Internationalizing CCUS Chains for India's Carbon Neutrality

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Overview

India is the third largest CO_2 emitter in the world and the ascending trend has not shown clear signs of leveling off. Electricity generation is the most important contributing sector. This paper examines the role of internalized CO_2 capture, utilization and storage (CCUS) chains in decarbonizing India's electricity for eventual carbon neutrality. We build a source-sink matching optimization model and unlike previous research, include transport by ship to overseas CO_2 storage sites. We initialize the model with open-source data on power sector emissions and sinks to work out the least-cost solutions for achieving various CO_2 matching scenarios. CO_2 can be captured in fossil-fuel-fired power plants in India, while the utilization and storage could be either within or beyond the country's border. We assess the potential chain of shipping CO_2 to the Middle East for enhanced oil recovery and CO_2 storage. The economics of such international CCUS chains may affect the role of CCUS in India's decarbonization scenarios. We provide first order estimates of costs and conditions to make such a proposition attractive. The model is available with an open-source license and is customizable to include additional sources, onshore and overseas sinks, and transport terminals.

Methods

Mathematical model of carbon source sink matching is programmed as a linear program. The objective function minimizes the total cost of matching CO_2 from sources to sinks which is obtained by adding the cost of capture, transportation by pipeline and/or ships, and storage of the CO_2 at onshore and off shore locations, and, subtracting the sales revenue obtained from the sale of CO_2 for its productive use in EOR. Since the majority of EOR potential considered is outside India, the EOR process which includes, injection, oil production and its sale is not endogenous in the model. But since these aspects form a critical part of the value stream for viability of CO_2 use, they are analyzed and discussed in a separate section following the results. The source code is written as a model generator which uses the specified data to create a modelling instance.

The model finds the minimum cost infrastructure for carbon capture, transport, utilization and storage from the perspective of Indian regulators. This model examines two scopes for the cost minimization. Scope 1 considers CO_2 capture costs, transport costs (pipeline for domestic sites and shipping for overseas), storage costs for domestic non-EOR sites, and CO_2 sales revenue for domestic and overseas EOR (Enhanced Oil Recovery). Unit CO_2 sales revenue (\$/ton CO_2) is taken as an externally determined variable for cost recovery and all EOR projects are assumed to contribute this rate.

Scope 2 considers unit CO_2 sales revenue not as an independent variable. Instead, the cost recovery is directly calculated to result from EOR and climate policy. Domestic EOR projects are assumed to contribute all oil revenue as all relevant costs/revenues are within the Indian economy, while overseas projects impose a cost recovery factor with partial contribution. The avoided CO_2 emissions may incur revenue from selling CO_2 emission permits in an emission trading market, avoid purchasing such permits or paying CO_2 emission tax.

The optimization model is a prescriptive model and since the phenomenon being modelled (source sink matching) will unfold over long-time scales, there is no scope for ground truthing. As is the best practice in such prescriptive energy system modelling we have done extensive testing of the model to sense check the results, built the model in an open source language, and made the source code and data available as open source (Howells et al., 2011; Pfenninger et al., 2018; Trutnevyte, 2016). The source code is accessible at (Sharma & Xu, 2021).

The proposition that we intend to evaluate is: Is it viable to use the shipping to transport CO_2 from Indian power plants to the middle east for enhanced oil recovery? Under which conditions can such a proposition become viable? In assessing this proposition, the key variables would be: Quantity of CO_2 which can be used for EOR in the Middle East and the sales revenue which can be obtained from the sale of CO_2 for its productive use in EOR, the cost of storing CO_2 at inland sites and at sites close to the Indian coastline.

Results

The average cost (\$/ton) of CO_2 matching increases with increasing matching target and reduces with increasing unit sales revenue of CO_2. At 800 Mt matching target, with a unit sales revenue of 22.5 \$/t CO_2 the average matching cost is 21 \$/t CO_2. This is because 800 Mt CO_2 is stored in domestic EOR locations for unit sales revenue of 22.5 \$/t, offsetting the capture and transport costs. The remaining costs must be recovered through a carbon price and/or oil price to make the proposition viable. An increased sales revenue from the sale of CO_2 can increase the extent to which the capture and transport costs are offset. This offsetting will depend on additional parameters of oil price, oil productivity (t oil/t CO_2) and the expectation or not of carbon negativity from the EOR process. The matching cost increases to 43.5 $t CO_2 for a unit CO_2 sales revenue of 0 $/t CO_2. At this sales revenue, the storage cost is saved as long as the CO_2 EOR potential is not exhausted. For matching the entire 57.8 Gt of CO_2, the average matching cost varies from 65 $/t CO_2 for a unit CO_2 sales revenue of $0 /t CO_2 to $48.8 /t CO_2 for a unit sales revenue of $22.5 /t CO_2.

The changes in marginal matching cost ($/t CO_2) with increasing matching targets, with and without non-domestic EOR are computed. For higher matching targets the marginal matching costs are higher compared to the average matching cost. As long as the matching target is the less than or equal to the total EOR potential, for a high enough CO_2 sales revenue, the marginal matching cost is always set by the use of CO_2 for EOR. In this analysis, for a matching target of 50,000 Mt, and a CO_2 sales revenue above 22.5 $/t CO_2, no CO_2 is stored at domestic non-EOR locations. The marginal matching cost, including the CO_2 sale revenue, in this case is 60.7 $/t CO_2. For this instance, unless the carbon price is 60.7 $/t CO_2, this proposition is not viable. For a given CO_2 price, e.g., 30 $/t CO_2, an additional 30.7 $/t CO_2 is needed to make the proposition viable. This additional 30.7 $/t CO_2 can be obtained with a high EOR productivity (t oil/t CO_2) and/or a high oil price. High EOR productivity makes the EOR process carbon positive, i.e., the CO_2 produced from firing of the oil produced by the EOR process is higher than the CO_2 injected. For a matching target of 10,000 Mt, the marginal matching cost varies from 40.7 $/t CO_2 for a CO_2 sales revenue of 25 $/t CO_2 to 59.3 $/t CO_2 for a CO_2 sales revenue of 0 $/t CO_2.

The main proposition that we set out to evaluate in this work was the attractiveness or not of shipping CO_2 for EOR in Middle East. While there is substantial potential for CO_2 EOR in the Middle East the suitability of shipping CO_2 depends on unit CO_2 sales revenue. Figure S2 compares the scenarios with EOR storage (both domestic and non-domestic) alone against a scenario where shipping CO_2 for non-domestic EOR is not permitted. At low unit CO_2 sales revenue of 2.5 $/t CO_2 its far expensive to only allow EOR storage of CO_2. For low unit CO_2 sales revenue, it is cost effective to allow storage at domestic non-EOR sites. For high CO_2 sales revenue of 22.5 $/t CO_2 storing CO_2 domestically is not cost effective. It is better to ship CO_2 to Middle East for EOR. We estimate that as CO_2 sales revenue increases from 0 to 17.5 $/t CO_2 in step sizes of 2.5 $, the corresponding increase in the CO_2 shipped overseas increase in step sizes of 11.2 Gt, 11.5 Gt, 7.3 Gt, 7.5 Gt, 5.9 Gt, 3.9 Gt and 2.4 Gt respectively. Additionally, CO_2 EOR allows to offset the gap between the matching cost and the carbon price.

Conclusions

The results indicate the potential of shipping CO_2 captured at power plants in India to the Middle East. This research provides first order estimates of the quantity of CO_2 which can be shipped to the Middle East cost effectively and how this estimate varies with changes in CO_2 sales revenue. Under a high matching target and an attractive CO_2 sales revenue it becomes cost effective to ship large quantities of CO_2 captured from the Indian power plants to the Middle East for EOR. In any case, as soon as there is some alignment in the market and the policy mechanisms, which could be in the form of a carbon tax, tax credits, small scale shipping of CO_2 from India to the Middle East should be piloted to acquire further insights into the prospect opportunity. The CO_2 EOR is expected to serve as a ramp to unlock the geological storage of CO_2 by offering cost reductions from learning by doing.

The proposal to ship the CO_2 captured in India power plants to the Middle East, presented and assessed in this paper, as demonstrated can emerge as an opportunity under the right set of conditions. The conditions assessed in this paper include the matching target and the CO_2 sales revenue. The other relevant factors are also discussed.

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