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Opportunities in India for Carbon Capture and Storage as a form of climate change mitigation

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Abstract

India is a nation with a rapidly growing economy, achieving an 8.5% GDP growth rate in 2006 and 9.2% in 2007. This rise in economic growth goes hand in hand with an increase in the country's energy demand, which is currently met, as in many evolving economies, by fossil fuels. Coal is the dominant commercial fuel, accounting for almost 70% of the total energy consumption, but India still faces serious electricity shortfalls. Both the Stern Review and The International Energy Agency's World Energy Outlook reports have listed Carbon Capture and Storage (CCS) as a carbon mitigation strategy for India. It is unclear, if, how, or when, CCS will have a place within the Indian system.

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1. Introduction

Carbon dioxide is regarded as one of the main greenhouse gases that is causing global warming and forcing climate change. In 2005 the CO₂ concentration in the atmosphere was 379 ppm, which greatly exceeds the natural range of the last 650,000 years (180 – 300 ppm) [1]. The primary source of the increase in atmospheric CO₂ concentrations is from the combustion of fossil fuels. Both past and future anthropogenic CO₂ emissions will continue to contribute to warming and sea level rise with grave implications globally. Developing countries are particularly at risk, as their infrastructures are most vulnerable to extreme events, and there is an expectation that climate change will worsen their food security, water availability and health, in addition to accelerating biodiversity losses [2]. India is a developing country that perfectly illustrates the nature of this challenge involved in developing its economy whilst also preventing dangerous climate change.

India is currently in a major predicament. Its development goal to bring a considerable portion of its population out of poverty is currently being undermined by the vulnerability to climate change. India's economy is growing at the rate around 9% per annum, while emitting significant amounts of greenhouse gases (GHGs) from fossil fuel use. The International Energy Agency (IEA) predicts that India will be in the top three emitters of the world by 2030, (it is currently ranked sixth) [3]. Therefore, India is a priority target for CO₂ reduction. However, almost half of India's

households (56%) do not have electricity, and women and girls spend a total of 80 billion hours each year collecting firewood [4].

The vast majority of India's population (70%) lives in rural areas, and agriculture accounts for 35% Gross National Product (GNP) and directly employs more than 60% of the Indian population [3]. The Indian government plans to invest heavily in the rural sectors, seeking to achieve more than 4% agricultural growth per year over five years, according to the draft paper for the 11th national plan, which will run from 2007 to 2012 [4]. According to the Intergovernmental Panel on Climate Change (IPCC), some of the most severe impacts of climate change will hit India's agriculture and natural resources [2]. For example, Himalayan glaciers are amongst the fastest retreating in the world; glacial meltwater that feeds the major rivers on the sub-continent accounts for 37% of India's irrigated land, loss of this glacier meltwater could cause water shortages for 500 million people [2].

Since a high proportion of India's energy comes from coal, and because the country's escalating fuel needs raise concerns around security of supply, Indian policymakers are taking a growing interest in promoting energy efficiency and renewables, as demonstrated by the recently launched National Action Plan on Climate Change (NAPCC) [5]. Additionally, to meet the anticipated demand for electricity, the Indian government also plans to invest in nine coal-fired Ultra-Mega Power Plants (UMPPs), which have a power generating capacity of 4GW per unit i.e. 36GW overall. There are already secured bids and contracts with international partners for three of these UMPP, with construction set to start later in 2008 [6]. Considering that just over half of India's current CO₂ emissions are from large point sources [3], it may be that such current and future sources could be a suitable starting point for capturing emissions, transporting them, and then storing them in porous rock as a mitigation strategy against dangerous climate change.

Given this context, the aim of this paper is to present an overview of the current large point sources and the potential sites for geological storage in India, highlighting the opportunities, and the blockages, that could arise for implementing a carbon abatement technology such as Carbon Capture and Storage (CCS).

2. Methods

The overarching aim of this study is to discover whether it is possible to implement CCS technology in India, and if so, how difficult the techno-political and economic process will be. The research will be based on at least two selected case studies, the focus being to investigate characteristic demonstration sites in India where the CCS technology chain could be put into effect. The aim is to assess the different types of mechanisms involved in the impetus or barriers for incorporating CCS into India's energy development programme. Data will be gathered in the UK and India, through interviews with representative stakeholders within industry, government, academia and environmental NGOs. Additional information will be collected from relevant policy, regulation and technical documents. The data gathered from the stakeholder analysis and the documental analysis will be used in a Technological Innovation Systems (TIS) approach for analysing the processes involved for implementing CCS technology in India. The TIS method, for each case study, will aim to map and analyse the CCS chain, emphasizing ways to improve the performance of the innovation system by overcoming the technology specific barriers. This approach involves three stages, starting with the mapping of the structure of the system, followed by its functions, and then linking these two in the final stage in order to analyse the performance of the functions [7]. This systematic analysis will highlight the main blocking and inducement mechanisms for technology implementation, which can aid in the formation of specific recommended actions to overcome the main barriers to implementation of the technology. Figure 1 illustrates the three stages of the TIS approach.

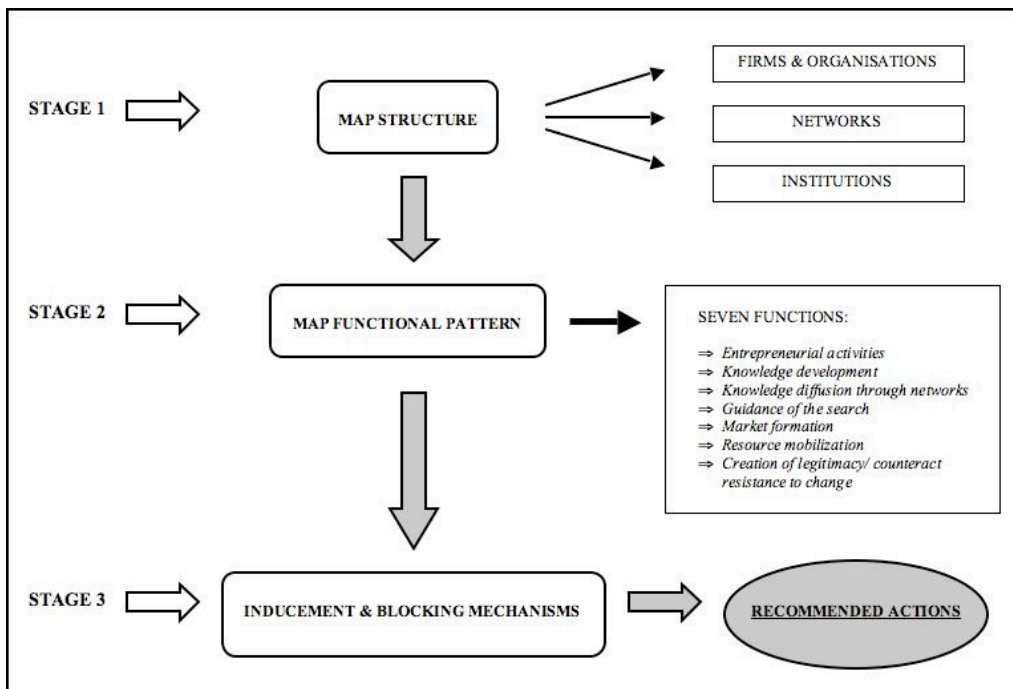


Figure 1: Schematic diagram, showing the different stages involved in a Technological Innovation System analysis.

3. India's sources of CO₂ liability

In 2006 the annual CO₂ emissions from large point sources in India was estimated to be 721 Mt CO₂, and a report by the IEAGHG [8] noted that this was roughly half of total emissions, which were approximately 1343 Mt in 2004. This section gives an overview of the various sectors that are contributing to these emissions.

3.1. Oil & Gas

India's proven reserves of oil are limited, where approximately 80% of current production is estimated to be from fields that have passed their peak. According to the IEA [3] the proven reserves amounted to 5.6 billion barrels at the end of 2006, which is roughly 0.4% of the world's reserves. The Indian oil reserves are primarily located in five sedimentary basins: Mumbai (38%), Cambay (20%), Assam Shelf (18%), Barmer (15%), and the Krishna-Godavari (KG) basin (7%) (see figure 2) [8]. Due to this limited resource, India presently imports about 100 million tonnes (or ~2 Mb/d) of crude oil, predominantly from the Middle East. India's current oil import dependence is at 70%, but this is projected to rise to 94% by 2030 [3].

At the end of 2006 India's proven reserves of natural gas amounted to 1101 Bcm, which is roughly 0.6% of world reserves [3]. Most of these reserves are located offshore, where 88% are non-associated gas and 56% of all gas reserves. It seems that the prospects for Indian gas production rely on the development of non-associated gas fields, as the 29 fields currently in production are only 30% depleted and the 154 discovered fields not yet producing contain almost 900 Bcm of proven and probable reserves [3]. However, this is not meeting India's demand and gas imports are anticipated to double between 2005-2010 (currently at 17% of whole supply) [3].

3.2. Coal

Coal is the primary domestic source of fossil fuel, dominating the current Indian energy landscape, and the IEA [3] predicts that it is likely to dominate for the next couple of decades. India has the world's fourth largest hard coal reserves and is the third largest coal producer after China and the USA. These hard coal resources (to a depth of 1200 m) are estimated to be 255 Billion tonnes in total, and 60% of these resources lie within 300m of the surface, making them potentially exploitable by surface mining techniques [3]. However, the majority of the indigenous coal is of poor quality with an average heating value of 4500 kcal/kg, compared to over 6000 kcal/kg for most internationally traded coals [3], making it unsuitable for the iron and steel industry in particular. For this reason, coal imports have grown significantly over the past two decades. The IEA [3] predicts that the overall share of imports in Indian primary coal supply would increase from 12% in 2005 to 28% in 2030 under present day government policies and measures. It is in this sector that CCS could play a major role, particularly in regards to new-build power plants. This may be a strategy for making significant cuts in CO₂ emissions from the electricity and industrial sectors that are discussed below.

3.3. Electricity

India's power sector is ranked 5th in the world in terms of installed power-generating capacity, and one of the most CO₂-intensive in the world due to its power station efficiency being very low by international standards. Power stations emitted on average 943g of CO₂ per kWh of electricity produced in 2005, which is more than 50% higher than the world average [3]. These emissions in total accounted for nearly 60% of India's total CO₂ emissions in 2005. India's electricity generation is predominantly fossil fuel based, with coal accounting for over 70 % of the fuel used for the past fifteen years.

There are a number of new initiatives taken by the Indian government in reforming the power sector. Presently, efforts are underway to develop a more efficient 125 MW IGCC unit, though its efficiency is expected to reach only 39%, which is well below the efficiency standards of IGCC plants (46%) that are now being developed in OECD countries [3]. In 2006 the Ministry of Power launched an initiative to develop Ultra Mega Power Plants (UMPPs), each with a 4 GW capacity. So far, nine sites have been selected, four of which are going to be pithead projects and the remaining five are to be coastal projects (figure 2) [8]. It is anticipated that these UMPPs will add around 257 Mt CO₂ emissions and 36000 MWe installed capacity within 7-8 years [8]. These projects represent a massive point source of CO₂ emissions, and according to a study by Mott MacDonald [6, p1-9] they may be considered as a "globally competitive opportunity for CCS, offering substantial economies of scale." They go on to highlight that "designing the UMPPs as capture ready retains the option to retrofit CCS once the relevant technologies reach greater maturity and the economic driver exists" [6, p1-9].

It is important to note that India is still seriously struggling to provide electricity to all its citizens. In 2005 the annual per-capita electricity generation was one of the lowest in the world at 639 kWh, which was over four times lower than the world average and fourteen times lower than the average in the OECD (8870 kWh) [3]. The IEA [3] predicts that power generation in India could grow to more than 1900 kWh per capita by 2030 under current government policies, but this will still remain very low by OECD standards.

3.4. Industries

Out of India's final energy demand in 2005 the industrial sector accounted for 28% of the total [3]. The main drivers of this industrial energy demand are the iron and steel, chemical and petrochemical, cement, food, paper and textile producing sectors. These industries are expected to continue to expand for the foreseeable future, where coal and oil presently meet most demand, but electricity use is on the rise. Over the next couple of decades India will face a sharp rise in demand for energy in sectors such as steel and cement that would be needed for the country's infrastructure, such as highways and railways. In addition, growth in India's automobile industry (currently at almost 20% per year) and in the housing and white goods sector is increasing steel demand. However, the steel industry currently has to import almost 50% of its coking coal needs and is facing a real challenge to keep up with this demand [3].

It is also important to take note of India's fertilizer and chlor-alkali industries, where the country is currently the 2nd largest (after China) producer of nitrogenous fertilizer (made from ammonia) in the world. Coal and naphtha are the primary feedstocks but there is an increased interest in possible switching over to natural gas.

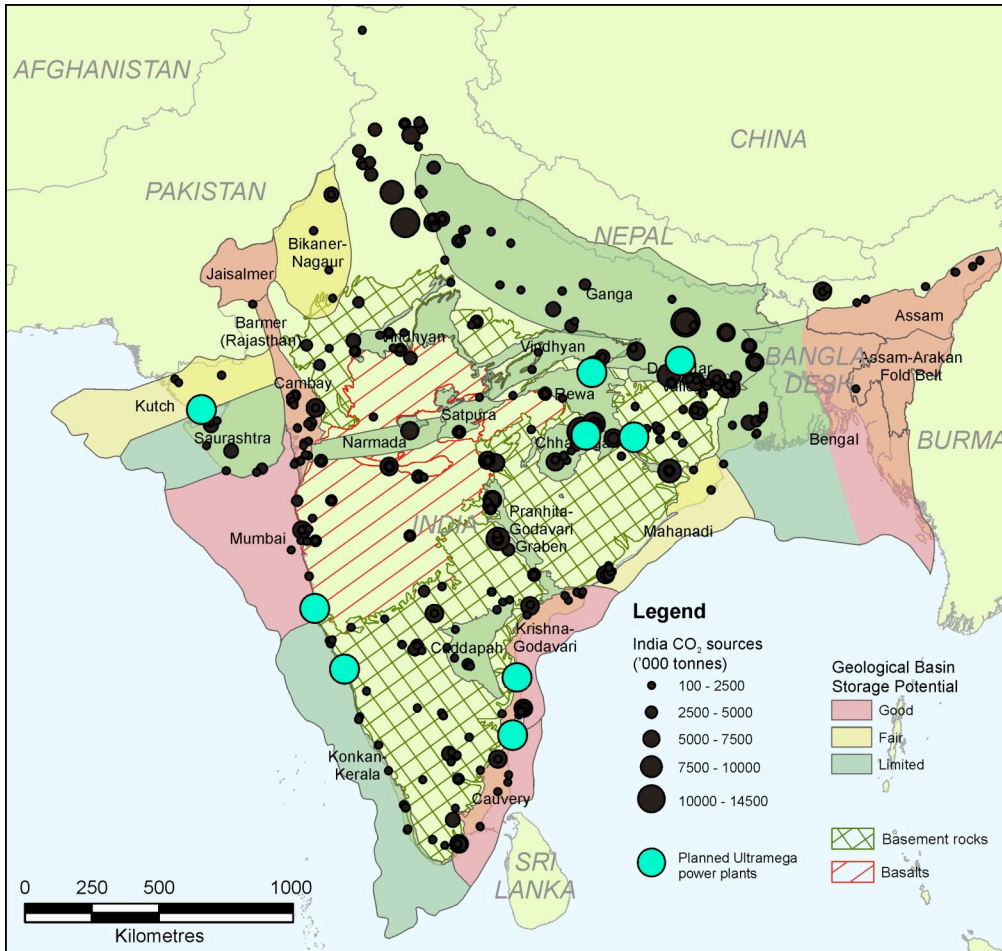


Figure 2: Present and future sources of CO₂ and geological basins with storage potential (Source: *A regional assessment of the potential for CO₂ storage in the Indian Subcontinent*. IEAGHG R&D Programme Report (2008), Cheltenham, UK).

4. India’s storage potential

CO₂ storage is an integral part of the CCS chain, and therefore it is important to quantify the storage potential of geological sites such as coal fields, oil and gas fields, and deep saline water-bearing reservoir rocks. Presently, there is a lack of knowledge in this area due to a general dearth of essential data required to characterise these sites. Nonetheless, some attempts have been made at evaluating the storage potential in India, initially by Singh et al. [9] who estimated that roughly 5 Gt CO₂ could be stored in unmineable coal seams, 7 Gt CO₂ in depleted oil and gas reservoirs, 360 Gt CO₂ in offshore and onshore deep saline aquifers, and 200 Gt CO₂ via mineralization in basalt rocks. The latter refers to laboratory experiments conducted by McGrail et al. [10] that demonstrated a relatively rapid chemical reaction of CO₂-saturated pore water with basalts to form stable carbonate minerals. This could be quite an appealing opportunity for India as a very extensive portion of the central peninsula consists of one of the worlds largest basalt lava flows known as the Deccan trap formation. However, this concept is still in the experimental phase and can only be considered a possibility if the basalt is adequately permeable to the CO₂ and can be demonstrated to be safe and secure [10].

A more recent study conducted for the IEA Greenhouse Gas R&D Programme [8] has revised down the estimates first made by Singh et al. [9]. This new assessment predicts that the storage in coal seams is likely to be constrained due to the fact that these coal reserves can be easily mined and used as fuel. Therefore, they calculate

the storage potential countrywide to be more of the order of 345 Mt CO₂ in the major coalfields, where none have the capacity to store more than 100 Mt CO₂, and only eight of the fields can store more than 10 Mt CO₂. For oil and gas reservoirs, the authors calculate the total storage capacity to be between 3.7 and 4.6 Gt CO₂. In addition, the authors note that only a few fields, such as the Bombay High field, offshore Mumbai, are thought to have ample storage for the lifetime emissions of a medium sized coal-fired power plant. None of the fields, it would seem, are large enough to store the lifetime emissions of India's planned UMPPs (currently estimated at 28-29 Mt CO₂/year for a period of 35 years, or 1 Gt CO₂ roughly). However, the authors do believe that there may be significant CO₂ storage potential "in the oil and gas-bearing sedimentary basins around the margins of the peninsula, especially in the offshore basins, but also onshore in the states of Gujarat and Rajasthan" [8, p. 2]. Yet, these potential storage sites are not well placed in respect to major CO₂ sources occurring in the central parts of the peninsula. Some areas in the northeast, such as Assam, are thought to have possible CO₂ storage, though this region is quite distant from the main emission sources, requiring thousands of kilometers worth of pipeline infrastructure, particularly if they were not to cross Bangladesh. Their study concludes that more realistic storage capacities for saline aquifers need to be quantified, most likely with the aid of oil and gas exploration information, such as seismic and well data.

5. CCS opportunities in India

Considering the industrial point sources of CO₂ and the relevant geological sites with storage potential in India, it may seem that there are only a limited number of opportunities for implementing CCS technology. There are however, a few options that one could consider, and the case studies for this study will focus on four possible options that may well be a starting point for demonstrating the technology in India. These are:

- *Capture of pure CO₂ streams in industry* – it may be easiest to apply capture technology to industry where processes already produce pure streams of CO₂, e.g. the gas and fertiliser industries. However, a study by Shackley & Verma [11] found that there is actually a shortage of CO₂ at many Indian fertiliser plants because they tend to use all the CO₂ that is generated from ammonia production in neighbouring urea plants. In fact, it was found in some cases that extra CO₂ generating units had been constructed at various facilities in order to supplement the supply of CO₂ for urea manufacture [11]. Supplying waste CO₂ could displace this generation.
- *Enhanced Oil Recovery (EOR) offshore & onshore* – the Indian government has already started developing plans for using CO₂ from an offshore sour gas facility at Hazira, Gujarat for EOR at an onshore site 70 km away. An estimated 1200 tonnes of captured CO₂ would be transported to this oil field on a daily basis (0.36 Mt CO₂ /yr) and be used to maintain pressure in the field, rather than decrease the viscosity of the oil remaining in the field¹. This results in a large percentage of the CO₂ remaining in the pore space and not returning to the atmosphere [11]. Furthermore, the assessment by the IEAGHG [8] indicates that there is potential for CO₂ storage in the offshore basins around Gujarat, such as the Cambay, which are in close proximity to the Hazira industrial belt (see figure 2).
- *CCS technology with coal & power sector* – carbon abatement in the coal and power sector could start with efficient generation technologies, such as advanced supercritical steam conditions [6]. In addition, it may be possible to design the new generation of power plants in India, such as the UMPPs, to be 'capture-ready', an approach implying "low upfront costs and unimpaired performance", enabling a future retrofit of CCS "when the necessary regulatory or economic drivers are in place" [12].
- *Export of CO₂ for foreign EOR activities* – one option may be to capture the CO₂ emissions from large industrial areas in India and export them to be used for EOR purposes in other countries, essentially the Middle East. Some of the planned UMPP projects are going to be based on the coast, where it is anticipated that large shipping terminals will form an integral part of the project. These UMPP projects, such as Mundra, are particularly designed for imported coal. It may be also possible to capture CO₂ from such large power plants and ship this to countries for EOR activities. States such as Qatar are dominant gas producers with established LPG tanker traffic, and so these tankers could be converted to take return loads of CO₂ for injection into depleted gas or heavy oil fields [13].

¹ There are different approaches available to enhanced oil recovery. When CO₂ is used as a miscible gas to reduce viscosity much of it is produced with the additional oil so it must be re-injected for permanent storage.

6. Barriers and enablers to CCS

India has joined a number of international initiatives to speed up the development and dissemination of CCS technologies, notably the Carbon Sequestration Leadership Forum (CSLF), which provided a mandate for the involvement of the Department of Science and Technology (DST), and effectively engaged with industry experts. As a result, the DST has established the Indian CO₂ Sequestration Applied Research (ICOSAR) network that is currently examining CO₂-EOR scoping studies [11]. However, the government of India holds a reserved position towards the investigation into CO₂ storage potential or zero-emission coal-fired power plants, due to barriers such as the higher costs and technical uncertainties associated with CCS technologies.

The cost of building a plant with CCS technology is currently very high as there are no major demonstration projects ready on the scale required by India. This cost should come down over time, especially if the EU's plans for twelve demonstration projects by 2015 come to fruition. An incentive could be the gaining of revenues through certified emission reductions (CERs) under the Clean Development Mechanism (CDM), as India is a signatory to the UNFCCC and its Kyoto Protocol. However, with the current pace of climate change negotiations, it seems unlikely that CCS would have much of a role to play in meeting CO₂ emission reductions via the CDM in the first commitment period [11]. If CCS were to be considered in a similar CDM framework in the post-Kyoto commitment period (beyond 2012), then this may be a possible method to finance CCS deployment in India (depending on the price of carbon at the time).

In the legal context, CCS projects with offshore storage may be initially the easiest to deal with. India is currently not a signatory of the London Convention or its protocol, hence not legally bound by its conditions, but if it were to consider offshore storage, particularly with an international partner, then it may be pressured into joining the treaty. For energy security reasons, in 1997 the Indian government adopted a New Exploration Licensing Policy (NELP), which is based on production-sharing contracts (PSCs). This allows acreage to be awarded under a competitive-bidding process, which has fundamentally changed the prospects for gas supply in India, whereby thirty oil and gas discoveries have been made since NELP was initiated [3]. It is in these PSCs that there may be an opportunity to incorporate CCS-related legislation.

The present day political backdrop of India is that of a coalition government and this is quite an important factor to consider in terms of policy development. This has been the predominant form of government in India for the past 10-12 years and it poses a major challenge for the decision making process. Indian coalition governments have generally been formed by a leading national party depending on some major and minor regional parties for critical support and survival in the parliament. The result has often been that there are 'too many cooks', each with different agendas, all slowing down the process for enacting laws and passing bills. There can also be long delays in implementing measures, even once they have been passed into law, because of India's slow bureaucratic pace and fragmented government structures. All of these factors have undermined any form of innovation. Despite new reforms such as NELP, the energy sector is heavily regulated through state-run companies. If CCS were to be implemented then it may need to follow the footsteps of India's IT Sector. The IT sector, in particular, has contributed heavily to the recent boom in India's economy through reforms that allow private sector participation and investment into R&D. It may be that more mechanisms for facilitating private industry-led R&D would encourage technological innovation in the energy sector.

7. Next steps

The aim of this study is to see how CCS may have a role within the energy system of India. The regulatory CCS system in UK/EU federal settings will be contrasted to the Indian context. A suite of geological, and technological issues will be considered, using data from the British Geological Survey and similar institutions in India. Meetings and interviews with stakeholders in India will investigate policy, legal issues. Case studies will identify possible actions for projects to get ready to deploy CCS in the future, and key drivers for implementing these potential actions will be discussed. For example, it is likely that none of the world's UMPP projects are explicitly intended to be capture-ready, but this position may change depending on the progression of CCS in the years to come.

8. Conclusion

A growing Indian economy requires more electricity. Fossil fuel use is expected to continue to dominate energy supply in India for decades to come. This is expected to triple India's current emissions to almost 3.3 Gt CO₂ /yr by 2030. Carbon abatement technologies such as CCS have the potential to reduce impacts of greenhouse gas emissions on climate and ocean acidification. If CCS is to have a role within the Indian national energy system, then conflicts will need to be resolved, such as the impact on electricity delivery.

Four styles of plausible CCS opportunity in India have been identified: 1) Pure CO₂ from existing industrial plant or natural gas production; 2) CO₂ use for enhanced oil recovery; 3) "Conventional" CCS with dedicated scrubbers built at existing, or planned new UMPP; 4) Export of CO₂, via reverse loads in shipping delivering LNG.

Further work will assess barriers and enablers to India CCS with a Technology Innovation Systems theory, engaging state, academic and industry representatives, and involving documentation and personal experts from both the UK and India.

9. Acknowledgements and disclaimer

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