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Carbon Credit Mechanisms: A Market Based Approach to Climate Mitigation

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Introduction: Climate change is mainly caused by human activities, and it results in the release of harmful greenhouse gases like carbon dioxide, methane, and nitrous oxide into the atmosphere. Among the various sources of 'C' emission, electricity and heat generation is the major activity both in the World (32.25 percent) as well as in India (35.86 per cent) where Agriculture acts as the fourth major player of CO_2 emission in the World (11.60 per cent) and in India, it has a dominant role which stand in second position with 21.92 per cent share. Rising GHG emissions, especially from electricity and agriculture, pose a major climate challenge in India. Though carbon markets offer a tool for mitigation, awareness and participation remain limited. Understanding carbon trading mechanisms is essential to enhance their role in reducing emissions.
Objectives: To know the different carbon trading mechanism to mitigate carbon emission.
Carbon Market: In simple terms, the carbon market is buying and selling carbon credits; each credit indicates one ton of carbon dioxide (or similar gases) that's been removed from the

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atmosphere or prevented from being released. These credits can be traded at both national and international carbon markets. There are two main types of carbon markets: compliance markets and voluntary markets.

Major Findings:

Compliance Market: The compliance market is run under the certain rules and regulations, which is given by the United Nations Framework Convention on Climate Change (UNFCCC). It's backed by regulations and helps monitor emissions across countries and industries. India issued approximately 106 million tons (MT) of CO_2 emissions upto mid-2024.

Voluntary Market: The voluntary carbon market is designed for those who choose to act on climate change, even when they're not legally required to. Whether it's businesses, organizations, or individuals, they can purchase carbon credits to support initiatives such as reforestation or clean energy projects. India issued approximately 43.4 MT carbon credits in 2024, making it the second-largest issuer globally after the United States.

Conclusion: This dual engagement reflects not only India's dedication to reducing emissions but also its strategic approach to integrating economic incentives with environmental responsibility, thereby supporting its broader goals for sustainable development and a low-carbon future.

Keywords: Cap and trade mechanism; carbon credit; carbon offsetting; compliance market; voluntary market.

1. INTRODUCTION: CARBON EMISSIONS AND CLIMATE CHANGE

Climate change is no longer a far-off danger; it is an urgent worldwide concern. Greenhouse gas (GHG) emissions refer to the atmospheric release of various gases from different sectors over a defined period.The main greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) (Gavin, 2010; UNFCCC, 2022; Defra, 2023). Their levels have increased significantly since the Industrial Revolution, primarily due to human actions like fossil fuel combustion, deforestation, and industrial growth (IPCC, 2021).

These gases function as a heat-retaining blanket around the Earth, leading to increased global temperatures, melting ice caps, rising sea levels, and more intense and frequent weather occurrences (UNEP, 2022).

The immediacy of the circumstance is evident. The Intergovernmental Panel on Climate Change (IPCC) cautions that to prevent the most severe impacts of climate change, we need to restrict global warming to a maximum of 1.5°C beyond pre-industrial levels (IPCC, 2021). Achieving this objective requires prompt and revolutionary steps.

1.1 GHG Emission Scenarios in World and India

The total GHG emission is estimated to be 54.59 Bton carbon equivalent in 2020.In 2022, China is in first position of global GHG emission with 30.68 percent share followed by United States (13.61) and India (7.62) out of the world GHG emission accounting. Fig. 1 highlights the sectoral contributions to global greenhouse gas (GHG) emissions from 1991 to 2021. Throughout these decades, Electricity and Heat Production has consistently been the largest contributor, peaking significantly in 2011. Other major sectors like Agriculture and Transport have shown noticeable increases, reflecting rising global demand for food and mobility. Meanwhile, Manufacturing and Construction as well as Industry have demonstrated steady growth, indicating their expanding role in emissions. Land Use Change and Forestry contribute relatively smaller but consistent amounts. Minor sectors such as Bunker Fuels, Waste, and Buildings contribute less overall but have shown slight growth over time.

Fig. 2 focuses on the sectoral GHG emissions in India over the same period. Here, Agriculture remains the top emitter in the initial two decades (1991 & 2001) decades, maintaining consistently high emission levels. Electricity and Heat Production exhibited a sharp rise, becoming the prime and first-largest source by 2021. The Manufacturing and Construction and Transport sectors have gradually increased, reflecting ongoing industrialization and growing mobility. Notably, Land Use Change and Forestry appears as a net negative contributor across the decades, indicating its role in carbon sequestration during those years. Emissions from other sectors such as Industry, Buildings, and Waste show moderate but steadily increasing contributions over time.

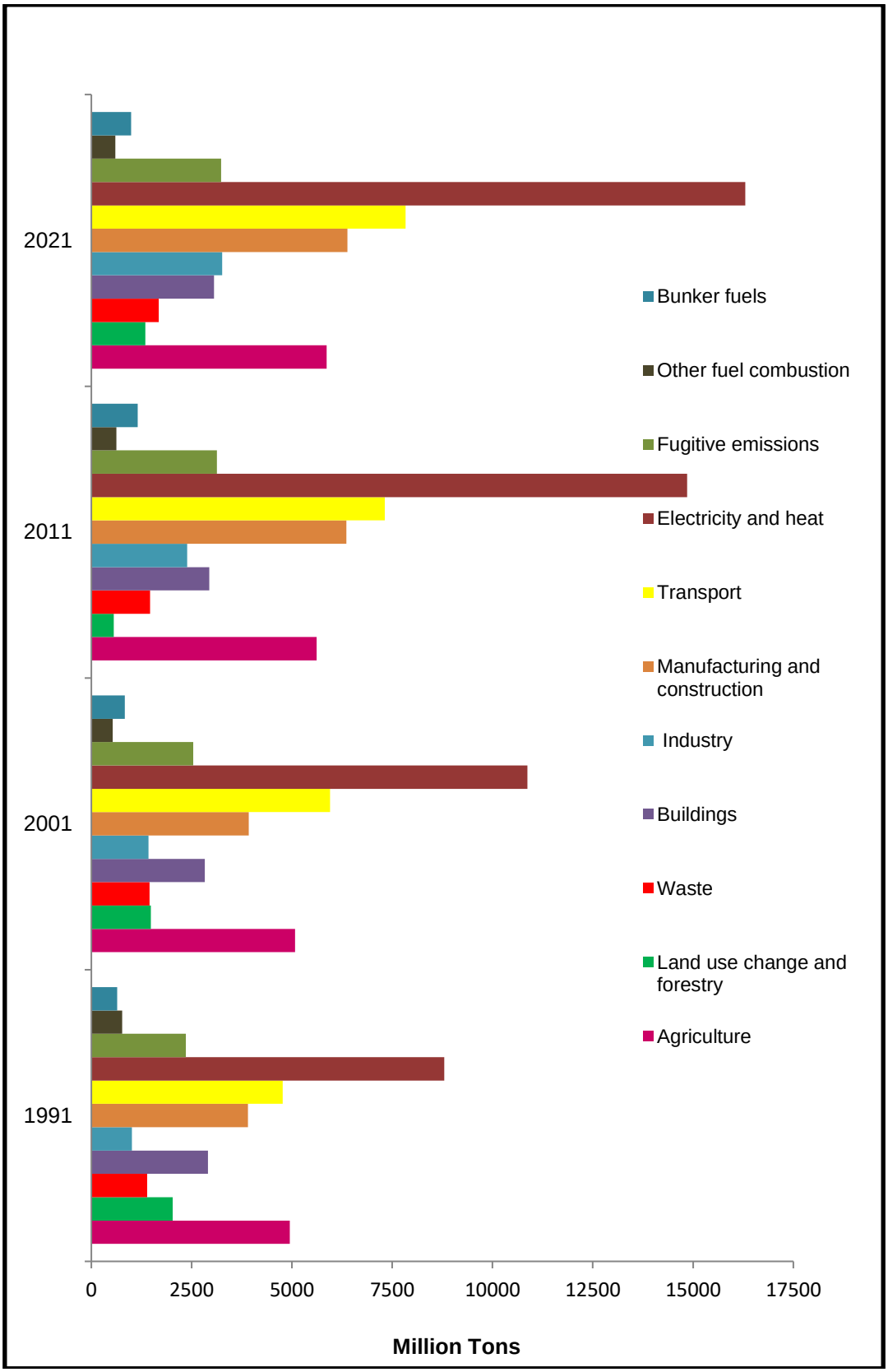

Fig. 1. Decadal-wise sectoral contribution to global GHG emissions (1991- 2021)
Source: Climate Watch (2024)

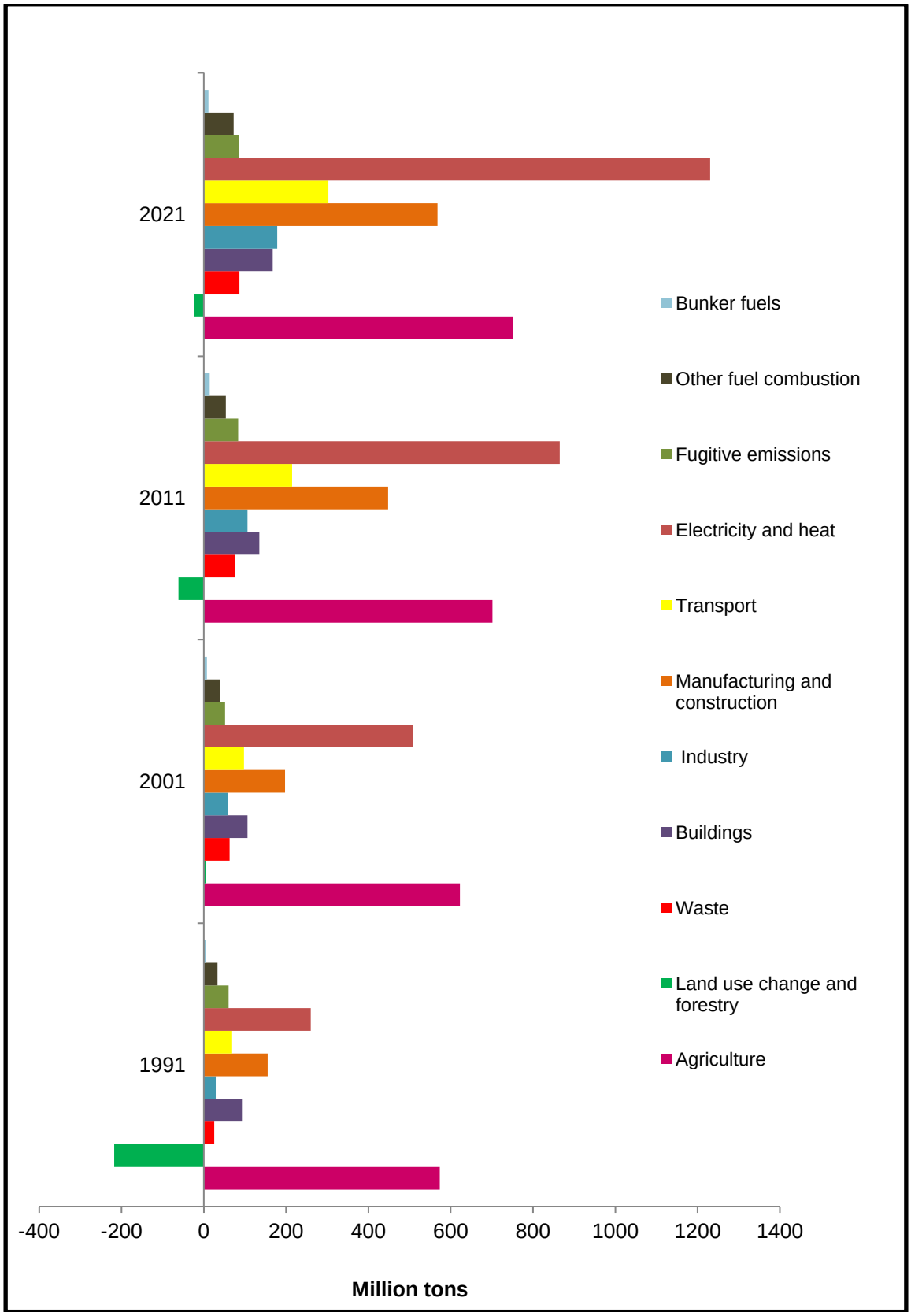

Fig. 2. Decadal-wise sectoral contribution to GHG emissions in India (1991- 2021)
Source: Climate Watch (2024)

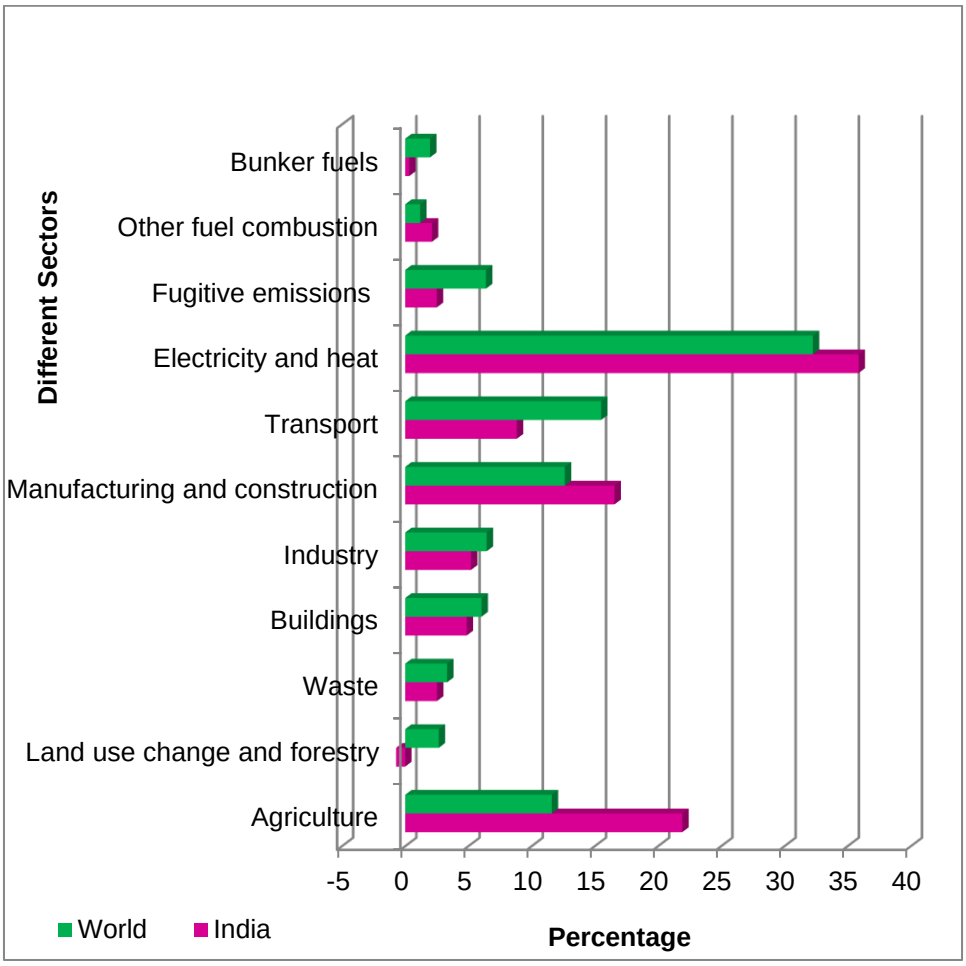

Fig. 3. Sectoral contribution of GHG emission shares in the world and India (2021)
Source: Climate Watch (2024)

A comparative analysis of Fig. 3 reveals distinct differences between global and Indian emission profiles. Globally, Electricity and Heat Production remains the dominant source, followed by Agriculture and Transport. In contrast, India's agricultural emission proportion heavily dominated the world scenario, though it became the second-largest contributor following Electricity and heat generation in 2021. This contrast reflects differing developmental stages and sectoral priorities: while global emissions are primarily driven by industrial and energy sectors, India's emissions profile l s still largely influenced by its agricultural base. Nevertheless, the rapid growth in India's energy and manufacturing sectors indicates an ongoing transition toward a more industrialized emission pattern.

In terms of emission shares in 2021 (Fig. 3), Electricity and Heat accounted for 32.25 per cent globally and 35.86 per cent in India, underscoring the heavy reliance on fossil fuels for energy. Agriculture plays a significantly larger role in India (21.92 per cent) compared to the global average (11.60 per cent), making it the second-highest contributor in India. Similarly, Manufacturing and Construction holds a higher share in India (16.56 per cent) than globally (12.62 per cent). Conversely, Transport and Industry have greater global shares (15.50 per cent and 6.44 per cent) than in India (8.33 per cent and 5.20 per cent), reflecting more developed infrastructure and industrialization worldwide. Additionally, Fugitive Emissions and Land Use Change & Forestry contribute more globally, whereas India shows minimal or even negative contributions from land use change, likely due to reforestation efforts.

Rising greenhouse gas (GHG) emissions, especially from electricity and agriculture, pose a major climate challenge in India. As global emissions continue to increase, there is an urgent need for scalable, market-based solutions

to address climate change. In response, businesses, governments, and international organizations are exploring innovative strategies to reduce emissions. One of the most promising approaches is carbon trading—a market-driven mechanism that offers financial incentives for emission reductions. Though carbon markets provide a valuable tool for mitigation, awareness and participation, particularly in developing countries like India, remain limited. This underscores the importance of carbon trading mechanisms and it is essential to strengthen their effectiveness in reducing emissions and supporting sustainable development goals.

2. CARBON MARKETS: A SUMMARY

As climate change becomes more urgent, carbon markets are gaining attention as a practical, market-based way to cut greenhouse gas (GHG) emissions. These markets work by allowing the trade of carbon credits each representing one metric ton of carbon dioxide (or its equivalent) that's been reduced or removed from the atmosphere. Built on systems like cap-and-trade and carbon offsetting, carbon markets let organizations that reduce more emissions than required sell their extra credits. Meanwhile, those that exceed their limits can buy credits to stay within regulations or meet voluntary climate goals (Kossoy et al., 2015; Mehling et al., 2018).

This approach creates a financial incentive to cut emissions in the most cost-effective way possible. It also encourages innovation in clean technologies and low-carbon solutions (Stavins, 2008; Tietenberg, 2010). By putting a price on carbon, these markets help make sure the true environmental costs of emissions are reflected in everyday economic decisions essentially aligning business goals with climate action (Newell et al., 2013; Stern, 2007).

2.1 Types of Carbon Markets

Carbon markets can be categorized into two primary types viz., compliance markets and voluntary markets (Cambridge University Press 2012).

Compliance markets are built around clear legal rules and regulations. Systems like the European Union Emissions Trading System (EU ETS), California's Cap-and-Trade Program, and China's National ETS require companies to stay within set emission limits (Ellerman et al., 2010; ICAP, 2023). These programs ensure that polluters are held accountable and are actively working toward cutting their emissions. On the flip side, Voluntary Carbon Markets (VCMs) are driven by companies and organizations that want to go above and beyond what's required. They may do this to meet internal sustainability targets, show leadership on climate action, or respond to growing pressure from customers and investors (Hamrick & Gallant, 2017; Verra, 2022).

Together, both types of carbon markets play a big role in the global fight against climate change. They help fund climate-friendly projects and create a bridge between environmental goals and economic growth (World Bank, 2022; UNFCCC, 2021).

3. COMPLIANCE CARBON MARKETS

These markets operate under strict national or international laws, requiring organizations to follow detailed emission limits. What makes them work well is a strong system of Monitoring, Reporting, and Verification (MRV), which keeps things transparent and trustworthy (OECD, 2020). Because participation is mandatory, these markets push companies to get creative, cut emissions, and become more engaged in climate solutions.

3.1 Emissions Trading Schemes (ETS)

At the heart of many compliance carbon markets is something called the Emissions Trading System (ETS) a "cap-and-trade" approach that puts a price on pollution and rewards efforts to cut emissions. Here's how it works: governments set a cap on the total amount of GHG that certain industries are allowed to emit. Companies within those industries are given or can buy a certain number of allowances, each representing the right to emit one ton of CO_2 or its equivalent. If a company emits less than its allowance, it can sell the extra into the carbon market. If it emits more, it must buy more allowances from the carbon market. This setup helps ensure that emissions are reduced where it's cheapest to do so, all while motivating companies to innovate and improve efficiency (Ellerman & Buchner, 2007).

One of the best-known examples is the European Union Emissions Trading System (EU ETS). Launched in 2005, it remains the largest and most influential carbon market in the world. The EU ETS covers major polluting sectors like power and heat generation, heavy industries (like cement, steel, oil refining, and paper), and even

aviation within the EU (European Commission, 2022). Over the years, it has gone through several updates to make it more environmentally effective tightening emission limits, boosting market stability, and raising the cost of carbon to drive meaningful action (European Environment Agency, 2021).

Now in its fourth phase (2021–2030), the EU ETS is a key part of the European Green Deal and supports the EU's ambitious goal of cutting net greenhouse gas emissions by at least 55 per cent by 2030. It has recently expanded to cover maritime transport and plans to include buildings and road transport under a new, separate system known as EU ETS II (European Commission, 2023).

Beyond Europe, emissions trading is spreading globally under the framework of the Paris Agreement. Through Article 6.2, countries can work together voluntarily by trading what's known as Internationally Transferred Mitigation Outcomes (ITMOs). This allows countries to team up in reaching their climate targets, building on the groundwork laid by the earlier Kyoto Protocol and moving toward a more flexible and cooperative approach to global emissions reduction (UNFCCC, 2022).

3.2 Clean Development Mechanism (CDM)

One of the standout tools introduced under the Kyoto Protocol was the Clean Development Mechanism (CDM). This innovative system gave developed countries a way to meet part of their emission reduction targets by investing in climate-friendly projects in developing nations. In return, they received Certified Emission Reductions (CERs) carbon credits that could be traded and counted toward their Kyoto commitments (UNFCCC, 2020).

The CDM supported a wide variety of projects, all aimed at cutting greenhouse gas emissions while also encouraging sustainable growth. These included renewable energy initiatives like wind, solar, and small-scale hydropower helping replace fossil fuels and cut carbon emissions. It also backed energy efficiency upgrades in buildings and industries, methane capture from landfills and livestock, and reforestation and afforestation efforts to restore natural carbon sinks. Even sustainable agriculture projects were included, reducing emissions from land use while improving the lives of local communities (UNFCCC, 2020; UNEP DTU, 2018).

At its core, the CDM aimed to strike a balance delivering real environmental benefits while also contributing to development in lower-income countries. It attracted billions in investment, especially across Asia, Africa, and Latin America, and supported over 8,000 registered projects. For many developing countries, it was their first opportunity to engage with global carbon markets in an organized way (UNEP DTU, 2018).

However, the system wasn't without its flaws. A major concern was additionality ensuring that the projects truly delivered emissions cuts beyond what would have happened anyway. Critics argued that some projects would've gone ahead even without CDM support, calling into question the real impact of the credits issued (Schneider, 2007; Cames et al., 2016). There were also concerns about whether local communities actually received the promised environmental or social benefits (Boyd et al., 2009).

Because of these challenges and the evolution of global climate policy the CDM is now being phased out. It's being replaced by a new framework under Article 6.4 of the Paris Agreement, commonly referred to as the Sustainable Development Mechanism (SDM). This new system builds on lessons learned from the CDM, but it's designed to be more inclusive, aligning better with each country's own climate plans (NDCs). Unlike Kyoto, which only put legal targets on developed nations, the Paris Agreement involves all countries, making this new approach broader and more flexible (UNFCCC, 2022).

Though the CDM's era is ending, its legacy lives on shaping the future of global carbon markets and reminding us of the importance of transparency, good governance, and balancing efficiency with fairness.

3.3 Regional and National Initiatives

Outside the EU, many other countries and regions have developed their own compliance carbon markets, tailored to their specific economic and climate goals. These efforts reflect a growing global belief that market-based approaches can be powerful tools for reducing emissions.

As of 2025, the global compliance carbon market is growing rapidly. In 2024 alone, it was valued at around USD 113 billion, and it's expected to nearly quadruple reaching over USD 458 billion

by 2034. This surge reflects the growing pressure on countries and companies to meet climate goals and adopt cleaner practices (Global Market Insights, 2025).

In China, it launched its national Emissions Trading System (ETS); now the world's largest in terms of emissions covered in 2021. It began with the power sector, which alone accounts for over 40 per cent of China's emissions, and plans are in motion to expand into industries like steel, cement, and aluminum. This system is central to China's goal of reaching carbon neutrality by 2060 (ICAP, 2023). In the United States, the California Cap-and-Trade Program has been in place since 2013. It covers energy, manufacturing, and transportation fuels and is linked with Québec's program in Canada showing how local-level partnerships can help advance climate goals (CARB, 2022). Meanwhile, South Korea launched Asia's first economy-wide ETS in 2015, and New Zealand a pioneer in carbon trading has continuously adapted its system to include sectors like forestry and agriculture, which are vital to its emissions profile (Ranson & Stavins, 2016).

These examples show that emissions trading systems are highly adaptable. When designed well with transparency, solid rules, and wide sector participation, they can be powerful tools not just for hitting national climate targets, but also for attracting green investment, sparking innovation, and ensuring a fair and inclusive transition to a low-carbon future.

4. VOLUNTARY CARBON MARKET

Not all climate action comes from government rules or mandates. In fact, many companies, organizations, and individuals are choosing to take action on their own. That's where voluntary carbon markets (VCMs) is emerged. They give people a chance to offset their carbon footprint by supporting certified projects that reduce or remove greenhouse gases from the atmosphere. In doing so, they help expand participation in climate solutions, even when it's not legally required (Donofrio et al., 2020). These markets are especially important because they bring non-state actors like businesses and local communities into the fight against climate change, including in places and sectors that aren't yet covered by official regulations.

4.1 Types and Standards of Projects

There's a wide range of project types that contribute to the voluntary carbon market, each taking a different approach to cutting emissions: Nature-based solutions focus on using natural systems to absorb carbon. This includes planting trees (afforestation and reforestation) and improving forest management practices. Renewable energy projects like solar panels and wind farms help reduce reliance on fossil fuels and lower carbon emissions. Community-level projects such as distributing clean cook stoves or supporting sustainable farming cut emissions and improve local livelihoods at the same time. Methane capture from landfills or livestock operations is another powerful solution, as methane is one of the most harmful greenhouse gases.

To make sure these projects actually deliver meaningful climate benefits, they need to meet rigorous standards set by trusted certification bodies. The most widely recognized are the Verified Carbon Standard (VCS) from Verra, the Gold Standard, and the Climate Action Reserve (CAR) (Forest Trends, 2023; Verra, 2022; Gold Standard, 2021).

4.2 Market Dynamics and Trends

In recent years, voluntary carbon markets have taken off, fueled by the global push for net-zero emissions, growing pressure from investors, and increased public demand for corporate climate action. In 2021 alone, the market for voluntary carbon credits surpassed $2 billion, helping offset hundreds of millions of tonnes of emissions around the world a clear sign that environmental responsibility is becoming a central part of how companies do business (Ecosystem Marketplace, 2021).

Across industries, businesses are now integrating carbon credits into their broader sustainability strategies. While fully decarbonizing operations and supply chains can take time, voluntary carbon credits offer a practical interim solution allowing companies to tackle emissions that are currently hard to eliminate, all while supporting impactful climate projects worldwide (Blaufelder et al., 2021).

As the market expands rapidly, so do concerns about its credibility and consistency. That's where initiatives like the Taskforce on Scaling Voluntary Carbon Markets (TSVCM) and the Integrity Council for the Voluntary Carbon Market (ICVCM) step in. These organizations are working to strengthen the foundation of VCMs by promoting greater transparency, standardizing

procedures, and safeguarding the environmental integrity of the credits being bought and sold (TSVCM, 2021; ICVCM, 2023).

In 2024, the global voluntary carbon market issued approximately 287 million tonnes of CO_2 equivalent ($MtCO_2e$) in carbon credits, marking a 7 per cent decrease from 2023. Despite this dip, around 177 million credits were retired?, signaling stable demand amid market fluctuations (LinkedIn, 2024; Carbon Market Watch, 2024). The market's total value reached USD 1.55 billion in 2024 and is projected to grow to USD 1.89 billion in 2025, reflecting a strong compound annual growth rate (CAGR) of 21.9 per cent (The Business Research Company, 2024).

4.3 Obstacles and Opposition

While voluntary carbon markets (VCMs) are growing fast and attracting attention, they also face a number of serious challenges especially when it comes to ensuring credibility and earning public trust. One of the biggest concerns is additionality. For a carbon credit to be meaningful, the emissions reduction it represents must be something that wouldn't have happened without the incentive from the credit. If a project would have moved forward anyway, then it's not really "offsetting" anything and that casts doubt on its actual climate benefit (Gillenwater, 2012; Schneider, 2009). Permanence is another sticking point, especially for nature-based projects like forest conservation and reforestation. These carbon sinks can be unexpectedly reversed by wildfires, disease outbreaks, or even future land development erasing years of hard-earned progress (Cames et al., 2016). There's also the issue of double counting, where the same emissions reduction might be claimed by both a project developer and a government for national targets. This muddles the math and weakens the reliability of climate accounting, particularly in international climate agreements (Prag et al., 2012).

Adding to the complexity is the lack of consistency across standards and methods. Without a single regulatory body to oversee the entire VCM ecosystem, the quality, transparency, and credibility of carbon projects can vary dramatically. For buyers, this makes it difficult to know what they're really paying for and for the public, it can raise concerns about whether the market is truly delivering on its promises (Lazarus et al., 2016; Broekhoff et al., 2019). But it's not all doom and gloom. Reform is underway. Organizations like the Integrity Council for the Voluntary Carbon Market (ICVCM) and the Voluntary Carbon Markets Integrity Initiative (VCMI) are stepping in to develop common principles, tougher verification standards, and greater transparency.

5. CARBON TRADING IN INDIA

5.1 India's Role in the Compliance Market

India is one of the leading countries in carbon credit trading, participating in both compliance and voluntary markets. In India, the compliance carbon market is still in its early stages. However, the country has already laid important groundwork through initiatives like the Perform, Achieve, and Trade (PAT) scheme, which helped save over 106 million tonnes of CO_2 emissions between 2015 and mid-2024 (Bureau of Energy Efficiency, 2025). With the recent launch of the Carbon Credit Trading Scheme (CCTS), India is now moving toward a more structured and regulated carbon market. While the exact volume of carbon credits traded is yet to be seen, these steps signal a strong commitment to using market-based tools to tackle climate change.

The country has earned carbon credits by reducing emissions across fifteen sectors, including energy industries, energy distribution, manufacturing, chemical industry, construction, transport, metal production, mining and mineral production, afforestation and reforestation, agriculture, forestry, and other land use (AFOLU), among others. Under the compliance market, the Clean Development Mechanism (CDM) was adopted by developing countries like India. The first CDM project from India an HFC-23 abatement project in Gujarat was registered in 2005. India was the leading developer of CDM projects until 2008, after which it was overtaken by China. A total of 3,023 projects (Fig. 4) have been approved by the National CDM Authority (NCDMA). Maharashtra leads with 398 approved projects, followed by Gujarat with 391, and Tamil Nadu with 379. Maharashtra alone accounts for approximately 13 per cent of the total approved projects. Most of the carbon offset projects in India are focused on energy generation (Solar, wind, Hydro, biogas etc.). These efforts form a crucial part of India's broader strategy to reach net-zero emissions by 2070 (BEE, 2023; MoEFCC, 2022).

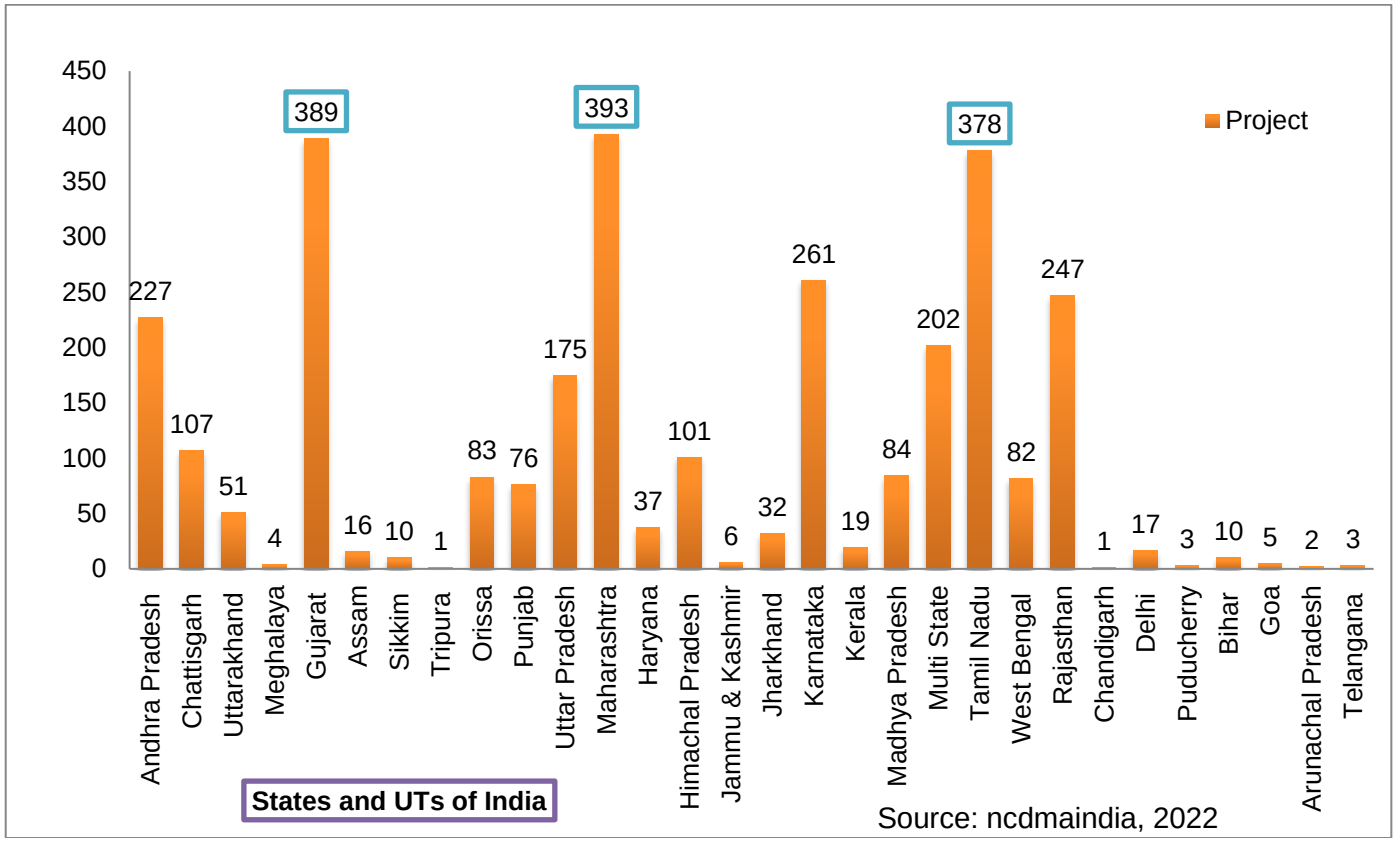

Fig. 4. Approved projects in NCDMA upto 2020

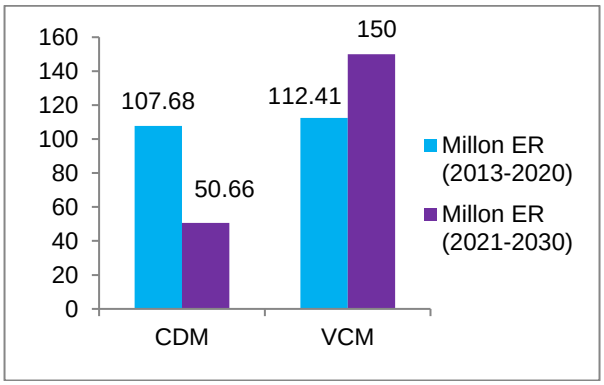

Fig. 5. Mitigation Potential (2013 – 2020 & 2021-2030) in India
Source: Ministry of Environment Forest and Climate Change, 2020

5.2 India's Role in the Voluntary Market

India is also stepping into the spotlight. With a strong pipeline of project-based credits especially in renewable energy, energy efficiency, and afforestation many rooted in the earlier Clean Development Mechanism (CDM), India is fast becoming a major supplier of high-quality carbon credits. Nature-based and community-focused projects are gaining traction, appealing to international buyers looking for meaningful and sustainable climate investments.

At the same time, Indian companies, particularly those in IT, manufacturing, and infrastructure, are starting to explore voluntary offsets to meet ESG (Environmental, Social, and Governance) expectations and build resilient, sustainable operations (BEE, 2023). The upcoming Carbon Credit Trading Scheme (CCTS), which aims to bring together voluntary and compliance markets, could give India's carbon credit ecosystem an even bigger boost in the coming years.

In this context, India emerged as a key player in the voluntary market, issuing approximately 43.4 million carbon credits, positioning itself as the second-largest global issuer after the United States (Abatable, 2024). The country also hosted 237 active carbon credit projects and had 76 active project developers, underlining a robust and expanding project development ecosystem within the nation (Abatable, 2024).

5.3 Mitigation Potential from both CDM and VCM (2013 – 2020 & 2021-2030) in India

The Fig. 5 illustrates the emission reductions (in million ERs) achieved through the Clean Development Mechanism (CDM) and the Voluntary Carbon Market (VCM) across two periods: 2013–2020 and 2021–2030. During 2013–2020, CDM achieved 107.68 million ERs, which significantly declined to 50.66 million ERs in the subsequent period. In contrast, VCM recorded 112.41 million ERs in 2013–2020, which increased substantially to 150 million ERs by 2021–2030. This indicates a clear shift from CDM to VCM as the preferred mechanism for emission reduction, highlighting the growing importance and effectiveness of voluntary carbon markets in global climate action efforts. The trend suggests a need for enhanced support and regulation of VCMs to further strengthen their role in meeting climate targets.

Together, these developments highlight how voluntary markets are evolving from optional extras to strategic tools playing a key role in global decarbonization efforts while offering a bridge toward deeper and more permanent emission cuts.

6. CONCLUSION

Both compliance and voluntary carbon markets play critical roles in the global response to climate change. Compliance markets are grounded in regulations and legally binding targets, while voluntary markets enable companies, communities, and individuals to take additional climate action beyond what is required demonstrating genuine environmental leadership. These markets facilitate the earning of carbon credits by funding or implementing projects that reduce, avoid, or remove greenhouse gas (GHG) emissions. By providing financial incentives for emission reductions, carbon credits help lower overall GHG concentrations, contributing directly to climate change mitigation

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used for grammar check.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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