 1980s with 151 million ha net loss that decade, and has since slowed. Since 1990, many countries in temperate regions (e.g., the United States, several European countries), but more recently also countries in tropical regions (e.g., Bhutan, Jamaica, and Azerbaijan), have experienced a net gain in forests, although globally there was approximately 47 million ha net loss in the past decade (257). The following section surveys policies that have helped drive this trend.

Payments for ecosystem services (i.e., financial compensation for ecosystem protection such as forest retention) have had a discernible though likely modest impact on forest conservation (258–261). The Reducing Emissions from Deforestation and Forest Degradation (REDD+) program specifically has led to reductions in deforestation rates and tree cover loss (36, 262), ultimately leading to emission abatement (36). Land tenure regularization may incentivize participation in REDD+, potentially boosting its overall effectiveness (263). The evidence on the impacts of REDD+ is, however, mixed (263). Payments for forest protection such as REDD+ have been criticized for leading to increased deforestation outside the project areas and for failing to sustain effects once payments are discontinued (258, 259, 261, 264, 265). Furthermore, effects may be overstated in the literature as a result of selection bias: Forest area with a low likelihood of being deforested in the first place is more likely to participate in REDD+, leading to exaggerated estimates of avoided deforestation.

Deforestation rates have demonstrably been reduced by supply chain initiatives and moratoria that prohibit deforestation (266–269), the establishment of low-deforestation zones or mixed-use protection (265, 270, 271), protected area designation (268, 272), environmental enforcement action plans (273), and conservation initiatives that combine legal protection and financial incentives (267, 274, 275). Similar to ecosystem service payments, carbon leakage risks exist (266, 267). Emissions and deforestation rates can further be lowered by the adoption of certain management practices, such as climate-smart forestry (276, 277), which includes, for example, active forest management to sustainably increase productivity. The effectiveness of certification schemes, such as the FSC label, has been questioned by several empirical studies (276, 278). Finally, the translation from forest cover/deforestation to net emissions implications is one of many additional uncertainties in the AFOLU sector.

3.5. Low-Carbon Technologies

Mitigation policies have had a discernible effect on technological change, most importantly leading to investments, capacity expansions, and cost reductions of low-carbon technologies. These are mutually enhancing, as cumulative investments and deployment lead to technology cost reductions (279), which in turn spur further capacity expansion.

The most significant shift toward low-carbon technologies as a result of mitigation policies has occurred in the energy sector. Technology support policies such as R&D funding or financial deployment incentives have unambiguously led to the global diffusion of solar and wind technology (91, 280–289), having been particularly impactful in the case of solar energy (281) and in the earlier stages of the diffusion process (282). Overall, feed-in-tariffs were most effective in attracting investments in, and increasing the share of, renewable electricity generation (283, 284, 286, 289–297), followed by tax incentives and other purchase subsidies (280, 285, 286, 296, 298).

Renewable energy obligations, such as renewable portfolio standards or clean energy standards (38, 290, 299, 300), as well as auctions and renewable energy tendering schemes (289, 301), have all also supported investments So have market-based measures, such as green certificates in conjunction with emission allowances (91, 302), although likely mainly in the long run (287). Carbon prices not only incentivized the substitution of natural gas for coal (44, 115, 119, 152) but also increased patenting activities (279). In an analysis of more than 100 countries, Best & Burke (281) found that carbon prices are associated with higher rates of solar and wind adoption, although overall, the evidence on impacts of carbon prices on low-carbon innovation is limited (44, 47, 303).

Multiple studies note that renewable energy policy in general, or the Kyoto Protocol specifically, has had a significant influence on innovation activities and investments in renewable energy in countries of the Global North and Global South (91, 295, 304). Several studies find that if the stringency of a policy instrument increases (e.g., R&D subsidies or tariffs are raised), renewable energy capacity and generation also increases (91, 286).

In the buildings sector, consumer purchase intentions and behavior with regard to household appliances were influenced by regulatory and informational measures [such as energy efficiency labeling (236)], while the uptake of residential solar photovoltaics (PV) was facilitated by purchase rebates and subsidies (280, 285) as well as municipal loan schemes (305). Energy efficiency policies, especially financial subsidies and energy labels, have also been shown to increase the number of commercially relevant patents (306). Large-scale subsidy-based programs designed to incentivize fuel switching [e.g., from wood or kerosene to liquefied petroleum gas (LPG)] in residential cooking within countries of the Global South yielded mixed results: On the one hand, these programs led to the desired outcome, namely the purchase or use of new, more efficient boilers. On the other hand, households often also continued to use their old cooking devices and fuels, so air pollution and GHG emissions were not reduced as much as hoped (307–313).

In transport, the uptake of EVs has been positively affected by purchase incentives [e.g., subsidies or tax rebates (48, 314–318)], other financial incentives [e.g., free parking or charging (316, 319, 320)], nonmonetary incentives [e.g., access to bus lanes (319, 321)], and the provision of public and private charging infrastructure (314–316, 320–326). Public procurement (321), EV readiness as a building requirement for new property developments (321), informational measures (314, 315, 322), and favorable gasoline-to-electricity price ratios (322) have also been associated with EV adoption. Additionally, the cumulative number of EV-related policies positively affects EV uptake (322).

Tax incentives for the purchase of more fuel-efficient or less carbon-intensive cars led to a reduction of CO_2 intensities of new vehicles in Norway (327) and to an increase in the adoption of low-emission vehicles in the United Kingdom (328). The effect of differentiated registration taxes differs from country to country but appears to be positive overall (329, 330). Policies promoting alternative modes of transport, such as public transport subsidies, have reduced the share of car users (331) but are at risk of being offset by an increase in overall travel demand or reducing other low-carbon modes of transport (331, 332).

In industry, carbon prices have led to investments in new equipment and production technologies that are less energy-intensive (114, 333). More generally, policies of all types, but subsidies especially, have been shown to promote the adoption of green energy technologies among firms (334). With regard to cross-sectoral findings, public procurement has increased uptake of environmentally friendly technologies (38, 335). One can conclude that mitigation policies of various types have positively affected environmental innovation and the diffusion of low-carbon technologies across sectors (279, 336).

3.6. Cross-Cutting Findings

Policy mixes are, theoretically and empirically, superior to standalone policy instruments (47, 134, 190, 195, 281, 287, 302, 337–339). They demonstrate a higher effectiveness in reducing emissions (195) and stimulating innovation (339). The literature offers several explanations as to why this is the case: The superiority of policy ensembles over individual instruments may be due to the mutually reinforcing nature of policies (190, 340) and positive policy spillovers (279, 285, 339) as well as temporally varying effects (287). The combination of different policy instruments may also enable policymakers to address a multitude of adverse effects simultaneously (341, 342). Several scholars highlight that policy mixes are most effective when well-balanced, i.e., entailing both push and pull instruments (279, 339, 343, 344), for which there exists some empirical evidence (147, 344).

Evidently, the specific policy design or policy mix configuration greatly impacts overall effectiveness. Generic design features (e.g., type, stringency, duration, monitoring, reporting, and verification provisions) decisively influence policy outcomes (281, 292, 299, 345). In the case of policy mixes, for example, perceived consistency and credibility were found to affect innovation expenditures on renewable energy technologies (292, 346). Thorough implementation processes (226), which are highly dependent on the institutional setting (334, 347), also play a key role in the overall effectiveness of a policy. Importantly, policy experimentation and learning are of crucial importance in ongoing mitigation efforts (279).

Finally, several nonclimate mitigation policies are having a considerable climate impact, leading to both higher and lower GHG emissions. One prominent example includes the Montreal Protocol, which was designed to protect the stratospheric ozone layer, but also led to avoided GHG emissions (348). Similarly, pollution abatement policies that regulate SO_2, NO_x, and PM emissions have been found to simultaneously reduce CO_2 emissions (349, 350), although not qualifying as impactful mitigation channels per se (351).

3.7. Quantifying Total Abatement

Substantiating the causal link between mitigation policies and emission reductions inevitably raises a question about the magnitude of effects. We found only one top-down estimate, which suggested that climate policies and laws were associated with 5.9 $GtCO_2$/year global emission savings in 2016 (43), translating to a 15% reduction compared to a world without mitigation policy. If extrapolated to emissions in 2021 as a theoretical exercise, abatement would amount to approximately 6.4 $GtCO_2$/year. Despite inevitably having methodological limitations, it is a useful starting point. In this section, we provide a first estimate of global impacts based on a wider variety of component studies, metrics, and methodologies.

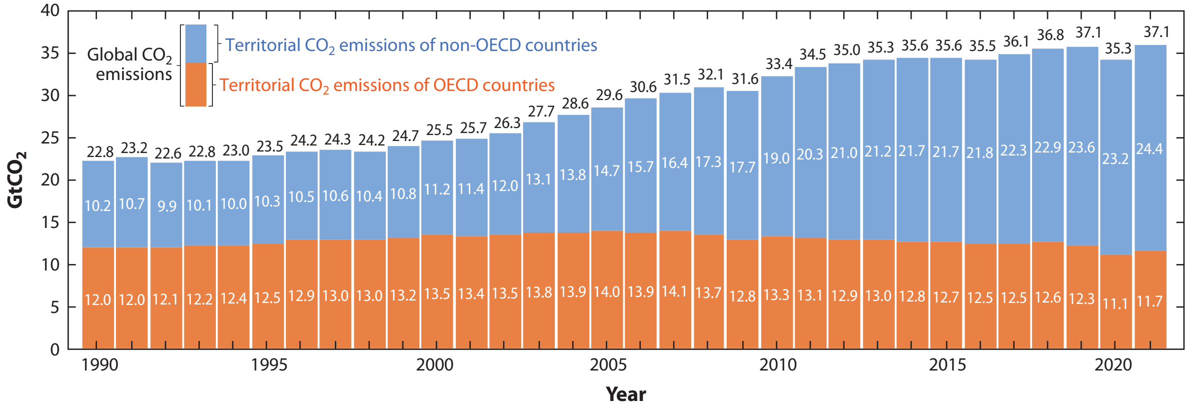
Several regional and large-*N* studies provide additional evidence of a sizable impact of climate policies. According to the most robust estimates, the Kyoto Protocol reduced emissions in Annex B countries by more than 10% below a no-policy counterfactual by 2012 (41), which was equivalent to more than 1 $GtCO_2$eq that year, and was complemented by additional abatement stemming from non-Annex B countries (71). The EU ETS (39, 40, 113) and other carbon pricing schemes (see Section 3.3.1) have led to annual abatement of approximately 200 $MtCO_2$/year. The abatement due to India's energy efficiency program is of a comparable scale (172 $MtCO_2$ in 2020) (168), and abatement due to energy efficiency policies in the EU was larger still (Section 3.4.1).

For relevant context, according to a 2020 publication by the United Nations Framework Convention on Climate Change (UNFCCC) (352), Annex I countries reported 2,624 policies and measures in their fourth biennial reports and quantified impacts for 38% of them, totaling emission abatement of 3.8 $GtCO_2$eq for 2020. Overall, Annex I parties' total emissions were 13% lower than in 1990, which was attributed to two main causes: the economic restructuring of economies in transition and the strengthening of mitigation actions. The 2022 UNFCCC synthesis report, which aggregates information from countries' latest available NDCs (353), shows that the projected emission levels for 2025 are 1.8 (4.8 for 2030) $GtCO_2$eq lower for those parties that submitted updated NDCs than in the previous report.

The global diffusion of renewable energy technologies can also be translated into emission impacts. When attributing 70% of the observed capacity expansion of wind and solar power to mitigation policies—which is a justifiable assumption given ample evidence on policies' substantial impact (91, 280–289)—renewable energy policy has likely abated emissions of 1.3 to 2.5 $GtCO_2$eq/year in recent years (163), depending on assumptions on the electricity mix that is being displaced. The IEA estimates that capacity additions of renewables and EVs in 2022 alone led to the abatement of 1 $GtCO_2$ (164) (0.7 Gt when attributing 70% to policy).

As noted, annual growth in global emissions has slowed over the past decade and emissions have declined in many countries (**Figure 2**). Given the persistence of effects and the cumulative

a Annual global CO_2 emissions



b Yearly absolute change in CO_2 emissions

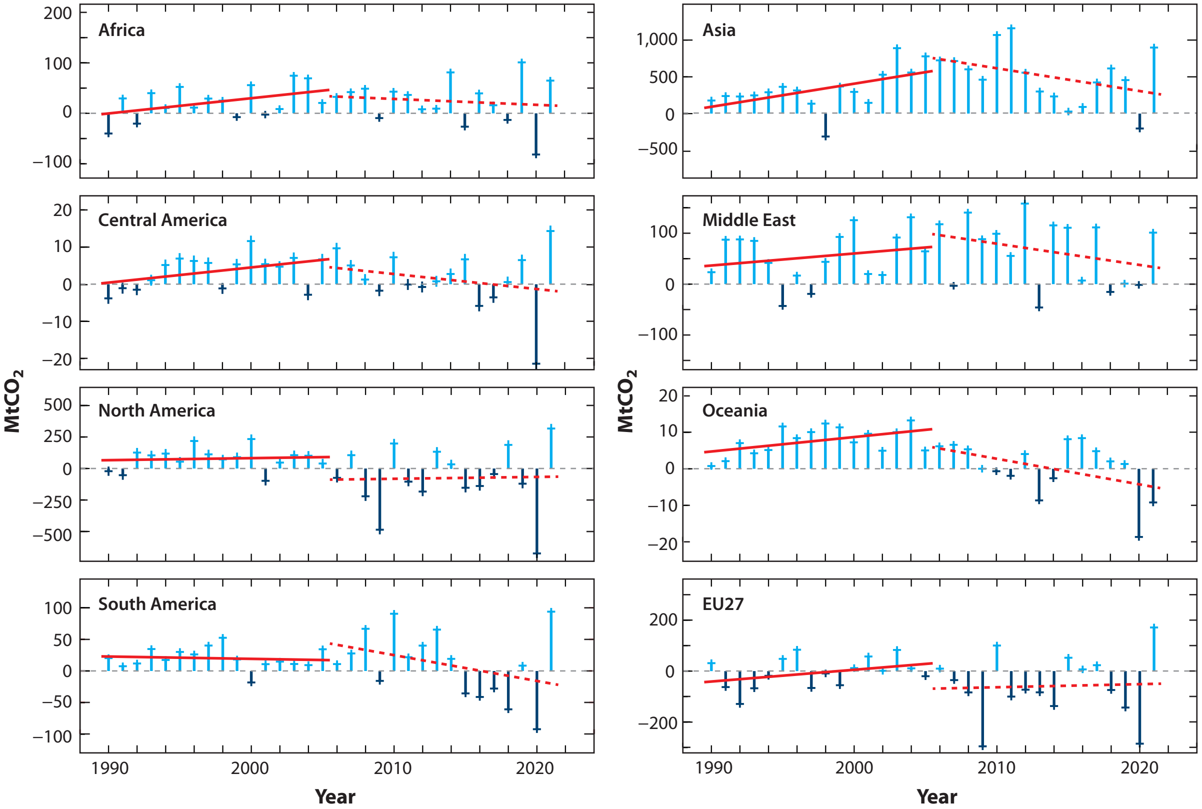


Figure 2

(*a*) Annual global CO_2 emissions. (*b*) Absolute change in CO_2 emissions. The blue bar lines show the annual absolute change in fossil fuel and industry CO_2 emissions by region. Data do not include emissions from LULUCF given the greater uncertainties in both global and national LULUCF accounting. The red lines show two sequential trend lines, one for 1990–2005 (*solid*) and one for 2006–2021 (*dashed*). Abbreviations: LULUCF, land use, land-use change and forestry; OECD, Organisation for Economic Co-operation and Development. Data from Friedlingstein et al. (371).

nature of annual emission savings, a policy that cuts global emissions by 0.1 $GtCO_2$ per year compared to the previous year will cause cumulative abatement of 1 $GtCO_2$ after 10 years. The slowing global trend suggests reductions in emission growth that is in line with above-mentioned abatement estimates, and the Annex I official reported estimates of policy impact are also broadly consistent.

Naturally, reductions in growth rates give rise to the question of whether we have reached peak emissions. Even though GHG emissions reached an all-time high in 2022, it remains difficult to distinguish trends and establish a counterfactual that accounts for the economic rebound and general uncertainties following the COVID-19-induced recession. In OECD countries, which account for 40% of today's emissions, CO_2 emissions peaked in 2007 and have declined since (354). On a per capita level, CO_2 emissions peaked in 2012 with 4.91 tCO_2 and fell to 4.47 tCO_2 in 2020. Had per capita emissions stayed at a high level of approximately 5 tCO_2/year, total CO_2 emissions would be higher by 3.6 $GtCO_2$ today.

Figure 3 summarizes the various estimated impact of mitigation policies and contextual observations relating to global emissions. Drawing together all lines of evidence as well as contextual

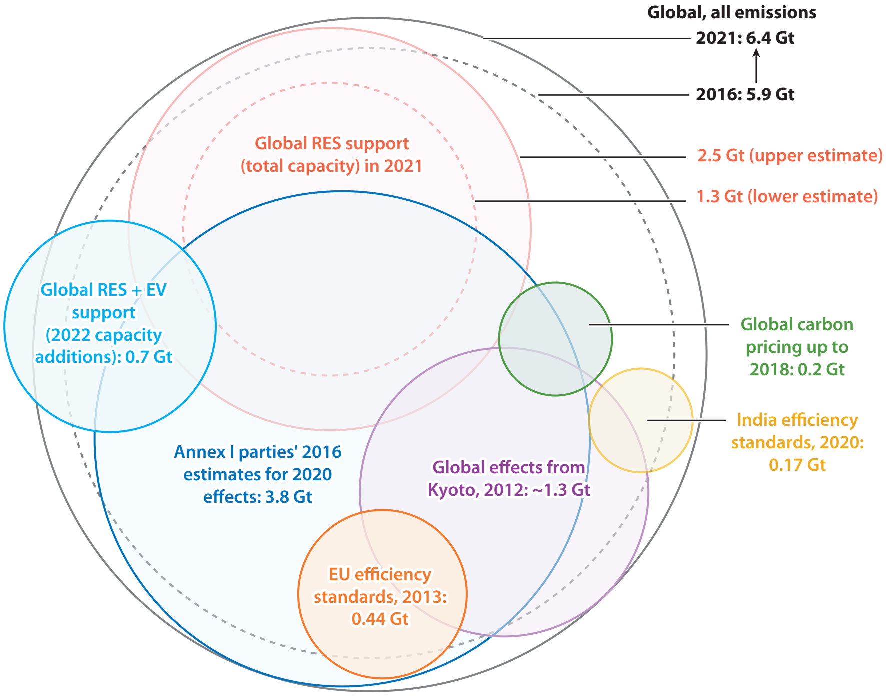


Figure 3

Overview of annual abatement estimates due to mitigation policy stemming from ex post policy evaluations (compared to a world without climate policies) and historic macro trends. The size of each circle is equivalent to the size of effect. Also, the placement of the circles indicates the (in)dependence of abatement effects and is an approximate function of the geographical and sectoral coverage as well as the type of policy instruments. For example, the EU is part of Annex I; therefore, the circle for the EU efficiency standards (*orange circle*) is situated within Annex I parties' abatement effects (*blue circle*). Abbreviations: EU, European Union; EV, electric vehicle; RES, renewable energy sources. Data from Bayer & Aklin (39), Anderson & Di Maria (40), Maamoun (41), Eskander & Fankhauser (43), Kuriyama & Abe (71), Best et al. (117), Rafaty et al. (118), IRENA (163), Malhotra et al. (168), Bertoldi & Mosconi (215), UNFCCC (352), and IEA (365). Note that our own calculations were conducted, primarily on the basis of the cited and additional data sources.

numbers, we deem the plausible range of emission abatement by 2020 to be 2–7 $GtCO_2eq$/year compared to a no-policy world, equivalent to 4–15% of total GHG emissions in 2020.

4. DISCUSSION

4.1. Limitations and Future Research

The field of mitigation attribution is still emerging and consequently there are several practical limitations to our analysis. Our method built and expanded on the literature selection and evaluation process in the preparation of the IPCC's AR6 Working Group III report, which we take as the best available representation of the research field at large, but it is impossible to review all of the existing relevant literature—much of which may be buried in reports and national evaluations rather than academic papers. Moreover, the field itself is not representative. Further research should focus on gaps in the coverage of instruments (e.g., regulatory policies), sectors (e.g., the industry and AFOLU sector), types of GHG emissions (non-CO_2 emissions), and regions (e.g., countries of the Global South). Additionally, since we focused on the immediate impact of mitigation policies on emissions, we only briefly note subsequent effects that may lessen their success (e.g., carbon leakage or rebound effects)—although these also need to set against the path-dependent, cumulative nature of many developments, and the opposing forces of positive spillovers as progress in policies and technologies lead over time to enhanced adoption globally.

There are some other problems that limit what can be firmly concluded. It remains methodologically challenging to construct realistic counterfactual or business-as-usual scenarios, and to separate the influence of mitigation policies from the rest of the noise. Regular annual fluctuations in emission levels are already substantive and get compounded by unexpected system shocks, such as the financial crisis or the COVID-19 pandemic. Publication bias may favor publishing more significant results (355, 356).

Although having noticed an increase in methodological rigor over time, as evidenced by the growing application of quasi-experimental, econometric methods, we also note that the challenges of self-selection bias, the influence of other socioeconomic trends, small sample sizes, short time frames, incomplete data, and black-box calculations are a problem to a greater or lesser degree across the literature. Future research should aim to maximize the utility of scientific research for policymaking by improving scientific integrity and sophistication while simultaneously limiting model complexity and deriving actionable policy recommendations.

This could include elaborations on the mechanisms through which policy effects occur, ultimately reporting both abatement estimates and channels of abatement. For example, did a carbon price lead to emission abatement because of a coal-to-gas switch, more efficient combustion equipment, an increase in the deployment of low-carbon alternatives, or a reduction in total demand? Overall, we hope that our results motivate further research into the question of policy effectiveness, so that future conversations on climate change mitigation are characterized by constructive dialogue based on shared evidence.

4.2. Looking Back and Looking Ahead

That emissions today are 60% higher than they were in 1990 has led some people to conclude that all efforts to combat climate change have been ineffective. Although it is true that we have collectively failed to "bend the global emissions curve" to the extent necessary to make it point unambiguously downward (17), and made insufficient progress to keep warming below 1.5°C, the literature we surveyed allows us to reject the notion that all efforts to date have been in vain. Efforts to mitigate climate change have reduced emissions compared to a world without climate policy and, most importantly, have laid the groundwork for accelerating progress in the future.

Changes in proximate emission drivers continue to create new sociotechnical and policy potentials that will enable enhanced abatement in the future. Transitions research has demonstrated that energy or sustainability transitions typically unfold in a nonlinear fashion—driven by the S-curve shaped diffusion of new technologies, practices, or complex sociotechnical system configurations (357, 358). While path dependencies and economic interests (359, 360) continue to act as significant transition barriers, there are numerous forces destabilizing the status quo and challenging the long-held dominance of the fossil fuel industry, such as increasing regulation or the diffusion of anti-fossil fuel norms (361), which unlock potential for further ambition.

The most prominent example of positive change is the expansion of renewables (see Section 3.5), which has far exceeded expectations (362). Cumulative deployment led to learning effects and economies of scale (363), which drove down prices (364) and thereby stimulated further deployment. This positive feedback mechanism is best documented in the case of solar PV and wind power and already contributes significantly toward total abatement (see Section 3.7). Meanwhile, other low-carbon technologies, such as heat pumps or EVs (365), are similarly starting to enter a phase of exponential growth. The displacement of their carbon-intensive counterparts over the next few years will materialize in additional sizable emission reductions. These reductions are not only due to direct decarbonization, as the emission factors per unit of energy for electricity decrease, but also due to efficiency gains from the electrification of end-use technologies leading to less energy lost in conversion as direct electricity use is more thermodynamically efficient than other fuels that produce heat as a by-product.

Importantly, positive feedbacks occur not only in the realms of new technologies but also in policymaking. Mitigation policies lead to changes in the real world that render more ambitious policies feasible. Such policy sequencing and ratcheting up has been observed in countries with several decades worth of climate policy experience (366, 367). Drivers include political interest feedbacks (368), such as changes in the composition and resource equipment of actor coalitions (369). In addition, there are social conformity feedbacks resulting from network effects and social norms (368, 370). These may lead to social tipping points that tip the scales in favor of less carbon-intensive lifestyles.

Despite these positive developments, we caution against unconditional optimism. Even though we are witnessing new dynamics in global trends, not all technological, political, or social changes ultimately enhance climate protection. Predictions about the future continue to be complicated by unforeseeable developments. Most recently, Russia's war against the Ukraine sent ripple effects through Europe and beyond that will have long-lasting impacts on countries' energy systems. Additionally, the complex web of interconnected actors and institutions with their myriad of (economic) interests heavily influences the speed and direction of change.

4.3. Policy Horizons

In terms of concrete policy recommendations, our review confirms that there exists no silver bullet approach to climate mitigation. Policy mixes that include different types of instruments tend to outperform single policy instruments, with impacts highly dependent on both policy design and implementation. Moreover, a policy that has been effective in reducing emissions in one country or sector may not necessarily have the same effect elsewhere. Nevertheless, there is now almost 30 years of mitigation policy to learn from.

Previously, reductions in energy intensity have been the key driver behind emissions abatement. Going forward, however, reducing carbon intensity will be of paramount importance given the need to reach climate neutrality. This highlights the central role of technology policy which particularly targets the replacement of carbon-intensive technologies with climate-friendly alternatives. Since low-carbon technologies largely reduce emissions by displacing carbon-intensive capital stock, their effects are largely persistent. They are less subject to rebound effects and leakage and may be more likely to create positive spillovers than some other measures. Nonetheless, policies targeting reductions in energy intensity (e.g., energy efficiency programs or carbon pricing) will continue to be important as they facilitate the transition to a fully decarbonized energy system and reduce overall costs.

Assuming that population growth is unlikely to be influenced by climate policy per se, one key remaining emissions driver is GDP per capita, on the assumption that higher economic activity as measured by GDP is associated with higher emissions—in which case, the traditional political equating of GDP growth with welfare is problematic. Our review is unable to assess the effectiveness of policies which might seek to curtail overall economic and resource consumption, in pursuit of sufficiency, given their paucity. If this is a path that policymakers decide to take, then our assessment is nonetheless helpful as we demonstrate which policies have successfully reduced energy demand and increased energy efficiency, which could act synergistically with the application of sufficiency-oriented policies, such as reducing working hours, to increase overall welfare while mitigating the adverse side-effects of economic activity. These policies have not yet been assessed ex post, however, and therefore could not be included in this review.

Of course, policy learnings from the past are not fully indicative of policy impacts in the future, and it remains possible that societies find new and maybe radically different paths in the coming years. Yet, experience serves as our best starting point when devising policies going forward. We demonstrate that mitigation policies have largely led to the changes they were intended to cause, which calls for a continuation and ratcheting up of existing efforts. At the same time, policy has to recognize the inadequacy of progress to date: Mitigation policies must become compatible with climate neutrality goals, which warrants an elimination—not just reduction—of GHG emissions.

5. CONCLUSIONS

Our review of the literature on the impact of mitigation policies culminated in three main findings. First, mitigation policies have demonstrably led to avoided GHG emissions, with the majority of studies reporting a statistically significant effect, either in terms of absolute, real-world reductions in their study sector/boundary or through counterfactual estimations relative to a world without these policies (**Figure 2**). Second, mitigation policies have had a discernible impact on proximate emission drivers, most notably leading to reductions in energy demand, energy intensity, carbon intensity, and rates of deforestation. Thirdly, mitigation policies have had a notable and positive impact on investments, capacity expansions, and cost reductions of low-carbon technologies, especially in the case of renewable energy technologies (e.g., wind and solar), energy-efficient appliances, and EVs. Additionally, we find that policy mixes are superior to standalone policy instruments and that the impact of policies heavily depends on policy design and the institutional context.

It may appear rather straightforward that mitigation policies lead to changes in emission trends. However, the causal link between climate action and real-world impacts remains insufficiently explored. Although the science on the cause of the problem—anthropogenic climate change—has reached consensus, the science on how to best tackle this problem has not. Our key contribution to the available literature lies in establishing an empirically based track record of climate action, focusing on methodologically sound ex post studies.

Policies appear to have delivered on their stated goals (at least to some extent) but do not have the breadth and depth needed to avoid catastrophic climate change. The results presented in this study suggest that we not only need more ambitious and well-designed policies, but we also need to overcome the barriers that prevent policies from realizing their full potential. These barriers exist in politics, society, and the historical record of development trajectories at large and are fundamentally uncertain and unpredictable. Achieving climate neutrality requires a transition to a fundamentally different global system, one which will have to be built in the face of the impossibility of certainty.

We can, however, estimate that mitigation policies to date have led to global GHG abatement of 2–7 $GtCO_2$eq/year in recent years, and changed the trajectory of both emissions and technologies. Although the existing set of policies is vastly insufficient for closing the remaining emissions gap for 2030 of 13–20 $GtCO_2$ (353), realized abatement has put us in a much better position compared to a world without three decades of mitigation policy. Additionally, changes in proximate emission drivers have created new abatement and policy potentials. Although debates continue about the scale and nature of future efforts implied by the 1.5–2°C range of the Paris temperature goals—a topic beyond the scope of this article—we tentatively conclude that delivering the goals would likely be inconceivable without the progress made to date.

SUMMARY POINTS

1. A variety of emissions mitigation policies have accumulated and expanded over past decades.
2. Climate policy has had a discernible impact on global emissions and its proximate drivers, while still being far from sufficient to meet the Paris goals.
3. Different policies have contributed in different ways and sectors, though in general multiple policies can be mutually reinforcing and build on previous progress.
4. A quarter of studies (26%) are international in scope, and econometric panel studies indicate significant emissions reductions associated with meeting Kyoto Protocol targets by 2012 (probably exceeding 1 $GtCO_2$/year). Another 30% of studies focus on EU/European countries that accounted for most of the emissions capped under the Protocol, but the scope of policies and of assessments has substantially broadened over time.
5. The largest single contribution to emissions mitigation to date is assessed to arise from the range of policies targeted to support renewable energy, but a wide variety of other policies aimed at both supply and demand, including pricing policies that affect both, have made important contributions as well.
6. Substantial methodological challenges and uncertainties remain particularly in quantified attribution of changes in overall emissions to specific policies.
7. By integrating various strands of empirical evidence, we estimate that mitigation policies had cut global emissions by 2–7 $GtCO_2$eq/year by 2020, relative to a world without those policies, equivalent to 4–15% of total GHG emissions that year.
8. There is much to learn from the successes and failures of emission mitigation policies; policy analysis can increasingly draw on not just what should be done, but what has been done and an assessment of what it delivered, emphasizing a new and more real-world focus for research on “what works?”

FUTURE ISSUES

1. There remain poorly charted areas of policy, especially around the land-use and agriculture sectors, and more widely around behavior and values that may affect consumption choices.
2. Research should explore and track more systematically a wider variety of proximate emission drivers and key indicators.
3. Forward-looking models should strive to include more social and empirical insights from ex post policy analysis.
4. Compared to the dominant focus of mitigation research on model-derived indications of what should be done in abstract, we suggest a need for more focus on what has proven effective and requires further acceleration and global implementation.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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