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Climate Change Mitigation Strategies: A Review of Recent Advances and Debates

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ABSTRACT

Recent developments in climate change mitigation strategies are thoroughly examined in this systematic review, which focuses on technological innovations, policy frameworks, economic instruments, and equity considerations. Web of Science, Google Scholar, Scopus, and JSTOR were among the key databases systematically searched to compile the review, which encompasses studies published from 2010 to 2024. A mix of terms like *"climate change mitigation," "renewable energy," "carbon pricing," "technological advancements," "policy frameworks," and "equity"* were employed to detect relevant studies. We started with 345 records found through database searching and finally, 89 studies were selected for the review. Studies that did not offer empirical data or that were opinion pieces were not considered for inclusion; instead, we examined peer-reviewed research that assessed the efficacy of climate mitigation strategies. Standardised instruments for evaluating the potential for bias in both randomised controlled trials and non-randomised studies were utilised for this purpose.

According to findings, solar photovoltaic costs have dropped by 82% and wind power by 39% due to technical advancements highlighted in the review. As a consequence, these renewable energy sources are becoming more competitive with fossil fuels. The results also highlight the significance of strong policy execution, especially in international accords, to achieve coordinated global climate action. Carbon pricing mechanisms, including carbon taxes and cap-and-trade systems, are essential economic tools for encouraging sustainable behaviour and investing in low-carbon technology; they currently affect about 22% of worldwide emissions. Important results show that renewable energy is vital to lowering greenhouse gas emissions, carbon pricing works to motivate climate action, and that a fair transition requires attention to equity concerns. Additionally, the review points out that present mitigation efforts are lacking, especially when it comes to the scalability of new technologies like hydrogen production and carbon capture and storage. Achieving global climate goals and securing a sustainable future requires a holistic strategy that incorporates technical, policy, and economic measures, with a heavy emphasis on fairness.

Keywords: Climate change mitigation, Renewable energy, Carbon pricing, Technological advancements, Policy frameworks, Equity, Low-carbon economy

Introduction

One of the most important issues we have now is climate change. People are mostly to blame because they release greenhouse gases (GHGs) as they cut down trees, make things in factories, and burn fossil fuels that cause these emissions.[1] It is also influencing our health, food security, water resources, ecosystems, and the economy.[2,3] New economic instruments, regulatory frameworks, and technological advancements are necessary for climate change mitigation strategies. Two innovative new ideas that might reduce emissions of GHGs are renewable energy sources and carbon capture and storage (CCS) systems.[4] It is possible for people from all over the world to work together and take action due to international agreements like the Paris Agreement. Putting a price on carbon and using other economic tools can help low-carbon technologies grow and induce people to cut down on their carbon emissions.[5]

In this work, we have explored current efforts to fight climate change including new information, major problems, trends, and ongoing discussions in the area. By putting together the results of several studies, this paper attempts to help us better understand the pros and cons of various mitigation strategies. The significance of work lies in a comprehensive analysis of new developments and recent progress in stopping climate change. Moreover, we have examined the newest changes in economic tools, policy, and technology. Environmental activists, legislators, and researchers can all benefit from this review. The study also finds places where information and actions are lacking and suggests future research and policy that should fill these gaps.

Many influential events are happening in the field of climate change. As countries try to meet their obligations under the Paris Agreement and other international agreements, they need to know which types of strategies for reducing GHG emissions work, their possible implementation, and their applicability to diverse cultural and social contexts. The study's findings could help policymakers decide to direct finances for low-carbon technology and push countries to work together to meet global climate goals. In sum, our research shows how to effectively implement numerous novel approaches to mitigating climate change and conveys important information about these strategies. It highlights the critical need for ongoing innovation and the integration of diverse perspectives to address the pressing issue of climate change.

Objectives

The main goal of this review is to examine the efficacy of climate change mitigation strategies in relation to technological developments, economic tools, and policy frameworks. The main objectives of the study are to,

i. Evaluate the potential of technological innovations to drastically decrease GHG emissions.

This includes renewable energy sources like solar and wind power as well as CCS systems.

ii. Analyse how carbon pricing mechanisms (such as carbon taxes or cap-and-trade systems) and other economic tools can encourage the adoption of low-carbon technology and change people's habits to be more environmentally friendly.

iii. Analyse how well national and international climate agreements, such as the Paris Agreement, have coordinated action on a global scale and how well they have ensured compliance.

iv. Recognise problems and opportunities, with a focus on issues surrounding the equitable considerations required for a fair transition and the scalability of new technology.

We highlight the ongoing debates and challenges in this field and provide a comprehensive analysis of the progress made in climate change mitigation based on the findings from various studies.

Literature Review

Historically researchers, scientists, and other academicians are in a pursuit to find ways to slow down climate change.[6] Laws, economies, and technical methods are all explored in the studies as ways to lower GHG emissions. In the next section, we will explain the technological advances that are allowing us to switch to a low-carbon economy. We will also explain national and international climate policies and economic tools that help reduce emissions.

Technological Innovations

In the battle against climate change, they are crucial because they allow us to use energy more efficiently and emit fewer GHGs.[7] Renewable energy technologies have made tremendous progress over the past several years, getting better and cheaper.[8] Now more people can get solar and wind energy for less money. *Photovoltaic (PV)* solar power has become 82% cheaper since 2010.[9,10] There are more PV panels on the market now than ever before because there is increased production and because supply chains are getting more competitive.[11] Better perovskite solar cells and bifacial solar panels that can take in light from both sides are examples of new technologies.[12] Wind power has also become a lot cheaper. In the last ten years, the price of one type of onshore wind energy has dropped by 39%.[13] This price decrease is due to new technologies that make it easier to collect energy and that cost less to maintain.[14] These technologies include bigger turbine blades, taller towers, and better materials. More offshore wind farms are also being built that are stronger and more stable wind resources at sea and have higher capacity factors.[15]

As renewable energy sources do not always work, we need to store energy to make sure there is a steady flow of power. Lithium-ion batteries, in particular, have become more efficient and cheaper as battery technology has changed which made it easier to store energy.[16,17] These changes are possible because of new electrode materials, electrolyte mixes, and battery management systems. Lithium-ion batteries are used in a lot of different areas like electric cars and power grid storage. Hydrogen storage, lithium-ion batteries, flow batteries, and compressed air energy storage are among the technologies that are still under investigation for energy storage.[18] According to the International Energy Agency (IEA) (2019), electrolysis is a good way to make hydrogen, which can be used in fuel cells and other heavy machinery.[19] The National Renewable Energy Laboratory found that flow batteries, which use liquid electrolytes, could store a lot of energy for a long time and could be used in grid applications.[20] The CCS technology stores CO_2 emissions from factories.[21] New CCS projects, like Norway's Northern Lights programme, show that it can be used on a larger scale. The goal of this project is to store CO_2 from factories in Europe in rock formations under the North Sea.[22] To discover ways to lower energy costs while increasing the rate of capture, new technologies such as oxy-fuel combustion, post-combustion capture, and pre-combustion capture are being studied.[23] Even though CCS has a bright future, it has to deal with problems like high costs, a lot of energy use, and opposition from the public.

The impact of CCS technology on power plants' CO_2 emissions is effectively illustrated in Figure 1. The reference plant gives off 0.8 kg/kWh of CO_2 if CCS is not used. Things get trickier at the plant when CCS is present, as it takes more energy to capture, move, and store CO_2, it makes more CO_2 per unit of energy, even though it only gives off 0.2 kg/kWh and captures 0.6 kg/kWh. The reason for this rise in CO_2 emissions is that power plants that use CCS technology are less efficient in general. There is more "CO_2 produced per unit of product" at the CCS plant than at the reference plant that does not capture it. This is because these processes require more energy and there may be leaks during transport. Despite this, the big drop in CO_2 emissions shows that CCS technology could help slow down climate change, even if it means using less energy.

Costs for CCS technologies ranged from $15 to $130 per metric ton of CO_2 in the year 2023. The prices per tCO_2 varied between $100 and $345. This is because

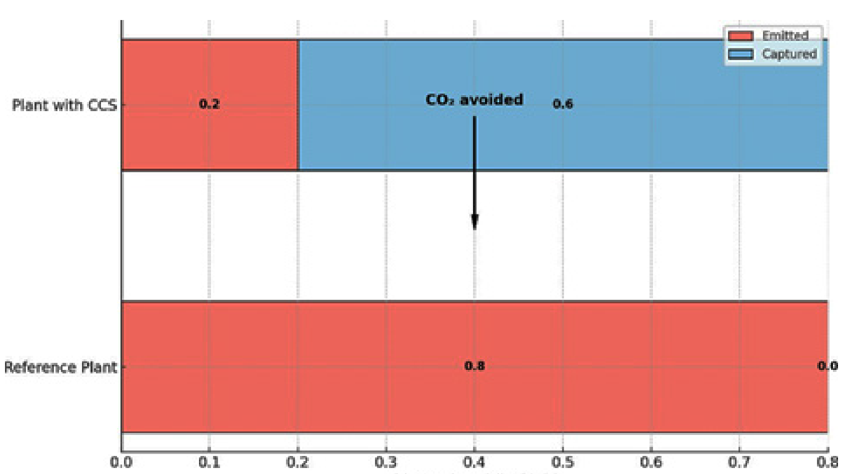

Fig 1 | Comparison of CO_2 emissions and capture for different plant types

Data source: Friedlingstein et al.[24] Global Carbon Budget 2023.

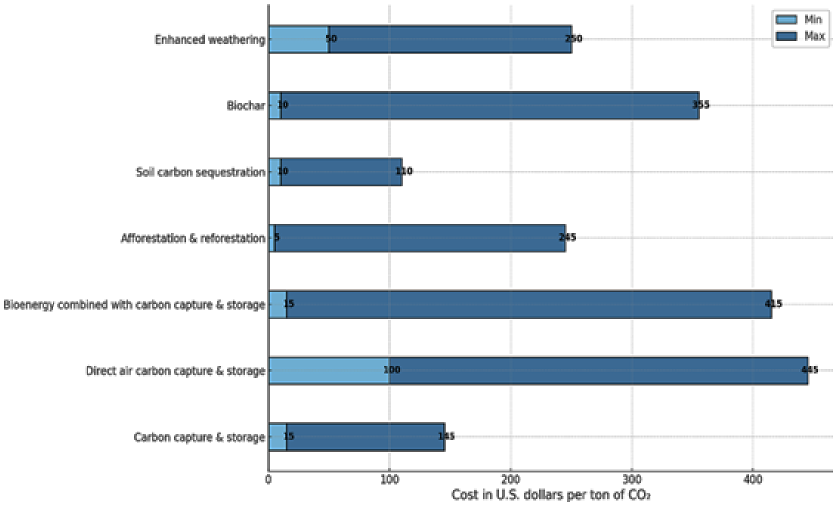

Fig 2 | Cost of CCS and CDR solutions worldwide in 2023[25]

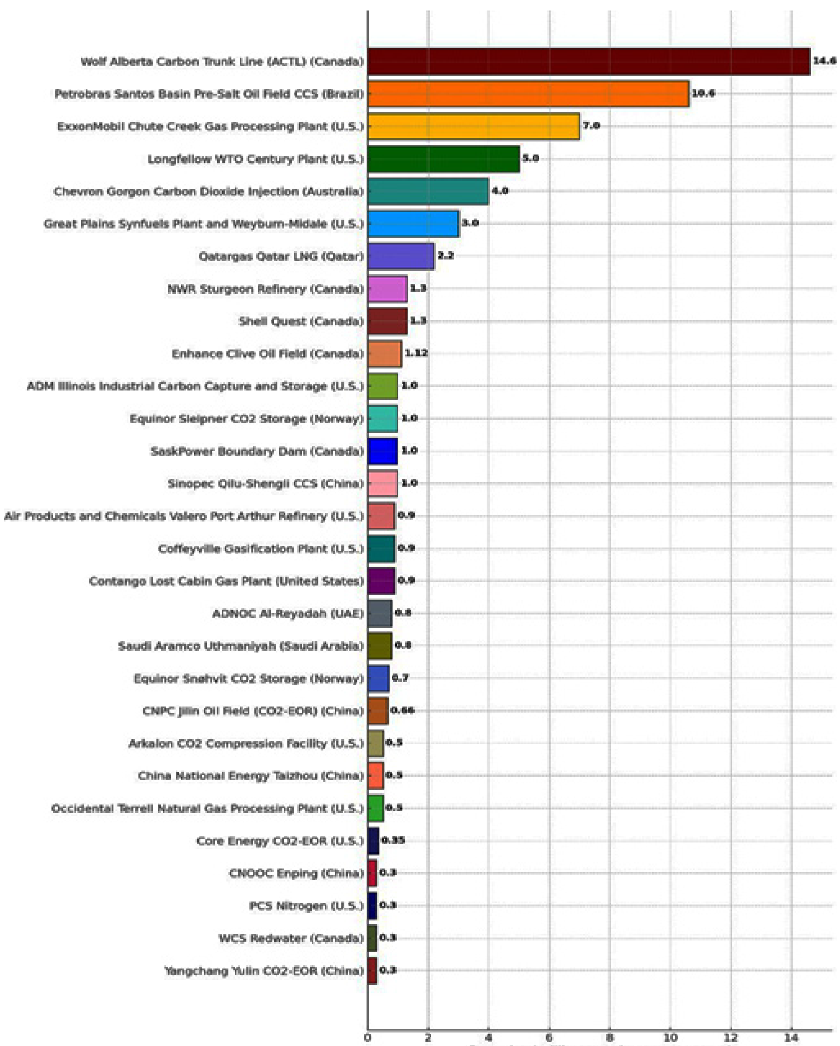

Fig 3 | Total annual capacity of operational large-scale CCS facilities around the globe in 2023.[27]

extracting CO_2 from the air directly is a more labour- and energy-intensive process. There was a time when people thought that solutions based on nature, like afforestation and reforestation, which include planting trees to absorb CO_2, would cost anywhere from $45 to $240 per tCO_2. A very broad price range was observed for bioenergy coupled with carbon capture and storage, which went from $15 to $400 per tCO_2 as depicted in Figure 2. The two most affordable options in the CCS and CDR ranges were biochar and soil carbon sequestration. Technologies that capture carbon may be pricey, but we need them to cut down on emissions and meet global climate goals.[26]

The Wolf Alberta Carbon Trunk Line in Canada is the biggest operational CCS facility in the world, as shown in Figure 3. With a capacity of 10.6 metric tonnes per year, the Petrobras Santos Basin Pre-Salt Oil Field CCS demonstrates Brazil's commitment to reducing carbon emissions through the use of new technology. The United States has invested in CCS, as evidenced by the 7 metric tonnes per year capacity of the ExxonMobil Shute Creek Gaz Processing Plant. The Longfellow WTO Century Plant in the US and the Chevron Gorgon Carbon Dioxide Injection project in Australia are two more important plants. Each can handle 5 and 4 metric tonnes per year, respectively. The fact that these projects are happening all over the world shows that CCS technologies are used in many places, like North America, South America, and Oceania. The Paris Agreement seeks to prevent global warming to significantly lower than 2°C compared to pre-industrial levels by coordinating international efforts to curb the phenomenon.[28] Emissions reduction programmes are in place at both the national and state levels like the Green Deal in the EU and cap-and-trade in California. A carbon tax is one of the best ways to use the economy to cut down on pollution and get more people to use technologies that use less carbon. These policy frameworks have changed over time.

International Agreements

At COP21, the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change, world leaders signed the Paris Agreement.[29] In the battle against global warming, this was a major victory. That we should all do our part to halt the spread of climate change was the driving force behind this massive event. The goal is for the temperature to rise no more than 1.5°C above what it was before industrialisation, and no more than 2°C. The Paris Agreement's main goal is to keep warming well below 2°C above pre-industrial levels this century. The second objective is to reduce emissions of GHGs without negatively impacting food production while simultaneously bolstering the global response to climate change. The nationally determined contributions (NDCs) are a key part of the Paris Agreement. These are the promises that each country made about how they will deal with climate change and cut their emissions. Every country has to send in a new NDC every five years. The nation's highest hopes should be reflected in each new NDC, and each one should be better than the last.

The Paris Agreement stresses the importance of giving developing countries financial and technical help because it knows that different countries have different levels of aptitude to deal with climate change. Developed nations are expected to lend a hand to developing nations in their battle against and adaptation to climate change.[30] Its goal is to raise $100 billion every year. Paris Agreement is very ambitious, but its success depends on the commitment and effectiveness of the signatory country. Different countries may not be able to reach their goals in the same way because of differences in political will, economic development, and the ability to put plans into action.

To meet their very high environmental goals, many countries have made big plans to cut down on pollution and switch to clean energy sources. The European Green Deal is one of these plans for the EU to be carbon-neutral by 2050.[31,32] While many countries have tried to meet the global temperature goals, their NDCs have either not been updated or been woefully inadequate. Some areas have had to stop or slow down their efforts to fight climate change because of the COVID-19 pandemic, political unrest, and economic downturns. The goals of the Paris Agreement can only be reached with the help of businesses, cities, and civil society groups, as well as states. The Global Covenant of Mayors for Climate & Energy and the Science-Based Targets initiative are two examples of public-private partnerships that aim to reduce emissions and increase global resilience to climate change.[33] For the Paris Agreement to work, everyone involved needs to keep working hard and do even more. Before sending in their updated NDCs, countries should immediately raise their goals and work harder. To reach these goals, we need to improve global cooperation, help developing countries as much as possible, and encourage the sharing of ideas and technology. Lots of resources are used and thrown away in electronics, batteries, and textiles, among other things. Many ideas are in the Green Deal for lowering carbon emissions from transport. Some of these are expanding public transport, getting more people to buy electric vehicles (EVs), and creating eco-friendly ways for people to get around cities.[34,35] Under the *"Fit for 55"* programme, cars and vans will have to follow stricter rules about how much CO_2 they can put into the air. With the Biodiversity Strategy, one goal is to protect 30% of Europe's land and sea.[36] On the other hand, the Farm to Fork Movement wants to make a food system that is fair, healthy, and good for the Earth.[37] There are weak economies in some EU member states, and it costs a lot to build green infrastructure and technology. This makes it hard to meet the Green Deal's high standards for climate action. For the Green Deal to work, action from all areas must be coordinated and consistent.

Economic instruments

Economic instruments are very important for fighting climate change because they give people and businesses subsidies to improve low-carbon technology and reduce emissions of GHGs.[38] One of these tools that has gotten a lot of attention and use around the world is carbon pricing, which includes both taxes and trading in emissions credits.

Carbon Pricing Mechanisms

A carbon tax establishes a direct price for carbon by taxing the quantity of carbon in fossil fuels.[39] It is the main goal to lower the costs that people and businesses have to pay because of carbon emissions. Since it will cost more to release CO_2, they will be more motivated to cut down on their carbon footprint. Either the mining or importing of fossil fuels or their combustion can be subject to the tax. One of the world's most stringent carbon taxes is in place in Sweden.[40] The price per metric tonne of carbon dioxide is around $120. Despite rapid economic growth, Sweden's GHG emissions have decreased by over 25% since the implementation of the country's carbon tax in 1991.[41] The carbon tax in British Columbia started at $10/tonne of CO_2 in 2008 and has been gradually increased to $50/tonne. Redistributing tax cuts to the general public, as is the case with revenue-neutral taxes, has reduced fuel consumption and emissions of GHGs without slowing economic growth.[42,43]

As of the year 2024, the worldwide carbon pricing instrument landscape is seeing several initiatives aimed at lowering carbon emissions and increasing sustainability. Some regions have used compliance tools like carbon taxes and emissions trading systems (ETS), while others have used crediting systems or a combination of the two. The presence of numerous such instruments in the North American, European, and Asian continents is indicative of robust regulatory frameworks and dedication to cutting carbon emissions in those regions.[44] The carbon credit markets are made up of forty subnational jurisdictions and forty instruments as well. This makes it clear how important it is for local governments to help reach national and international goals for lowering carbon emissions.

Cap-and-Trade Systems

When we trade emissions, it is called "cap-and-trade".[45] Most of the time, the cap is slowly lowered so that emission goals can be met. If a business wants to trade emission allowances with another business, it can get them or buy them. It does not cost a lot of money to use this market-based strategy to cut emissions, and people still have choices. The European Union ETS, which began in 2005, is the largest cap-and-trade zone in the world with nearly 40% of the EU's GHG emissions.[46] Electricity and industry have put out a lot less pollution since the EU ETS was put in place. Since the price of carbon went up recently, more money has been put into low-carbon technology, and emissions have gone down even more. Cap-and-trade programmes safeguard ecosystems by establishing transparent limits on pollution emissions.[47] The adaptability of trading allowances contributes to a reduced total cost of compliance.[48] In addition to promoting new technology, these systems can create a market for reducing emissions. Market fluctuations can affect carbon prices, making cost planning more challenging for businesses.

The Global Warming Solutions Act of 2006 (AB 32) established California's cap-and-trade programme, which is one of the most comprehensive and strict climate policies in the US.[49] By 2020, the programme aims to lessen GHG emissions in California to 1990 levels, and by 2030, those levels will have been cut by 40%. As part of the programme, regulated entities like power plants, factories, and fuel distributors are limited in how much GHG they can put into the air. As the cap is lowered every year, total emissions will slowly go down over time. Entities need to get permits to pay for their emissions. One allowance is equal to one metric tonne of CO_2. These allowances can be bought at state auctions, secondary markets, or through business-to-business trading. The trading mechanism gives people choices, which encourage them to cut their emissions in a way that does not cost too much. A company can only use a certain number of carbon offsets to meet their programme compliance requirements. Since it began, California's cap-and-trade programme has cut down on pollution, pushed for new environmentally friendly technologies, and brought in a lot of money for the state. Businesses have been pushed by the programme to use less energy and put money into renewable energy. When allowances are auctioned, the money goes to climate and environmental programmes that do things like use renewable energy, help low-income communities, and save energy and money.

Around 22% of the world's emissions will be covered by 60 different carbon pricing programmes by the year 2021.[50] Different national and regional situations require different approaches, as demonstrated by the inclusion of carbon taxes and cap-and-trade systems in these plans. In 2021, China launched its national ETS which initially was limited to the power sector, which was churning out 40% of the nation's carbon dioxide emissions.[51] Carbon pricing in Canada is a shared responsibility between the federal and provincial governments. The federal safety net ensures a uniform minimum price for carbon across the country. Carbon taxes in Quebec and cap-and-trade systems in British Columbia are two examples of how provinces can establish their systems.[52–54] Carbon pricing is a powerful motivator for innovation in low-carbon technology. These systems encourage investments in renewable energy, energy efficiency, CCS, and other technologies necessary for a low-carbon economy transition by assigning a monetary value to carbon emissions.

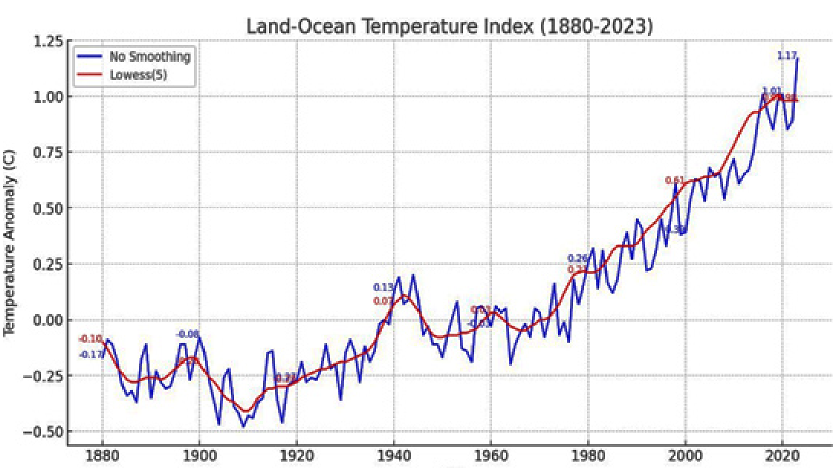

Fig 4 | Land-Ocean Temperature Index (1880–2023)

Source: Authors' Calculation based on data extracted from NASA's Goddard Institute for Space Studies (GISS). Credit: NASA/GISS[56]

Recent Evidence and Trends

Climate protection initiatives must prioritise the energy sector due to the high levels of GHGs it emits. A shift away from fossil fuels and towards renewable energy sources has been noticeable in recent trends. Renewable energy sources accounted for nearly 90% of 2020's overall power capacity increase.[55] Growing reliance on renewable power sources is a key component of international efforts to reduce carbon emissions. Solar and wind power have been pioneers, with massive investments resulting in improved technology and cheaper prices. Solar PV installations have skyrocketed as a result of falling costs. One of the most cost-effective methods to generate new power in many regions is through PV now. The efficiency and effectiveness of wind turbines have also contributed to the rapid expansion of onshore and offshore wind power.

Figure 4 compares the present-day average global surface temperature to the long-term average between 1951 and 1980. Global Interplanetary Science System (GISS) data shows that the average surface temperature of Earth reached a new record high in 2023. As compared to the average temperature before industrialisation in the late 1800s, the surface temperatures of the Earth were approximately 2.45°F (1.36°C) higher in 2023. The rate of global warming is being demonstrated by the fact that the past decade has been the warmest on record.

Electrification and Energy Efficiency

Strategies to reduce emissions should prioritise increasing energy efficiency and supplying electricity to critical areas. GHG emissions can be significantly reduced by shifting from fossil fuels to electricity, particularly electricity generated from renewable sources.[57] The proliferation of EVs is causing rapid shifts in the transportation sector.[58] As a result of falling battery prices, policies that promote them, and increased public awareness, the number of EVs sold worldwide surpassed 2 million units in 2019 and is continuing to rise.[59] All across the globe, governments are establishing targets to phase out gas-powered vehicles and increase funding for EV charging infrastructure. It is planned that by 2030, thirty million zero-emission vehicles will be on the roads in the European Union.

Another important area is the electrification of heating systems, especially those in buildings. Heat pumps are quickly becoming more popular than oil and gas boilers because they are cheap to run, are efficient, and can use electricity from renewable sources.[60] Rules and incentives are making this move towards greener, more energy-efficient building methods that make less heat possible. An important way to save energy is to make factories run more efficiently, use appliances that use less energy, and make buildings more energy-efficient.

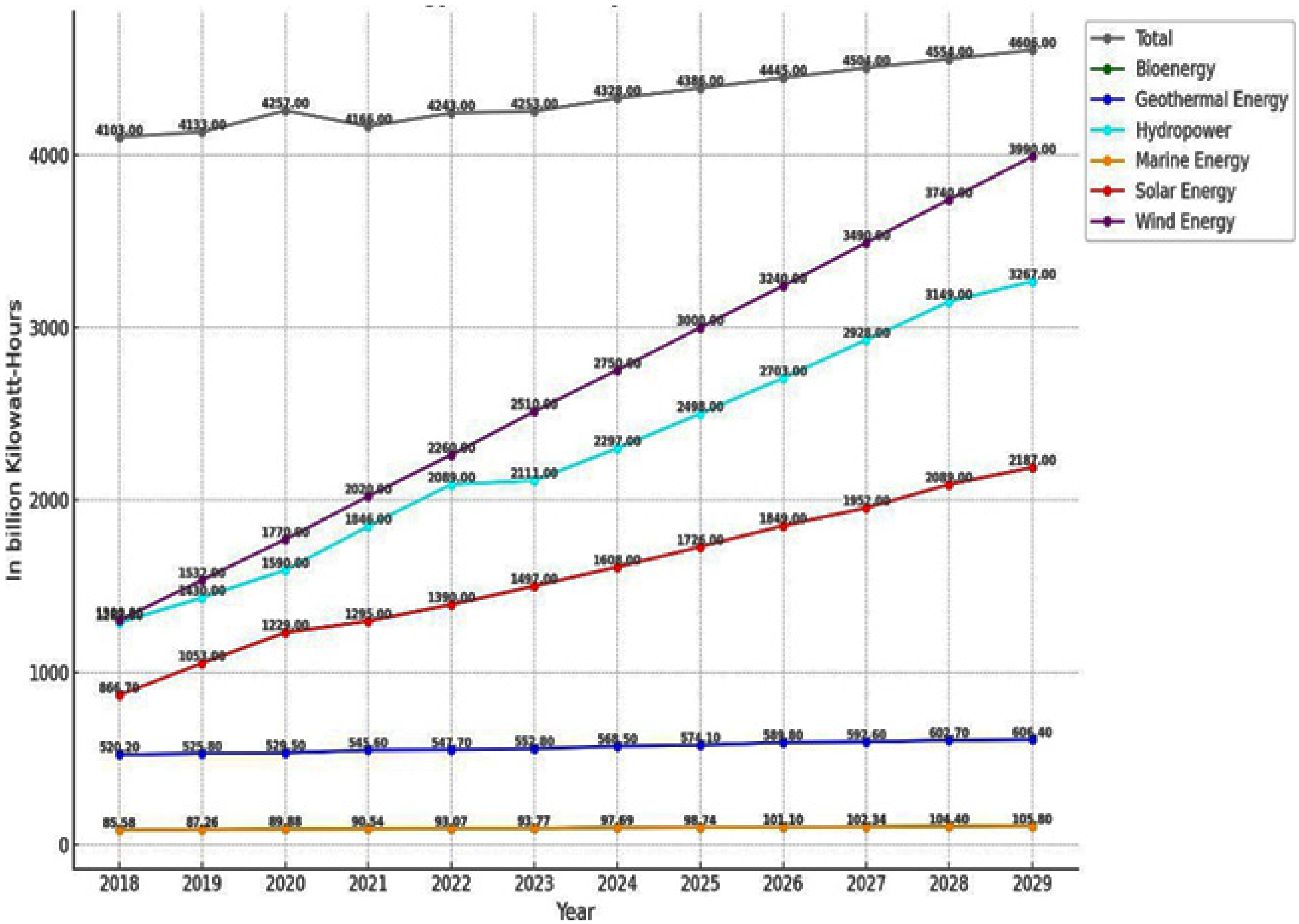

Fig 5 | Global Energy Production by Source (2018–2029)

Source: Statista (2024)

For the next ten years, fossil fuels and other traditional energy sources will still play a big role in the energy mix, even though renewable energy sources are growing in importance as depicted in Figure 5. People all over the world are working to fight climate change and lower GHG emissions through the use of new technology and good policies. This made it clear how important it is to have a strong energy infrastructure that can deal with problems on a global level.

Nature-Based Solutions

Nature-based solutions (NbS) protect biodiversity, make ecosystems stronger, and store carbon, among other things.[61] These benefits are becoming known to more and more people. Nature will be used in these plans to fight climate change, which is good for people's health and biodiversity. There are two good ways to store carbon: afforestation, which means planting trees where there aren't any already, and reforestation, which means planting trees where trees have been damaged. A lot of the carbon dioxide in the air is taken in and stored by forests. With new plans like the Bonn Challenge, 350 million hectares of land that people have damaged or destroyed by 2030 are supposed to be fixed up.[62] Wetlands that have been restored can store carbon, clean up water, and protect coastal areas from storm surges, among other things. Noon et al.[63] did a study that says restoring wetlands can help cut GHG emissions by as much as 14% by 2030. Planting trees on farmland is called agroforestry. NbS needs to carefully plan their activities, keep an eye on them at all times, and make sure they fit in with bigger goals for climate change and development.

Debates and Challenges

People in the developing world want resources to be shared more fairly and for more help to fight climate change. Many factors could influence different economies and ways of life, such as bad weather, rising sea levels, and problems with farming. Every country needs to do its part to stop climate change, but each has different duties and tools available to it based on its GHG emissions, level of development and past emissions. Many developing countries have had trouble putting effective plans in place to cut down on emissions and adapt to climate change because they think the promised aid, especially climate finance, has been inadequate and late[64]. The Group for the Conservation of Nature set up the Green Climate Fund (GCF) to help developing countries deal with the effects of climate change.[65] A big part of the conversation about climate justice has been the idea of loss and damage, which explains how climate change will offend people for a long time. Raimi et al.[66] explore that some people are concerned that relying too much on CCS could make it harder to use less energy and find new sources of energy. Green hydrogen, which is hydrogen made from renewable energy sources, is a key part of plans to cut carbon emissions.[67,68] Several things, like scale, market readiness, and policy support, affect how economically viable it is to use new technologies.[69,70] People who support these technologies explain that investing in them is necessary to meet long-term climate goals and could also help the economy grow and create new jobs.

For many reasons, it is not easy to implement policies effectively. To implement and enforce climate policies, long-term political support is essential.[71] Government or political agenda shifts have the potential to derail climate change mitigation efforts.[72] A potential slowdown or weakening of climate policies could be caused by industries and groups with a stake in fossil fuels fighting against policies that could harm their businesses. Complex climate policies necessitate robust administrative systems, which are not necessarily present, particularly in developing nations. However, to achieve more substantial reductions in emissions, there has to be improved coordination among member states' policies and the resolution of issues in various sectors. Policies have been more or less effective at various points in time due to shifts in American politics. For the world's climate change initiatives to advance, it is critical to address the arguments and challenges surrounding the reduction of climate change. Debates regarding the technical and economic feasibility of key technologies, such as CCS and hydrogen, highlight the necessity of policy frameworks and strategic investments to facilitate their development and utilisation. Strong execution, political determination, and overcoming economic and administrative challenges are necessary to ensure the success of policy frameworks. The international community can make climate mitigation strategies work better and get closer to meeting global climate goals by tackling these issues.

Methods

We used a methodological approach to systematically review the literature on climate change mitigation strategies. We have explored Web of Science, Scopus, JSTOR, and Google Scholar databases in depth. There were a lot of different words and phrases used in the search that had to do with coping with climate change. *"Climate policy," "renewable energy," "carbon capture and storage," "energy efficiency," and "electric vehicles"* were some of the most important keywords. The rules for being included were very strict, and one of them was how important it was to the fight against climate change. Studies that were not peer-reviewed, did not give enough information about their methods, or did not directly address the issue of climate change were not taken into account.

Table 1 | Inclusion and Exclusion Criteria for systematic review

Criteria	Description
Inclusion Criteria	
Peer-reviewed journal articles	Articles published in peer-reviewed journals between 2010 and 2023.
Climate change mitigation strategies	Studies focusing on climate change mitigation strategies, including renewable energy technologies (e.g., solar, wind), carbon pricing mechanisms (e.g., carbon taxes, cap-and-trade systems), policy frameworks, and equity in climate action.
Quantitative or qualitative analysis	Studies providing quantitative or qualitative analysis of greenhouse gas emission reductions, policy effectiveness, or the economic impacts of mitigation strategies.
Emerging technologies	Studies reporting on new or emerging technologies such as carbon capture and storage (CCS) and hydrogen production.
Exclusion Criteria	
Non-peer-reviewed articles	Non-peer-reviewed articles, such as opinion pieces or editorials.
Irrelevant focus	Articles that do not directly address climate change mitigation or do not provide empirical data.
Incomplete methodolog	Studies that do not clearly describe their methods or whose data could not be verified.
Language restrictions	Articles not published in English.

This systematic review was conducted by the PRISMA 2020 guidelines.[73,74] The goal of this review is to provide a comprehensive evaluation of the most recent advancements in climate change mitigation strategies, focusing on technological, policy, and economic instruments. Below, we describe each stage of the review process in detail, including eligibility criteria, information sources, search strategy, study selection process, data collection, and risk of bias assessment.

Eligibility Criteria

The inclusion and exclusion criteria were carefully designed to ensure that only relevant and high-quality studies were considered for this review.

Information Sources

The systematic review was conducted using the following databases: **Web of Science**, **Google Scholar**, **Scopus**, and **JSTOR**. The search was limited to studies published between **2010 and 2024** to focus on recent advancements and developments in climate change mitigation strategies. To ensure a comprehensive search, reference lists of selected articles were also examined to identify additional relevant studies.

Search Strategy

A structured search strategy was employed to retrieve relevant studies in Table 2. The search terms were developed to cover a wide range of topics related to climate change mitigation, including:

Table 2 | Structured search strategy

Search Component	Description
Keywords	"Climate change mitigation," "Renewable energy," "Carbon capture and storage," "Carbon pricing," "Policy frameworks," "Hydrogen production," "Equity in climate action," "Low-carbon technologies."
Filters Search Fields	Articles published in **English** and limited to **peer-reviewed journals**.
Search Fields	Search was conducted in the **title, abstract, and keywords** of articles to identify relevant studies.
Timeframe	Studies published between 2010 and 2024.
Databases Searched	Web of Science, Google Scholar, Scopus, and JSTOR.

Table 3 | Data collection process along with description

Data Collected	Description
Study Title, Year of Publication, Author(s)	The title of the study, the year it was published, and the names of the authors.
Study Design	The type of study conducted (e.g., experimental, observational, case study, systematic review).
Type of Climate Change Mitigation Strategy	The mitigation strategy discussed, such as renewable energy, policy frameworks, carbon pricing, or emerging technologies like CCS or hydrogen production.
Key Findings	Key outcomes related to the study, including greenhouse gas emissions reductions, cost-effectiveness, and policy impacts.
Equity Considerations and Barriers	Equity issues mentioned in the study, such as impacts on low- income communities, and potential barriers to implementing the mitigation strategy.

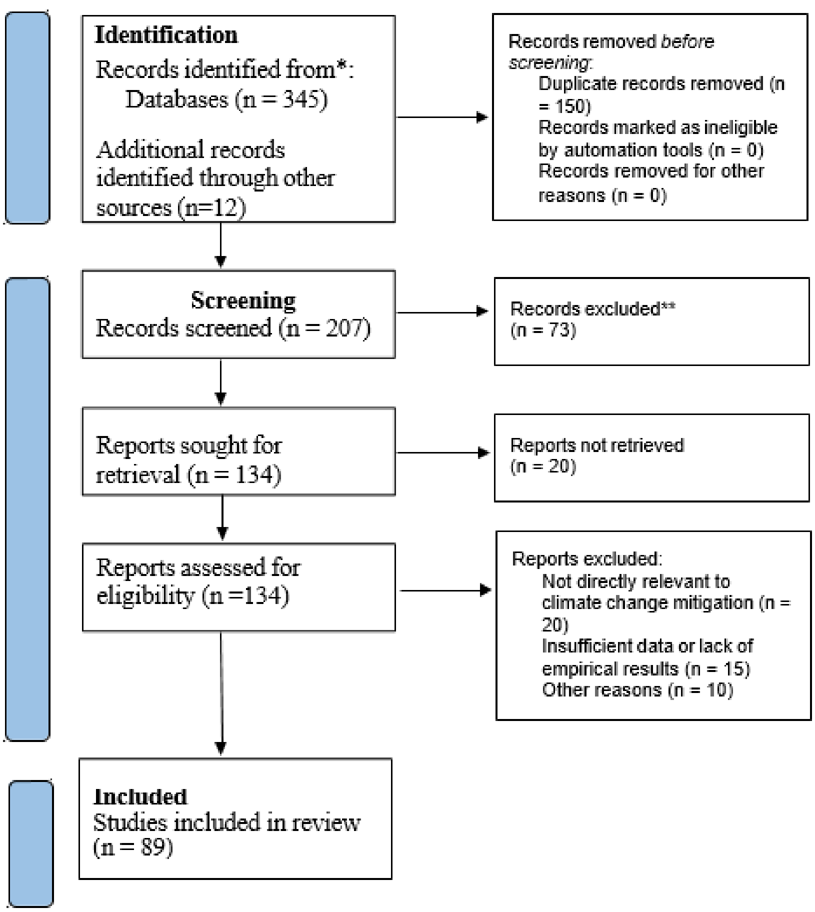

Fig 6 | PRISMA flow diagram values

Selection Process

The PRISMA flow diagram shows the study selection process for this systematic review. We started with 345 records found through database searching and another 12 records found through other sources. After removing duplicates, we had 207 records left to screen. Out of these, 150 records were excluded during the initial screening because they did not meet the basic inclusion criteria.

After that, 134 full-text articles were evaluated to see if they were eligible. Twenty articles did not deal with climate change mitigation directly, fifteen did not have enough data or empirical findings, and ten were not peer-reviewed or were opinion pieces; these factors led to the exclusion of 45 articles. A total of eighty-nine studies were considered for inclusion in the review's qualitative synthesis. Research like this sheds light on promising new avenues for combating global warming, such as renewable energy, carbon pricing, policy frameworks, and cutting-edge innovations like hydrogen generation and CCS. The review's analysis and conclusions are based on these studies because of the rigorous selection process that went into their inclusion.

Figure 6 is a PRISMA flow diagram depicting the complete selection process. It shows the total number of studies that were found, screened, evaluated for eligibility, and eventually included in the review.

Below is the data collection process presented in a Table 3.

Risk of Bias Assessment

For this purpose, we conducted a systematic review of the included studies using the AMSTAR 2 criteria to assess their potential for bias.[75] We used two tools to check for bias—the Cochrane Risk of Bias Tool for randomised controlled trial (RCTs) and the ROBINS-I tool for NRSIs—to make sure the studies that were included were high-quality. Biases in selection, performance, detection, attrition, and reporting were among the criteria used to assess each study. We classified the overall risk of bias for each study based on the criterion's rating of "low," "high," or "unclear" risk of bias. The results and their interpretation were based on this evaluation. In addition, Table A1b of the appendix contains the AMSTAR 2 self-evaluation criteria checklist.[75]

Effect Measures

The effectiveness of strategies to combat climate change was mainly evaluated in quantitative studies by looking at the percentage of GHG emissions that were reduced. The efficiency of carbon pricing in reducing emissions, the effectiveness of international agreements such as the Paris Agreement in promoting coordinated global action, and the cost-effectiveness of renewable energy technologies were other important outcome measures.

Synthesis Methods

To compile all of the studies' findings, researchers used both quantitative and thematic analysis. Renewable energy, carbon pricing, and policy framework studies were analysed using descriptive statistics to summarise their frequency and characteristics. The primary goals of this research were to (1) identify commonalities and (2) assess the total effect of mitigation strategies on GHG emissions. Equity issues, difficulties in scaling technologies, and the efficacy of various policies were among the themes and patterns revealed by a thematic analysis of the collected data. Commonalities in the data were used to classify it (e.g., technological advancement, policy efficacy, equity). The themes were able to be refined and analysed more thoroughly through multiple rounds of coding.

Our research was organised according to three criteria: geographical location, strategy type (such as renewable energy or carbon pricing), and scope (national vs. international). We explored the themes to see how they related to one another and to shed light on the problems and discussions surrounding climate change mitigation.

Thematic Analysis

Thematic analysis was employed in conjunction with quantitative analysis to identify and elucidate recurring themes and patterns within the literature. To do this, we had to sort the extracted data into categories based on common themes like new technology, the effectiveness of policies, economic tools, and issues of equity. The themes were discovered after several rounds of coding and data improvement. During the first round of coding, we took into account many of the points made in the literature. Later rounds of coding were more targeted, with an emphasis on themes that appeared in numerous studies. There had to be an investigation into the interconnectedness of various topics, their function within the broader context of climate action, and the possible insights they might provide into the ongoing arguments and discussions. Part of this process involves analysing the literature on *"equity and climate justice"* for frequency of mention, issues raised, and proposed solutions. The findings, when combined, painted a comprehensive picture of the tactics employed in the battle against climate change.

Results

There are four parts to this work: policy frameworks, new evidence and trends, problems and debates, and new technologies and trends. In the past ten years, PV technology for the sun has come a long way. Sun PV costs 82% less now than it did in 2010. It is one of the least expensive ways to get power because of this. Solar PV electricity costs about $0.068 per kWh on average as presented in Table 4.[76] Since 2010, the cost of onshore wind has gone down by 39%. This is because turbine technology has improved, blade have become bigger, and materials have become better. Besides solar and wind power, other types of renewable energy have also come a long way. Some of these are biomass, geothermal energy, and hydropower. Each technology has its place in the world of renewable energy, and they all help to make the energy supply more stable and diverse. Even today, hydropower is one of the most dependable and long-standing renewable energy sources. New technologies have made small-scale hydro projects and pumped storage hydropower more efficient and less harmful to the environment.[77]

Table 4 | Cost comparison of renewable energy technologies

Technology	Cost Reduction (2010–2020)	Current Cost ($/kWh)
Solar PV	82%	0.068
Onshore Wind	39%	0.053
Offshore Wind	29%	0.084
Small-Scale Hydro	15%	0.040–0.060
Geothermal	~20%	0.050–0.100
Biomass	~25%	0.050–0.150

Source: Authors' Calculation by extracting data from literature

In the last ten years, the price of small-scale hydro has gone down by about 15%. Geothermal power uses the Earth's natural heat stores. Geothermal power is more useful now that drilling techniques and resource mapping have gotten better. Now that these changes have been made, geothermal projects are more flexible as they cost between 0.05 and 10 cents per kilowatt-hour (kWh). The exact price depends on where and how deep the resource is. Arc and advanced gasification are two of the most interesting new ways to turn organic materials into biomass energy. When these technologies are used, biomass energy production works better and lasts longer. Costs for biomass energy depend on the type of feedstock used and the technology used to process it which can be anywhere from $0.05 to $0.15 per kilowatt-hour (kWh).

All included studies were evaluated for potential bias using the appropriate tools: the Cochrane Risk of Bias Tool for RCTs and the ROBINS-I tool for non-randomised studies. RCTs had a low risk of bias in 75% of the studies, whereas the other studies had a moderate to high risk, mostly because of selection or attrition biases. Most non-randomised studies had a moderate risk of bias, especially when it came to reporting results about policy frameworks and economic instruments.

Costs for various renewable energy sources will decrease from 2010 to 2020, as shown in Table 4 by the percentage reductions. These cuts are noteworthy because they show how renewable energy is now competitive with conventional fossil fuels thanks to technological advancements, economies of scale, and enhanced efficiency. In the "Current Cost" column, we can find the average $/kWh cost for each technology in 2020. To grasp each technology's financial

Table 5 | Region-wise analysis of carbon plan, coverage and price

Region	Type of Mechanism	Coverage (% of emissions)	Price ($/ton CO_2)
European Union	Cap-and-Trade (EU ETS)	40%	40–50
Canada (Federal)	Carbon Tax	70%	30
California	Cap-and-Trade	85%	20–30
South Korea	Emissions Trading	70%	10–30
Japan	Carbon Tax	50%	3
New Zealand	Cap-and-Trade	49%	25–35

Source: Authors' Calculation by extracting data from literature

Table 6 | Impact of energy efficiency improvements

Sector	Measure	Emission Reduction Potential (%)	Description
Buildings	Insulation, efficient appliances	30–50	Enhancing insulation, with the use of HVAC, lighting, and other energy-efficient technologies
	Smart building technologies	20–40	Implementing automated controls, energy management systems, and IoT devices
Industry	Process optimisation, cogeneration	20–40	Improving industrial processes, adopting combined heat and power systems
	Energy-efficient machinery	15–25	Upgrading to energy-efficient motors, pumps, and compressors
Transport	EV adoption, public transport	25–35	Promoting electric vehicles, enhancing public transit systems, and supporting active transport
	Fuel efficiency improvements	10–20	Implementing stricter fuel efficiency standards for conventional vehicles

Source: Authors' Calculation by extracting data from literature

feasibility in the present energy market, these cost values are essential. Variability in project size, location, and technology employed contribute to the range of costs for technologies like small-scale hydro, geothermal, and biomass.

One big reason for the marked drop in price of solar PV technology is that economies of scale allow more goods to be made at a lower cost per unit. Perovskite solar cells are one example of how technological progress has increased efficiency and reduced prices. Solar panels now have fewer flaws and a longer lifespan due to automation and improved quality control during production. Technological advancement has also revolutionised the wind power industry. New, larger turbines with broader rotors and higher hubs allow for greater wind capture and power generation. Reduced damage to turbines and subsequent lower maintenance costs are the results of using lightweight but strong materials. Improvements in efficiency and adaptability to varying water flows have resulted from redesigns that include variable-speed turbines. In addition, innovative tools have been developed to mitigate environmental harm. Turbines that are kind to fish and sediment management systems that aid in stream cleanliness are two examples.

The development of enhanced geothermal systems (EGS) is a major accomplishment in the field of geothermal energy. In areas lacking natural hydrothermal resources, these techniques make geothermal energy production more feasible by increasing the porosity of rock formations. Improvements in drilling technology have allowed geothermal wells to be dug to greater depths with more precision at lower costs. Significant technological advancements have also helped biomass energy. Gasification and pyrolysis are two examples of modern conversion technologies that have greatly improved the efficiency and environmental friendliness of biomass energy production. Additionally, using a wider range of feedstocks, such as agricultural waste and energy crops, has made biomass energy more sustainable and economically viable.

Also, energy storage options have gotten better, which makes renewable energy systems more reliable. Improvements in lithium-ion batteries have made them more energy-dense, last longer, and cost less. Since 2010, the price of lithium-ion batteries has dropped by about 89%, and they now cost an average of $137 per kWh.[76] Capturing CO_2 costs between $50 and $100 per metric tonne, and the cost of storing it adds to the cost.[77]

Evidence suggests that carbon pricing systems, like cap-and-trade and carbon taxes, reduce emissions of GHGs and increase the adoption of carbon-efficient technology. With these tools, businesses and people are more likely to cut down on their carbon footprint because they put a price on carbon emissions. Because trading gives companies more freedom and lower costs, they can spend money on cleaner technologies and come up with new ideas. Up to 70% of Canada's emissions are paid for by the federal carbon tax.[78] Right now, the CO_2 tax is $30/tonne. The carbon pricing system's goal is to get people and businesses to switch to renewable energy sources and use less energy in general so that they pollute less and use less energy. People often get their money back from the carbon tax and use it to pay for projects that fight climate change.

KEPS, South Korea's plan to charge for carbon emissions, is another important one. It charges $10 to $30 per tonne of CO_2 and takes care of about 70% of the country's emissions.[79,80] It wants to help South Korea get to a low-carbon economy in the long run. For every tonne of CO_2 that is released, Japan charges a $3 tax, which covers about half of all emissions.[81] Putting a price on carbon is the first step the country is taking to make this happen. In New Zealand, a tonne of CO_2 costs $25 to $35. By giving people money to lower their carbon emissions, these systems encourage new ideas, make energy use more efficient, and help the move to a sustainable, low-carbon economy. To make carbon pricing work better and reach global climate goals, countries must continue to work together.

The following Table 5 shows that improving energy efficiency has affected different areas, including specific steps that can be taken and the extent of pollution they might cause.

Making different areas more energy-efficient has a big effect on lowering emissions, and some actions have a lot of future potential which is presented in Table 6. In the building industry, improvements like better insulation and using appliances that use less energy can cut emissions by 30 to 50%.82 Some of these changes are using lighting, heating, and cooling systems that use less energy. Automated controls, energy management systems, and Internet of Things (IoT) devices are examples of smart building technologies that can further reduce emissions by 20 to 40%. Manufacturing facilities can reduce their pollution output by 20 to 40% through process optimisation and the use of combined heat and power systems, also known as cogeneration.

Another option to reduce expenses by 15 to 25% is to acquire new, energy-efficient machinery such as motors, pumps, and compressors. In addition to reducing energy consumption, these measures improve the overall efficiency of industrial operations. It is possible to reduce transportation-related emissions by 25–35% by encouraging the usage of EVs and enhancing public transport systems. Another factor contributing to this decrease is encouraging the use of active transportation, such as walking and biking. Emissions could be reduced by 10 to 20% if conventional vehicles were to be more fuel efficient. Because of this, enhancing fuel efficiency is a crucial component of transportation emissions reduction efforts.

Thematic Analysis

Through a thematic analysis of the literature on reducing the effects of climate change, several important themes were found. These themes help to make sense of all the different parts of this complicated problem. Some of these themes are progress in technology, the usefulness of policies, economic tools, and concerns about fairness. A word cloud Figure 7 was used to show how often and how important different keywords and ideas were connected to these themes. The progress of technology is a theme that runs through many of the works. Innovative solutions are required in the fields of energy storage, renewable power, and CCS to reduce emissions of GHGs and transition to a green economy. Because of these advances in technology, renewable energy is getting cheaper, easier to get, and used by more people around the world. Another important point that was brought up was how well policies work. Setting goals to reduce emissions, promoting renewable energy, and putting in place adaptation measures are easier when policies work. The difference between what policies will do and what they do to reduce emissions is still a big problem. In light of this, it is clear that stronger systems of governance and accountability are needed. Carbon pricing mechanisms, which include cap-and-trade systems and carbon taxes, are economic instruments that aim to reduce emissions and promote the use of low-carbon technology.

The UNFCCC's "common but differentiated responsibilities" principle means that developed countries, which have historically contributed more to global emissions, should lead efforts to decrease them and help developing countries with money and technical

Table 7 | Themes and policy implication for mitigation

Theme	Description	Implications for Mitigation
Technological Advancements	Innovations in renewable energy, energy storage, and CCS	Drive cost reductions and enhance feasibility
Policy Effectiveness	Success and challenges of international and national policies	Need for robust implementation and enforcement
Economic Instruments	Role of carbon pricing and financial incentives	Promote low-carbon technologies and behaviour change
Equity Considerations	Distribution of responsibilities and support for developing countries	Ensure a fair and just transition
Public Awareness and Engagement	Importance of societal support and individual actions	Enhance public support for policies and promote sustainable behaviours
Technological Innovation and Research	Development of new solutions and improvements in existing technologies	Ensure long-term sustainability and drive continuous improvement
Financial Mechanisms	Funding for mitigation projects through green bonds, climate finance	Provide necessary resources for large-scale implementation
Adaptation Strategies	Enhancing the resilience of communities and ecosystems	Intertwine with mitigation to manage climate-related disruptions

Source: Authors' Calculation by extracting data from literature help. Making sure there is a fair and just transition means fixing the fact that climate change hurts vulnerable groups more than others and making sure that all countries have the tools and skills they need to help reduce the effects of climate change. Besides these main themes, several other themes were found to be important for a full understanding of how to stop climate change. Some of these are educating and involving the public, developing and researching new technologies, finding ways to pay for things, and coming up with ways to adapt. Raising public awareness and getting people involved are important for getting people to support climate policies and take actions that reduce emissions. New technologies and better versions of old ones are made possible by technological innovation and research, which are very important for long-term sustainability. Large-scale projects to reduce climate change can get the money they need from financial tools like green bonds and climate finance. While adaptation strategies are mainly about dealing with the effects of climate change, they are linked to mitigation efforts because they make communities and ecosystems more resistant to changes caused by climate change.

It is important for global efforts to reduce climate change to take into account technological, policy, economic, and fairness issues all at the same time. The thematic analysis in Table 7 found several recurring themes in the literature. These themes included changes in technology, the effectiveness of policies, economic tools, and issues of fairness. The following word cloud (Figure 7) shows the themes and keywords that appear most often.

This review's findings demonstrate substantial advancements in creating economic tools to support low-carbon technology and in lowering the prices of renewable energy. Still, there are a lot of obstacles to overcome, especially when it comes to being fair in climate action and scaling up new technologies like CCS. According to the results of the thematic analysis, if we want to reach our global climate goals, we need to combine economic, policy, and technological approaches while keeping equity at the forefront.

Fig | 7 Word cloud of thematic analysis

Source: Authors' Calculations

Discussion

The work explains that strategies to fight climate change are complicated and we need to examine the problem as a whole if we want to solve it effectively. New technology is crucial for reducing energy sector carbon emissions, as demonstrated by the significant advancements in renewable energy sources such as solar and wind power. Since the costs of these technologies have gone down a lot, they are becoming more competitive with fossil fuels. A more sustainable energy system and reduced emissions of GHGs can only be achieved with the widespread adoption of renewable energy sources.[83] Planned action on climate change is made possible by international and national policy frameworks. Signatories to the Paris Agreement agree to lower their GHG emissions. However, these frameworks would not work unless they are strictly put into place and enforced. Some countries show their intention to cut emissions, but when it comes to taking action, they do not always follow through. So, there is an intention-behaviour gap regarding the implementation and enforcement of environmental projects. These findings back up the idea that countries need stronger government systems if they want to reach their lofty climate mitigation goals.[84]

Reducing emissions and encouraging the development of low-carbon technology requires the application of economic instruments, such as a price on carbon. Some areas have seen success with carbon taxes and cap-and-trade programmes.[85] Some of these are California, the European Union, and Canada. These systems give people money to buy cleaner technologies and cut down on pollution. This helps the economy move towards a low-carbon state. Making sure that efforts to reduce climate change are fair and effective means dealing with issues of climate justice and fairness. To lessen the effects of climate change, developing countries need more help and a fairer distribution of responsibility.[86] This is why the UNFCCC's "common but differentiated responsibilities" principle says that developed countries should lead the way in lowering emissions and helping developing countries with money and knowledge.[87] It is still hard to take fair action on climate change because people have different amounts of money and technology available.

It is not possible to reach decarbonisation until the economy and technology are fixed. CCS and hydrogen technologies have a lot of potential, but they are too expensive and hard for most people to use to gain wider currency. People who are against these technologies say that they could put off dealing with more important problems that need to be fixed right away, like switching to renewable energy sources or making homes use less energy. A few countries are not doing what they are supposed to do, which makes it harder for everyone to keep temperatures below the levels agreed upon in the Paris Agreement. According to them, there needs to be more openness, responsibility, and strong policy actions to close this gap. These studies show that policies are not always followed with the ambition and effectiveness that is needed.[88, 89]

Making people more concerned about climate change is also very important for these main ideas. Policy and technology efforts can be helped by learning more about climate issues and getting people to take action. It is impossible to say enough about how media, community projects, and educational campaigns change the way people think and act. Research and new technologies are also needed to find new cost-effective solutions and improve the ones that are already out there. A lot of studies in the past have only explored one part of reducing climate change, like certain technologies or policies, without giving a full picture of how these parts work together. Also, there has not been enough attention paid to the problems that come up when trying to put plans into action or the difference between what was promised and what happened. To address these knowledge gaps, this review examines climate change mitigation from multiple perspectives, including policy, economics, technology, and equity. Constant evaluation and adjustment of strategies to ensure they are still achieving climate goals is also highlighted, underscoring the significance of strong implementation.

Limitations

Although there are a number of caveats, this systematic review does a thorough job of analysing new approaches to reducing the effects of climate change. Because this review exclusively considers publications that have been peer-reviewed, there is a risk of publication bias. Overconfidence in the efficacy of certain tactics may result from the publication bias that favours studies with statistically significant or favourable outcomes. Further reducing the review's generalisability was the fact that it only included papers published in English, which may have omitted crucial research from non-English-speaking areas.

A further point to consider is selection bias. It is possible that important insights, like those from government and industry sources regarding the practical implementation of mitigation strategies, were lost due to the exclusion of grey literature and non-peer-reviewed reports. Another difficulty is the diversity of the studies that were considered; these studies cover a wide range of topics, from renewable energy technology and economic instruments to policy frameworks and geographical locations. The results were not as precise as they could have been because of a formal meta-analysis due to the variety of study designs and outcomes, but thematic analysis helped synthesise the data.

It is possible that earlier foundational work on climate change mitigation was missed due to the review's timeframe, which only considered studies published between 2010 and 2024. Some of the included studies may have their results from self-reported data or underreported limitations, even though a risk of bias assessment was done for all of them. Despite these caveats, the review sheds light on where climate change mitigation efforts stand right now and identifies critical areas where more study and action are needed. On the other hand, researchers in the future should try to be more thorough in their approaches. This means using more rigorous meta-analytical methods, expanding their scope to include more languages, and incorporating grey literature.

Conclusion

This work highlights the importance of global collaboration and integrated strategies in fighting climate change. For comprehensive climate mitigation strategies to work, they need to combine new technology with strong policy frameworks and useful economic tools. There have been big steps forward in technology for renewable energy, energy storage, and carbon capture. This has made it cheaper and easier to use on a large scale. For these technologies to work, policies and financial incentives must be put in place to help them grow and be used by many people. Even though this work shows a lot of progress, there are still issues and debates that affect how climate action is taken. One of the hardest things is making new technology that a lot of people can afford and use easily. Some examples of cutting-edge technology that are out of reach for the majority of people due to their high price tags include hydrogen and CCS. More money, time, and work will need to go into research and development to make them more useful and scalable. Private companies and government agencies should collaborate to find these issues because new investments and ideas can help save money and make things run more smoothly.

All countries must share responsibility and resources fairly for everyone to be able to help with global climate action. Simply giving developing countries more money will not solve their fairness issues; they also need to be able to share technology and get better at what they already know to find long-lasting solutions. Another important issue is the difference between stated and achieved reductions in emissions. For international agreements like the Paris Agreement to have any effect, the promises that are made must be kept. Many countries are not meeting their NDCs, so there needs to be stricter accountability and enforcement. If we want to close this gap, we need more openness, stronger oversight, and policies that can be changed right away. Even though these technologies have a bright future for lowering emissions in places where they are not currently working, their high cost and long list of unresolved technical problems will probably keep most people from using them. In the future, researchers should try to find faster and cheaper ways to build the infrastructure that these technologies need to work.

Another important area is research into making policy frameworks that work better and are fairer. To reach our climate goals, we need to look into how to make current rules better and come up with new rules that will be strictly enforced. Comparing different national and local policies through research may help shed light on good ways to do things. It is also important to prioritise research on the role of international cooperation and ways to make global frameworks stronger so that cooperation is easier. Researchers should work to create and use carbon pricing systems in the best way possible so that they cause the least amount of economic harm and the most reductions in emissions. An important part of this effort is to look into how different carbon pricing, coverage, and recycling methods affect different groups and industries. It is important to know how these tools affect society and the economy to make policies that work and are fair for everyone. Last but not least, we need to learn a lot more about the issues that come up when it comes to fairness and climate justice.

We need to make sure that everyone has a say in how decisions are made, and we need to think about how climate policies affect different groups of people. This can help us figure out how to make the switch to a low-carbon economy fair for everyone. These findings provide a wealth of promising policy recommendations for future climate change responses. First, governments should work together to make and enforce rules that address all aspects of the issue, such as its technological, economic, and social aspects. These plans should have clear, attainable goals, a way to reach those goals, and enough money to carry out the plan. Partnerships between the government and private sector can also help get people to invest in low-carbon technologies and come up with new ideas. A targeted study that answers these questions can help make climate action more effective, fair, and long-lasting.

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APPENDIX

Table A1a | PRISMA 2020 Checklist for the Review Article on Climate Change Mitigation Strategies

Section	Topic	Item	Description	Description
ABSTRACT	Structured summary	1	Provide a structured summary including objectives, eligibility criteria, information sources, risk of bias, included studies, and synthesis of results.	Abstract (Page 1)
	Rationale	2	Describe the rationale for the review in the context of what is already known.	Introduction (Page 1)
INTRODUCTION	Objectives	3	Provide an explicit statement of the objectives being addressed.	Introduction (Page 1)
METHODS	Eligibility criteria	4	Specify the inclusion and exclusion criteria for the review and how studies were grouped for synthesis.	Methods: Eligibility Criteria (Page 7)
	Information sources	5	Specify all databases, registers, websites, organizations, reference lists, etc., searched or consulted to identify studies. Provide dates of coverage.	Methods: Search Strategy (Pages 7–8)
	Search strategy	6	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	Methods: Search Strategy (Pages 7–8)
	Selection process	7	Specify the process for selecting studies	Methods: Study Selection (Page 8)
	Data collection process	8	Specify the methods used to extract data from reports, including how many reviewers extracted data, and how discrepancies were resolved.	Methods: Data Extraction (Page 8)
	Data items	9	List and define all outcomes for which data were sought, including how measures of effect were handled.	Methods: Data Extraction (Page 8)
	Study risk of bias assessment	10	Specify the methods used to assess the risk of bias in individual studies, including the criteria used and how the assessment was conducted.	Methods: Risk of Bias Assessment (Page 8)
	Effect measures	11	Specify all measures of effect for each outcome.	Methods: Synthesis of Results (Pages 8–9)
	Synthesis methods	12	Describe the methods used to synthesize results and how they were determined.	Methods: Data Synthesis (Page 9)
	Reporting bias assessment	13	Specify any methods used to assess the risk of bias due to missing results in a synthesis.	Methods: Bias and Sensitivity Analysis (Page 8)
RESULTS	Study selection	14	Provide the number of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions.	Results: Study Selection and PRISMA Flow Diagram (Page 8)
	Study characteristics	15	Cite each included study and present its characteristics.	Results: Study Characteristics (Page 9)
	Risk of bias in studies	16	Present risk of bias assessments for all included studies.	Results: Risk of Bias Assessment (Page 10)
	Results of individual studies	17	For all outcomes, present, for each study, the results and effect sizes.	Results: Findings from Studies (Pages 10–11)
	Results of syntheses	18	Present the results of each synthesis	Results: Findings from Studies (Pages 11–12)
	Certainty of evidence	19	Present assessments of certainty of evidence for each outcome.	Results: Certainty of Evidence (Page 10)
DISCUSSION	Discussion	20	Provide a general interpretation of the results in the context of other evidence.	Discussion (Pages 12–13)
	Limitations	21	Discuss the limitations of the evidence included in the review and of the review process.	Discussion: Study Limitations (Page 13)
OTHER INFORMATION	Support	22	Describe the sources of financial or other support for the review.	Not applicable
	Competing interests	23	Declare any competing interests of the review authors.	No Competing Interests

Table A1b | AMSTAR 2 Self-Evaluation for the Systematic Review of Climate Change Mitigation Strategies

	AMSTAR 2 Item	Description	Compliance
1	**Research Questions & PICO**	Population: Global stakeholders. Intervention: Climate mitigation strategies. Comparator: None. Outcome: Emission reductions, policy effectiveness.	Yes
2	**Protocol Established**	A protocol was developed but not registered.	Partial Yes
3	**Study Design**	RCTs and NRSI were included with clear justification.	Yes
	Selection		
4	**Comprehensive Search Strategy**	Comprehensive search across Web of Science, Google Scholar, Scopus, and other databases. Grey literature was not included.	Partial Yes
5	**Study Selection in Duplicate**	Two independent reviewers selected studies, with consensus used to resolve disagreements.	Yes
6	**Data Extraction in Duplicate**	Data extraction was performed by two independent reviewers with consensus to resolve discrepancies.	Yes
7	**List of Excluded Studies**	Excluded studies were listed, but specific justifications for exclusions were not always provided.	Partial Yes
8	**Study Descriptions**	Detailed descriptions of study characteristics (technologies, policies). More details on timelines could be added.	Partial Yes
9	**Risk of Bias Assessment**	Risk of bias was assessed for included studies.	Yes
10	**Funding of Included Studies**	Sources of funding for included studies were reported where available.	Yes
11	**Meta-Analysis Methods**	No meta-analysis was conducted.	Not applicable
12	**Impact of RoB on Meta-Analysis**	No meta-analysis was conducted.	Not applicable
13	**Interpretation of RoB in Results**	Risk of bias was considered in interpreting the results.	Yes
14	**Heterogeneity Explanation**	Heterogeneity was discussed in terms of different regional impacts and mitigation strategies.	Yes
15	**Investigation of Publication Bias**	No quantitative synthesis was conducted, so publication bias was not assessed.	Not applicable
16	**Conflict of Inter est Disclosure**	No conflicts of interest or competing funding sources were reported.	Yes

Source: Shia et al.[75]