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A preliminary analysis of increase in water use with carbon capture and storage for Indian coal-fired power plants

Naushita Sharma [a,*], Siba Sankar Mahapatra [b]

[a] School of Sustainable Engineering and Built Environment, Arizona State University, USA
[b] Department of Mechanical Engineering, National Institute of Technology Rourkela, Rourkela, India

HIGHLIGHTS

- Analysing the effects of CCS technologies on water usage for Indian thermal power plants.
- Consequences of implementing cooling systems in conjuncture with CCS.
- Probabilistic modelling has been carried out to obtain trend-based results.
- Amine-based capture system with wet cooling towers give optimized results.

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ABSTRACT

Coal shall continue to be the mainstay of Indian energy sector. Nevertheless, if greater decarbonization is desired owing to more stringent climate regulations, CO_2 capture and storage may be an important technology. This work focuses on identifying the impact of carbon capture techniques on the water usage of Indian coal-fired power plants. The paper also compares two cooling systems i.e. wet cooling towers and air cooled condensers in their implications on plant performance parameters. To date, various studies have been conducted discussing the effect of CCS technologies in terms of cost and energy requirements in Indian context. However, with stringent water consumption regulations, there is a need for analysing the water-stress caused due to these technologies. This paper uses the Integrated Environmental Control Model (IECM v9.2.1), developed at the Carnegie Mellon University, USA, to carry out a probabilistic modelling to gain insight into the water-energy nexus for CO_2 capture systems in India. It is found that, in terms of cost, energy usage and water consumption, the suitability of amine based capture type is maximum. Membrane based capture technique is the most cost intensive whereas ammonia based capture is the most water intensive technology. With inclusion of cooling systems to post-combustion CO_2 capture systems methods, it is noted that wet cooling towers perform better than air cooled condensers. But, in a highly water-stressed scenario, air cooled condensers will be preferable due to minimum water consumption. The paper also conducts a sensitivity analysis on the parameters that affect the choice of CO_2 capture system and cooling systems such as fuel type, steam cycle heat rate and unit components of cooling systems.

* Corresponding author.
E-mail address: nsharm48@asu.edu (N. Sharma).

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1. Introduction

The Indian power sector is dominated by coal-based electricity generation. The demand for electricity is estimated to rise from 776 TWh in 2012 to 2499 TWh by the end of 2030 (MoEFCC, 2015a). The installed capacity of coal-fired power plants is close to 190 GW, contributing to around 60% of the total installed capacity (CEA, 2017). The demand for coal-based power generation is projected to increase in the subsequent years due to increased economic and population growth (Garg and Shukla, 2009; Chikkatur et al., 2009). The coal-based installed capacity is projected to increase to 224–410 MW by 2032, under various scenarios (WISE, 2013). Similarly, Indian Energy Security Scenarios (IESS) 2047 suggests that capacity may increase from 149 GW in 2012 to 290–723 GW under least and aggressive effort scenarios. In India, coal-based power generation has the least cost of generation of around US$ 45/MWh as compared to nuclear (US$ 60/MWh) and renewable based generation (US$ 75–225/MWh), providing a rather cost-effective means of power generation (Banerjee, 2014). The cost estimates for the year 2020 are US$ 66/MWh for pithead coal and US$ 77.24/MWh for imported coal (Shearer et al., 2016). Owing to the relatively slow growth of renewable sector and high pricing of oil and gas based power generation, coal-based electricity production will continue to be the major thrust in the power sector in the near future.

Power generation through coal-fired power plants is associated with large quantities of greenhouse gas (GHG) and particulate matter emissions. Energy sector, with a share of 71% is the highest contributor to the overall national greenhouse gas (GHG) emissions (MoEFCC, 2015b). The CO_2 emissions from thermal power sector was estimated to be 902 Mt for the year 2015 (Sadavarte and Venkataraman, 2014). Coal-related CO_2 emissions are predicted to increase two-folds to nearly 3700 Mt in 2015–2035 (Aydin, 2014). The emissions from coal-fired power plants need to be reduced in light of stringent climate obligations. The Intended Nationally Determined Contribution (INDC) from India commits to a 33–35 percent reduction in GHG intensity economy by 2035, as compared to 2005 levels. Further, the Paris Climate Agreement aims at reducing the end-of-century temperature rise to "well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degree Celsius" (UNFCCC, 2015). Many works have suggested that use of CO_2 capture and storage (CCS) in India may be necessary for similar limiting of temperatures to 2 degrees Celsius. Shukla and Dhar (2016) discuss the effect and usefulness of CCS which can sequester nearly 30 Gt–CO_2 under conventional low-carbon scenario (CLCS) and sustainable low-carbon scenario (SLCS) by 2050. Shukla et al. (2015) predicts that the use of fossil-fuels will be phased out by 2050 to promote an era of decarbonized power generation. Similarly, high carbon pricing will encourage investment in CCS to attain the 2020 emission peaking (Garg et al., 2014). To achieve the target of "temperatures well below 2 degrees and further to 1.5 degrees Celsius", scaling up of CCS infrastructure is extremely important. The CO_2 sequestration using CCS is forecasted to increase from 10 fold in 2015–2030 to >100 folds in the 2030–2050 period (Rogelj et al., 2016).

Electricity generation from thermal power plants is directly linked with utilization of water resources at different stages of power production. Coal-based energy production consumes approximately 60% of the total water usage in the power sector (WEO, 2016). The implementation of low-carbon technologies to mitigate climate change can exacerbate water stress or may become limited due to water scarcity. Freshwater consumption in low-carbon scenarios implementing CCS with and without retrofits is estimated to increase from 4.5 km^3/yr in 2010 to 200–210 km^3/yr in 2030 (Chandel et al., 2011). Similar estimates by Zhai and Rubin (2015) indicate an increase in freshwater consumption by 24%–42% between 2010–2030. Use of CCS in thermal power plants will increase the water consumption 8 times in case of open-loop systems and 2.5 times in case of closed loop systems (Faeth and Sovacool, 2014). Klapperich et al. (2014) notes an increment of 90% in water consumption with the use of amine-based capture systems in sub-critical and super-critical plants. Byers et al. (2014) carried an analysis for the current thermal capacity and generation of United Kingdom and noted a surge in water consumption and abstraction from 118 m^3/MWh to 222 m^3/MWh for plants with CCS as compared to those without CCS techniques. Kyle et al. (2013) assesses the water consumption with CC-S technologies in power sector to increase from 75 km^3/yr to 225 km^3/yr during 2000–2100.

2. Background

2.1. Water use in Indian power plants

India has the largest global blue water footprint,[1] contributing to 24% of the global blue water footprint, with a total water footprint of 1182 Mm^3/yr (Mekonnen and Hoekstra, 2011). The current water demand of 813 Gm^3/yr is projected to increase to 1450 Gm^3/yr by 2050 (MoWR, 2011). The average per capita availability is predicted to decline by $\sim$38% by 2050, as compared to 2001 levels due to expansion in population and rise in consumption for agricultural as well as industrial sectors, resulting in an extremely water stressed condition (Gupta and Deshpande, 2004; Schlosser et al., 2014). In the said period, the industrial water demand is likely to increase to 145–160 Gm^3/yr, with the power sector contributing to $\sim$45% of the total industrial water usage (NCIWRD, 1999; Amarasinghe et al., 2007; IGES, 2013).

[1] Blue water footprint is water extracted from surface or groundwater resources which is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time. Irrigated agriculture, industry and domestic water use can each have a blue water footprint (Source: http://waterfootprint.org/en/water-footprint/what-is-water-footprint/).