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Prospects of carbon capture and storage (CCS) in India's power sector – An integrated assessment ☆

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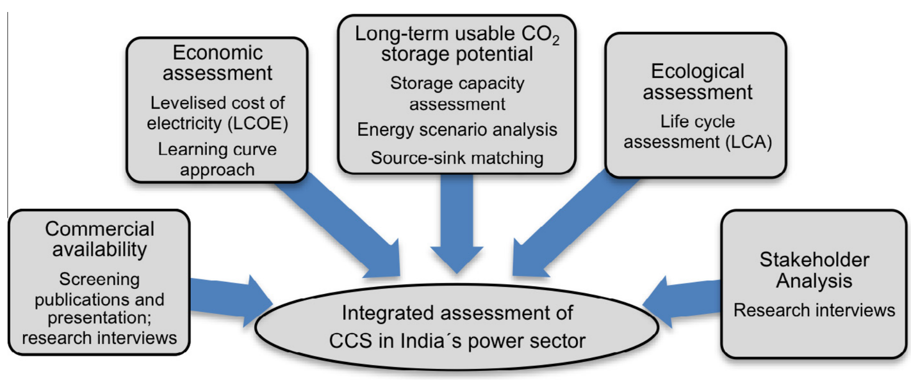
HIGHLIGHTS

- In this study an integrated approach is chosen to assess CCS in India.
- Five different assessment dimensions are covered.
- Several conditions need to be fulfilled if CCS is to play a future role in India.
- The most crucial requirement is a reliable storage capacity assessment for India.
- Further requirements are economic viability, ecological impacts and public support.

GRAPHICAL ABSTRACT



Set of methods used for the integrated assessment

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ABSTRACT

Objective: The aim of the present article is to conduct an integrated assessment in order to explore whether CCS could be a viable technological option for significantly reducing future CO_2 emissions in India.

Methods: In this paper, an integrated approach covering five assessment dimensions is chosen. However, each dimension is investigated using specific methods (graphical abstract).

Results: The most crucial precondition that must be met is a reliable storage capacity assessment based on site-specific geological data since only rough figures concerning the theoretical capacity exist at present. Our projection of different trends of coal-based power plant capacities up to 2050 ranges between 13 and 111 Gt of CO_2 that may be captured from coal-fired power plants to be built by 2050. If very optimistic assumptions about the country's CO_2 storage potential are applied, 75 Gt of CO_2 could theoretically be stored as a result of matching these sources with suitable sinks. If a cautious approach is taken by considering the country's effective storage potential, only a fraction may potentially be sequestered. In practice, this potential will decrease further with the impact of technical, legal, economic and social acceptance factors. Further constraints may be the delayed commercial availability of CCS in India, a significant barrier to achieving the economic viability of CCS, an expected net maximum reduction rate of the power plant's greenhouse gas emissions of 71–74%, an increase of most other environmental and social impacts, and a lack of governmental, industrial or societal CCS advocates.

Conclusion and practice implications: Several preconditions need to be fulfilled if CCS is to play a future role in reducing CO_2 emissions in India, the most crucial one being to determine reliable storage capacity

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figures. In order to overcome these barriers, the industrialised world would need to make a stronger commitment in terms of CCS technology demonstration, cooperation and transfer to emerging economies like India. The integrated assessment might also be extended by a comparison with other low-carbon technology options to draw fully valid conclusions on the most suitable solution for a sustainable future energy supply in India.

Nomenclature

Acronym

E1	high coal development pathway
E2	middle coal development pathway
E3	low coal development pathway
S1	high storage scenario
S2	intermediate storage scenario
S3	low storage scenario

Abbreviations

CCS	carbon dioxide capture and storage of CO_2
GDR	Greenhouse Development Rights
GHG	greenhouse gas
GWP	global-warming potential
IGCC	Integrated Gasification Combined Cycle
LCA	life cycle assessment
LCOE	levelised cost of electricity
NGO	non-governmental organisation
O&M	operation and maintenance
PC	pulverised coal
PLF	plant load factor
SC	supercritical

1. Introduction

Carbon capture and storage (CCS)[1] for reducing carbon dioxide emissions from fossil fuel-fired power plants and industrial sources is the subject of intensive global debate. CCS is considered a technology option that could contribute significantly to achieving the objective of decreasing greenhouse gas (GHG) emissions by 50–85% by 2050 [1]. This radical reduction is imperative in order to prevent the rise in global average temperature from exceeding a threshold of 2 °C above preindustrial times by 2100 [2]. For the time being, however, unabated use of coal is on the rise. This development is mainly driven by coal-consuming emerging economies that experience a rapidly growing demand for energy. The aim of the present article is to explore whether CCS could be a viable low-carbon option for India, which is one of these key countries. Respective analyses for China and South Africa will be presented in upcoming articles.

The main objective of the analysis is to estimate how much CO_2 can potentially be stored securely for the long term in geological formations in India. Based on source-sink matching, this CO_2 storage potential is compared with the quantity of CO_2 that could potentially be separated from power plants according to a long-term analysis up to 2050. This analysis is framed by an assessment of the commercial availability of CCS technology, an evaluation of levelised costs of electricity, ecological implications and stakeholder positions.

It is not the aim of the article to elaborate the role, CCS might play in a future sustainable energy system in India in comparison to other low-carbon technology options like renewable energies. Although this question is most challenging, this article focuses on a sound analysis of CCS by itself providing the basis for a future comparative assessment.

To our knowledge, no assessment with a comparable comprehensive scope has been published before. CCS in India started gaining interest in 2008, when publications first mentioned CCS as a possible mitigation measure in coal-using countries.[2] Several later publications explored the challenges of CCS with a direct focus on India [3–7], and a few applied a holistic view rather than considering single issues [8–10]. However no source developed long-term energy scenarios by 2050 including CCS and evaluating the possible impact through an integrated assessment. Our article therefore aims to close this gap by providing a holistic, long-term analysis of the potential role of CCS in India.

The presented paper first describes the methodologies applied in the individual assessment aspects of the study (Section 2). The outcome of each assessment step is given in Section 3. Subsequently, the authors combine the assessment dimensions to present an overall result from an integrative perspective (Section 4). The paper closes with an outlook on the needs for further research (Section 5).

2. Methodology

In this paper, an integrated approach covering five assessment dimensions is chosen. However, each dimension is investigated using specific methods.

(1) The assessment of the *commercial availability of CCS technology* is based on screening publications and presentations by international CCS experts on the current state and expected course of development of CCS in the years ahead. The term *commercial availability* refers to the time when the complete CCS chain could be in commercial operation, incorporating large-scale CCS-based power plants, transportation and storage.

(2) The derivation of India's *long-term usable CO_2 storage potential* consists of three different methods:

(2.1) The aim of the *storage capacity assessment* is to systematically analyse and compare existing capacity estimates for India with regard to their assumptions, the methodologies applied, the chosen parameters and the data sources. The concept of the "techno-economic resource-reserve pyramid for CO_2 storage capacity" [11] is applied to classify the different capacity categories. Finally, three storage scenarios (S1–S3) are developed representing a range between a high and a low estimate of India's storage potential by taking into account different levels of uncertainty in storage capacity figures.

(2.2) An *energy scenario analysis* is used to estimate the amount of CO_2 emissions that could potentially be captured from power plants. Based on existing long-term energy scenarios for India,

[1] Also: Carbon dioxide capture and storage of CO_2.

[2] According to an analysis of peer-reviewed literature based on Scopus.