PERSPECTIVE PIECE

# ROLE OF CARBON CAPTURE, UTILIZATION, AND STORAGE IN INDIA'S CLIMATE POLICY

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## Abstract

*India has a rapidly growing economy with a coal-dominant energy system. Its global commitment to net-zero emissions by 2070 and national priorities for sustainable development present a challenge for climate and economic policies. At present, electricity generation, steel, cement, and other fossil-fuel dependent sectors have limited commercially viable and affordable options available for their decarbonization. To deal with these 'difficult to decarbonize' sectors, global and national scenarios aiming for net-zero emissions often rely on carbon capture, utilization, and storage (CCUS) technologies for abatement and removal of* $CO_2$ *from the energy systems. Here, we evaluate the role of CCUS in India's climate policy by understanding the projected demand for these technologies in net-zero scenarios, the technological alternatives in the context of India and international and national policies available for their deployment. The Paris agreement, through Article 6, enables parties to use voluntary cooperation for carbon trading to meet national climate goals. India also recently notified a list of mitigation and carbon removal activities (CCUS) that could be implemented under carbon credits mechanism of Articles 6.2 and 6.4 of the Paris agreement. Further, the establishment of carbon markets in India would pave the way for innovations and financing of upcoming CCUS technologies. We conclude with a recommendation to integrate the upcoming Indian Carbon Market (ICM) with relevant policies in energy and industrial sectors to promote experimentation, research, and commercialization of selected CCUS technologies, based on projected demands in net-zero scenarios. The early experimentation and deployment would also help in testing the multidimensional feasibility of these technologies and build socio-political acceptance for techno-economically viable alternatives.*

## Introduction

India is the fastest growing, large emerging economy, home to 17% of the world population, and has witnessed an economic growth rate of around 6% in the past three decades (World Bank, 2020). However, India's per capita income (measured as gross domestic product in terms of purchasing power parity) is still one-third as compared to the world average (World Bank, 2020). In terms of energy profile, around 17% of world's population consumes just 6% of the world's primary energy, 800 million people lack reliable access to modern cooking fuels, and the access to electricity is still unreliable in many rural areas (Sankhyayan & Dasgupta, 2019). Although, energy demand in India is expected to double by 2040 to become a quarter of the global demand, its per-capita energy consumption may remain 40% below the world average (IEA, 2019). The primary source of fuel for electricity is coal which is abundantly available in India. Coal production has grown an annual rate of 3.8% in the past decade and is expected to increase further to meet the rising energy demand (MoEFCC, 2023). Due to its dependence on coal and other fossil

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fuels, greenhouse gas (GHG) emissions from India have doubled to around 3.1 $GtCO_2e$ in 2019 as compared to their 2000 levels (MoEFCC, 2023). These emissions are projected to reach 4.6 to 5 $GtCO_2e$ per year by 2050 in a medium to high economic growth current policy scenario (Garg *et al., 2024).*

As a coal-dependent, fast growing, major economy, India's emissions trajectory is important for the global goal of net-zero energy systems. As a signatory to the Paris agreement, India has commitment to reach net-zero emissions by 2070. As part of the nationally determined contributions (NDCs), government of India has pledged to reduce the emissions intensity of its economy by 45% by 2030 as compared to the 2005 levels (MoEFCC, 2023). At the same time, India also wants to achieve affordable housing, health and education, clean energy and water access, food security and a better standard of living for all its citizens in the near future as outlined in United Nations' sustainable development goals (SDGs) (UN, 2015). The NDCs committed by India, endeavor to strike a balance between the development and climate goals. However, achieving 'net-zero' emissions in the latter half of this century, primarily from a fossil-fuel dependent electricity sector, pose additional challenges to balance the global climate targets and domestic development goals.

As the extant literature suggests, one of the biggest hurdles in reaching net-zero emissions from energy systems are the 'difficult to decarbonize' sectors. These sectors include energy intensive industries like steel and cement, long distance transport, aviation and reliable electricity generation (Davis *et al., 2018*). They are considered as 'difficult to decarbonize' due to the lack of commercially viable cleaner fuels and technologies that can affordably replace the fossil fuels currently used in these sectors. In this context, India's electricity generation, steel, cement, and other energy-intensive sectors are also dependent on fossil fuels with limited commercially viable and affordable options available at present for their decarbonization. To deal with these 'difficult to decarbonize' sectors, scenarios aiming for net-zero emissions often rely on carbon capture, utilization, and storage (CCUS) along with carbon dioxide removal (CDR) through technologies like bioenergy with carbon capture and storage (BECCS) and afforestation/reforestation (AR) to meet the climate goals (IPCC, 2018). An extension of CCUS, CDRs are defined as human efforts to remove carbon dioxide ($CO_2$) directly from the atmosphere (negative emissions), either through the enhancement of natural carbon sinks or by way of chemical engineering to reduce atmospheric $CO_2$ (Fuss et al., 2018; IPCC, 2022). The term "net-zero" is used to indicate zero emissions, achieved after accounting for the negative emissions from CDRs. The mainstreaming of CDRs in climate mitigation discussions has started only recently with integrated assessment models (IAMs) banking on negative emissions from BECCS and AR to achieve the below 2°C pathways (Fuss et al., 2018; Minx et al., 2018). The role of CDRs was first summarized in the Intergovernmental Panel for Climate Change (IPCC)'s 4th assessment (AR4) followed by AR5 highlighting the importance of negative emissions in achieving the 2°C goals. In the latest assessments (1.5°C Special Report and the AR6), pathwaysthat restrict the global temperature rise to 1.5°C by the end of this century rely on CDRs in the range of 150-1200 $Gt\text{-}CO_2$ (IPCC, 2018, 2022).

Recent research in India has also highlighted the need to explore carbon capture, utilization, and storage (CCUS) and carbon dioxide removal (CDR) technologies to decarbonize the energy sector and attain net-zero emissions (Garg *et al., 2017;* Patange *et al., 2022*; Singh *et al., 2024*; Vishal, Chandra, *et al., 2021)*. In this paper, we assess the role of CCUS and CDR in India's climate policies.

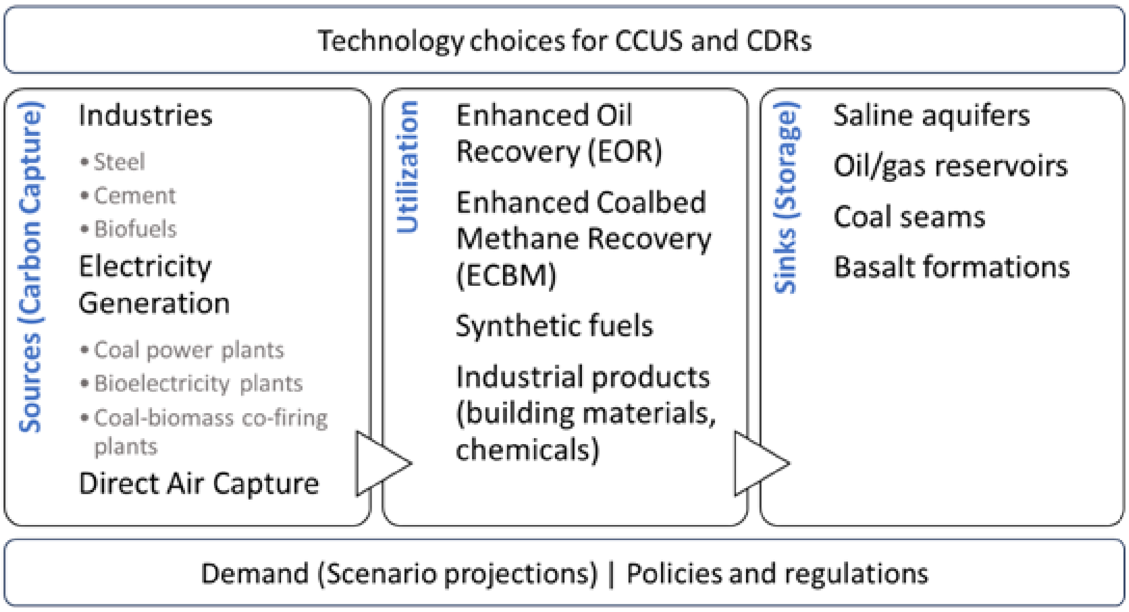

Figure 1 : Key elements to evaluate the role of CCUS in climate policy.

As illustrated in figure 1, we evaluate the role of CCUS and CDR technologies based on three key factors. First, the projected demand for these technologies in the near and long-term, second, the availability and feasibility of carbon capture, utilization, and storage technologies with possibility for carbon dioxide removal in the Indian context, and third, the policies and regulations to support and scale up these technologies to meet the projected demand for CCUS and CDR. By examining these three factors, we endeavor to inform the policy discussions on the deployment of CCUS and CDR technologies in India.

## Carbon dioxide removal in global and national scenarios

According to the latest IPCC assessment, between 1850 and 2019, a total of 2390 (±240) $GtCO_2$ of anthropogenic emissions were emitted. This has resulted in a global temperature rise ranging between 0.8 to 1.3°C. The remaining carbon budget to restrict the temperature rise between 1.5 to 2°C with more than 50 per cent likelihood is estimated to range between 300 $GtCO_2$ (1.5°C, 83% likelihood) and 1350 $GtCO_2$ (2°C, 50% likelihood) (IPCC, 2022). This remaining budget is reducing at the rate of 40-50 Gt-$CO_2$ per year, as suggested by the recent trends (Crippa *et al., 2020;* Olivier & Peters, 2020). The long term climate goals require total $CO_2$ emissions from fossil fuel combustion to reach zero between 2045 to 2065 (IPCC, 2018) and the transition of energy systems towards 'net-zero' emissions is an important step to meet these climate goals.

In climate policy literature, systems modelling is often employed to study various baseline and alternate policy scenarios to meet the integrated goals of climate, environment, and economic development. In the context of climate policy analysis, scenarios are tools that help in the development of alternative images of an uncertain future and to evaluate the energy system transitions and resultant emissions in an internally consistent manner (IPCC, 2000; Mietzner & Reger, 2005; O'Neill & Nakicenovic, 2008). Climate scenarios from integrated assessment models (IAMs) are periodically compared and analyzed in IPCC's assessment reports. The latest, sixth assessment report (AR6) on climate change mitigation, published in 2022, includes global emissions projections along with deployment of mitigation technologies like renewables, CCUS, and CDRs to meet the net-zero targets. In IPCC 2022 assessment of the modelled mitigation pathways, scenarios that limit global warming to 1.5 °C (>50% probability) with no or limited overshoot, result in cumulative net emissionsin the range of 330–710 GtCO$_2$. In these pathways, the remaining fossil fuels (coal, oil, and gas) in the energy systems are either phased out or abated using CCUS. Further,during 2020-2100,the global cumulative net negative emissions from CDR technologies are projected to be 20-660 GtCO$_2$ (IPCC, 2022). However, the current implementation of CDR stands at 2.2 GtCO$_2$/year, 99.9% of which is through conventional routes like afforestation/reforestation (S. Smith *et al., 2024).* Although afforestation/reforestation is an established methods for CO$_2$ removal, its negative emissions potential is constrained by the limited and temporary capacity of sequestering carbon in the above ground biomass (EASAC, 2018; Lal, 2004; Minx *et al., 2018*; P. Smith, 2016). In addition, evidence suggests that as temperatures rise, the ability of forests to sequester carbon reduces (Lal, 2004). Emerging CDR technologies like bioenergy with CCS and direct air capture account for 1.3 Mt Co$_2$/yr and less than half of this is currently stored in geological reserves (S. Smith et al., 2024). Although these emerging CDR technologies are growing rapidly, they also face implementation challenges due to technology risks, costs, and scaling issues (IPCC, 2022).

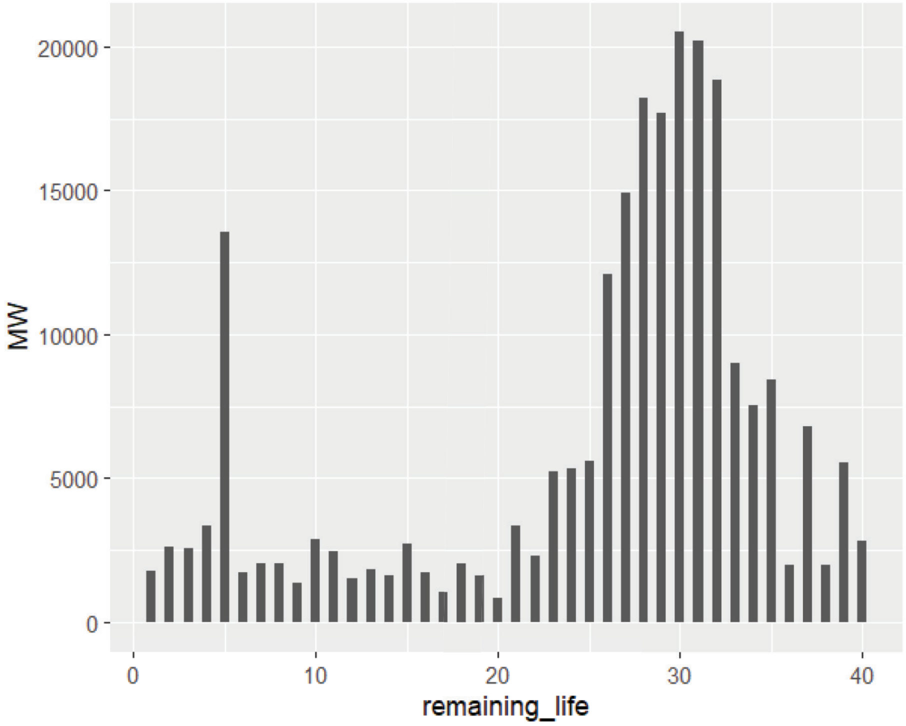

Figure 2 : Age structure of Indian coal power plants as of July 2024 (Source: Authors ‘illustration based on Global Coal Plant Tracker, Global Energy Monitor, July 2024 release)

In the Indian context, a recent modelling assessment of mitigation scenarios to achieve net-zero emissions by 2070 considers different technology options like nuclear, renewables and fossil fuels with CCUS. In the pathway that relies on CCUS, capacity of coal plants with CCUS reaches 207 GW by 2070 (Garg *et al., 2024).* Recent research also projects the demand of 400–800 Mt-CO$_2$/year by 2050 for India to meet its share of the 1.5°C carbon budget (Singh *et al., 2024).* Another study analyzing the net-zero scenarios for India found that the share of fossil fuels in primary energy mix declines to 5.5% by 2070 without CCUS but remains in the range of 19-30% with the deployment of CCUS technologies (Chaturvedi & Malyan, 2022). Given the nascent stage of CCUS deployment at present, these net-zero scenarios would require rapid deployment and scaling up of CCUS infrastructure in the country. In addition, majority of India's coal power plants are young with about 70% of total capacity installed after 2010 (Figure 2). Around 8 GW of new capacity has become operational in past two years after the announcement of the net-zero target by India which highlights the government's commitment to energy security and affordable electricity with reliance on coal-based generation. With India's NDCs and climate mitigation targets, the younger fleet of coal plants without CCUS face the risk of becoming stranded assets after 2050 in the net-zero scenarios (Garg *et al., 2024)*.

## CCUS and CDR technologies

As Figure 1 illustrates, the available technologies for CCUS and CDR can be categorized as sources for carbon capture, utilization, and sinks for permanent storage of captured $CO_2$. Carbon Capture, Utilization and Storage (CCUS) is broadly defined as industrial $CO_2$ removal through carbon capture, compression, transportation, utilization and storage in geological storage sites (Berend et al., 2014). As illustrated in figure 2, a large potential source for $CO_2$ in the future will be coal power plants. Another major source of $CO_2$ with potential for negative emissions is bioenergy with carbon capture and storage (BECCS). The technology involves burning of biomass in standalone or coal power plants (co-firing), to produce electricity and then use the CCS process to capture and store the $CO_2$ produced during the biomass combustion in geological reserves (Minx *et al., 2018)*. Biomass fuel is different from fossil fuels in the sense that $CO_2$ released from biomass combustion can be completely offset by capture of the same amount of $CO_2$ by growing new biomass in the given period. Therefore, if we capture the $CO_2$ released from burning of biomass through a technical intervention such as CCS, it will result in net removal of $CO_2$ from the atmosphere. The rising demand for steel and cement for housing and infrastructure also make these industries a major source of carbon capture in the future. When compared to coal power plants, flue gases from industrial processes for steel and cement production are a concentrated source of $CO_2$ (Pilorgé *et al., 2020)*. Further, biofuels processes like ethanol fermentation offer the purest stream of $CO_2$ and may become an important source of carbon capture following the biofuels policy in India (MoPNG, 2018). The biofuel production using renewable biomass feedstock also open avenues for CDR through BECCS. In addition, direct air carbon capture and storage (DACCS) is another potential source of $CO_2$ with abundant potential but high cost and energy penalty. DACCS is still in the research and development phase with many government and commercial parties trying to explore its commercial potential for future deployment (IPCC, 2022; Sutherland, 2019).

The captured carbon through different routes may be utilized for enhanced oil and gas extraction, synthetic fuel production or for various industrial purposes. In some cases, such as enhanced oil recovery (EOR), $CO_2$ is first utilized for oil recovery and then stored permanently in the oil wells constituting CCUS. If the source of $CO_2$ is atmospheric, like renewable biomass from energy plantations, this may also result in CDR. In other cases, like using $CO_2$ for producing building materials, the utilized $CO_2$ may not be stored permanently in the materials and would be considered as CCU. With emerging demand for carbon-neutral alternate fuels and materials, CCU can become a key route in India's climate policy (Singh et al., 2024; Vishal, Chandra, *et al., 2021)*.

In terms of storage potential, there are different estimates with a lot of uncertainty in case of India. According to Viebahn *et al. (2014),* the high, intermediate, and low-quality storage potential estimates are 143, 63 and 45 Gt-$CO_2$ divided among saline aquifers, relinquished oil wells and coal mines. However, based on expert consultations, the potential in coal mines (also with the alternative for coal bed methane recovery) will not be available for the next 10-20 years. Earlier studies have estimated the storage potential in the range of 572 to 105 Gt-$CO_2$ (Dooley *et al., 2005*; Singh, 2013). According to another study, the good quality potential lies between 47-48 Gt-$CO_2$ (Holloway *et al., 2009)*. The most recent assessment for India estimates a total potential of 395-614 Gt-$CO_2$ (Vishal, Verma, *et al., 2021)*. This wide range of estimates needs further evaluation and site-specific studies to ascertain the realistic potential of $CO_2$ storage in India.

**International and national policies supporting the deployment of CCUS**

Article 6 of the Paris agreement enable countries to establish voluntary cooperation in implementation of their NDCs . This voluntary cooperation includes (1) use of Internationally transferred mitigation outcomes (ITMOs), a market provision to trade carbon credits among countries (Article 6.2), (2) mechanisms to contribute to GHG mitigation and support sustainable development (Article 6.4) and, (3) non-market approaches (Article 6.8). Section 6.4 of the agreement also sets out the rules and procedures for Carbon Crediting Mechanism . These procedures include activity design for emissions reduction in host parties and to set baselines to demonstrate additionality, ensure accurate monitoring and calculate emission reductions achieved by the activity. The selected activity is then followed by development of mechanism methodology, approval, and authorization of the activity by a Supervisory Body, validation, registration, monitoring, verification, and certification. Public and private entities with surplus potential for emissions reduction and negative emissions through CCUS and CDR activities may consider using the Carbon Credit Mechanism for registering these projects and earn carbon credits from the international voluntary carbon markets.

At a national level, government of India has notified a list of activities that will be considered for trading of carbon credits under the voluntary cooperation as part of Article 6.2 and 6.4 of the Paris agreement. These include mitigation activities like green hydrogen, compressed biogas, sustainable aviation fuels and energy efficient technologies for difficult to decarbonize sectors. These mitigation activities offer scope for experimenting with innovative CCU technologies. In addition, CCUS is included as part of removal activities and may be explored for CDR projects in the future. Further, the Bureau of Energy Efficiency (BEE) recently announced the establishment of Indian Carbon Market (ICM) framework to promote carbon trading under compliance and voluntary mechanisms. The regulatory framework for ICM was incorporated in the Energy Conservation (Amendment) Act 2022. On the lines of BEE's Perform, Achieve and Trade (PAT) scheme, government will set emissions targets for large industrial entities (a.k.a. obligated entities) from selected sectors. These obligated entities will have to comply to certain GHG emissions intensities and will be issued carbon credit certificates (CCC) for emissions reduction beyond the set target in a compliance year. On the other hand, obligated entities not meeting their emissions intensity target can purchase the CCCs to meet their compliance targets. Similarly, non-obligated entities can register their projects under the voluntary mechanism. Projects on CCUS and other removals are proposed under Phase II of the voluntary offset mechanisms. Further, under the compliance mechanism, obligated entities from sectors like electricity, steel, and cement can consider CCUS and CDR as abatement technologies to reduce their emissions intensities and earn carbon credits. However, development of CCUS under the ICM will depend on future costs of these technologies and carbon prices that can support their commercialization and scale-up to meet the projected demands under various net-zero scenarios. In addition, government may also need to support infrastructure development and promotion of research and innovation in these sectors.

In line with the Paris climate goals, the cost of carbon to achieve net-zero emissions fall in the range of USD 40–80/$tCO_2$ by 2020 and USD 50–100/$tCO_2$ by 2050 (Stiglitz *et al., 2017).* At present, carbon is priced in India through a coal cess of INR 400/tonne of coal. A NITI Aayog estimate suggests that

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[3] *https://unfccc.int/process/the-paris-agreement/cooperative-implementation*

[4] *https://unfccc.int/process-and-meetings/the-paris-agreement/article-64-mechanism*

[5] https://unfccc.int/sites/default/files/resource/cma2021_10a01E.pdf?download

[6] https://moef.gov.in/uploads/pdf/revised_list_article_6.2.pdf

[7] https://beeindia.gov.in/en/programmes/carbon-market

this can raise up to INR 53 thousand crores in 2050 and finance around 31% of the carbon capture. Another recent assessment of net-zero scenarios for India estimates that a carbon price of INR 1700/ $tCO_2$ (approximately USD 25/$tCO_2$) may support the decarbonization of the electricity sector. Policies for pricing carbon could also be used to support the development of CDR technologies which could lead to their early-stage deployment and testing in the near-term. In addition, the introduction of carbon pricing could also make $CO_2$-EOR competitive with conventional oil, which is mostly imported in case of India. The carbon pricing instruments could also be used to finance $CO_2$ pipeline infrastructure and to research on geological sinks to reduce the uncertainties on $CO_2$ sequestration potential in India. According to a recent study of bioenergy-based $CO_2$-EOR at the mature oil fields of Ankleshwar, Gujarat, a carbon price of USD 40 to 60/t $CO_2$ may make this route competitive when compared to the conventional oil (Patange *et al., 2022).*

Apart from carbon pricing, an integrated approach to policy making could offer near-term opportunities to experiment with CCUS and CDR technologies. Early experimentation with new technologies like BECCS and DACCS using near-term opportunities could offer insights into their feasibility potential as long-term mitigation strategies. To explore such opportunities, the current policies and their corresponding institutions will have to be aligned towards the larger goal of net-zero energy systems. In India, there are policies in place to govern different sectors. For instance, the policies on energy access, doubling of farmers income, water conservation in agriculture, promotion of first and second-generation biofuels could be aligned with the schemes supporting enhanced oil recovery and the CCUS in the industrial sectors to explore CDR and negative emissions through the BECCS route. $CO_2$ capture is an expensive and energy intensive endeavor and could be made affordable through economies of scale. An alignment of energy sector policies towards the long-term goal of net-zero emissions could help in building systems with zero to negative emissions.

Finally, it is important to consider multi-dimensional feasibility of CCUS and CDR deployment in emission scenarios and discuss it with relevant stakeholders. The feasibility of realizing the projected emission reductions in the net-zero scenarios by 2050 is based on the techno-economic assumptions about CCUS, CDR and other clean energy technologies. However, other dimensions of feasibility such as institutional capabilities, social acceptance and national and international politics are also important to get a realistic picture of climate goals under a given scenario (Jewell & Cherp, 2020; Peng et al., 2021; Spencer *et al., 2018).* A recent study suggests that the net-zero or 1.5°C pathways may face issues in implementation due to institutional constraints (Brutschin et al., 2021). In case of India, the social and political feasibility of mitigation strategies to phase out coal from the energy system needs further evaluation. Replacing unabated coal with cleaner fuels would be technologically and economically feasible due to the rapid commercialization and falling costs of renewables. However, transitions without due consideration for governments and people dependent on coal for income and livelihood could create social and political issues in phasing out coal from the energy systems (Vishwanathan et al., 2018). Similarly, deployment of CCUS and CDR technologies would require governments to come up with appropriate regulations and get the relevant stakeholders and communities on board to ensure smooth and just transitions as envisaged by the scenario results. One way to achieve this is by investing in research, development, and demonstration of newer and less explored technologies to test their techno-economic feasibility as well as understand the socio-political issues that could arise from their large-scale deployment.

## Conclusions

India's global commitment to net-zero emissions and national priorities for sustainable development present a challenge for its climate and economic policies. With a coal dominant energy sector and rising demand for carbon-neutral alternate fuels to replace imported oil and gas, various routes of CCUS and CDR technologies may be considered as an alternative to achieve net-zero emissions from Indian energy systems. In the context of net-zero emissions and climate policy targets set by India, CCUS and CDR can serve two purposes. First, to given time for just transitions out of fossil fuel-based industries and electricity generation, ensuring energy security and avoiding stranded assets ins second half of the century. Second, as a source of negative emissions in second half of the century to compensate for residual emissions from difficult to decarbonize sectors. In this paper, we propose three key steps to understand the role of CCUS and CDR technologies in achieving net-zero emissions. First, the assessment of global and national scenarios to project the future demand for these technologies. Second, an assessment of available technologies for $CO_2$ mitigation and removal from the atmosphere. Third, evaluation of national and international policies to support the deployment of CCUS and CDR technologies in line with their projected demands under net-zero scenarios. The Paris agreement, through Article 6, enables parties to use voluntary cooperation for carbon trading to meet national climate goals. India also recently notified a list of mitigation and carbon removal activities (CCUS) that could be implemented under carbon credits mechanism of Articles 6.2 and 6.4 of the Paris agreement. Further, India has recently initiated a carbon market which could be integrated with existing sectoral policies to support the research and commercialization of new and upcoming technologies for net-zero emissions with due consideration for multi-dimensional feasibility of these alternatives.

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