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Designing an optimum carbon capture and transportation network by integrating ethanol distilleries with fossil-fuel processing plants in Brazil

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ABSTRACT

Different long-term mitigation scenarios indicate carbon capture and storage associated with biomass (BECCS) might play a significant role in climate-change mitigation efforts, especially when it comes to long-term temperature stabilization. The ethanol fermentation process is considered as an early opportunity for BECCS deployment due to its low capture costs. Being a major ethanol producer, Brazil stands in a privileged position for the development of this technological option. However, previous scientific studies indicate several challenges for the deployment of a CO_2 transportation network in the country, mostly as a result of the associated seasonality of the sugarcane industry and consequent idleness observed in the carbon transportation infrastructure. To address those issues, this study developed and applied a methodology to design an optimum carbon network considering an alternative concept: the incorporation of new CO_2 emission sources aiming at guaranteeing adequate operational flows throughout the year, minimizing idleness and reducing transportation costs. Findings indicate that the incorporation of new CO_2 emission sources reduces transportation costs. The inclusion of CO_2 from both the cogeneration process and fossil sources results in an average levelized cost of transportation of 26 US\$/tCO_2 (54% lower than transportation costs in the baseline case). However, this reduction in transportation costs does not compensate for the increase in capture costs, resulting in higher levelized abatement costs for the whole system. Indeed, cases including cogeneration have reached a levelized abatement cost of approximately 125 US \$/tCO_2 (84% higher than in the baseline case). Nevertheless, by reducing transportation costs the strategy adopted in this study could facilitate the development of a carbon transportation network. Additionally, the integration of fossil-derived CO_2 has proved beneficial to the system, allowing improvements in flow regularity and reducing idleness problems related to the seasonality of biogenic sources.

1. Introduction

Carbon capture and storage associated with biomass (BECCS) is expected to play a significant role in climate-change mitigation in the future (IPCC, 2014; Kemper, 2015). Recent results from different Integrated Assessment Models (IAMs) around the world highlight the role BECCS might play in the energy sector, especially when considering the strictest scenarios in terms of carbon budget (Smith et al., 2016). As a matter of fact, the 450 ppm scenarios typically rely on BECCS (and the possibility of providing negative emissions) to deal with CO_2 concentration overshoot, especially in the second half of the century (IPCC, 2014; Kemper, 2015).

BECCS can be applied to various technologies with different levels of CO_2 emissions (EBTP, 2012; IEAGHG, 2011). CO_2 capture from ethanol fermentation is a commercially proven technology with low specific costs, and therefore ethanol production is regarded as an important opportunity for BECCS deployment (Carbo, 2011; Kemper, 2015; Reiter and Lindorfer, 2015). In fact, according to Kemper (2015), the majority of BECCS projects currently operational worldwide have ethanol production plants as the source of CO_2, and use the captured CO_2 for enhanced oil recovery (CO_2-EOR).

Abbreviation: CAESAR, Carbon and Energy Strategy Analysis for Refineries

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Nomenclature

List

EOR	Enhanced Oil Recovery
FCC	Fluid Catalytic Cracking Unit
HGU	Hydrogen Generation Unit
IECM	Integrated Environmental Control Model
NGCC	Natural Gas Combined Cycle
RECAP	Refinaria de Capuava
REDUC	Refinaria de Duque de Caxias
REPLAN	Refinaria de Paulínia
REVAPL	Refinaria Henrique Lage
RPBC	Refinaria Presidente Bernardes

In terms of carbon sinks, this study has chosen to work with enhanced oil recovery (CO_2-EOR) as a storage option[1] for two main reasons: (i) technological experience and data availability, since the oil and gas industry has been extensively studying the geological structure and physical properties of oil and gas fields, as well as predicting movement, displacement behavior and trapping of hydrocarbon in such sites (IPCC, 2005), and (ii) the potential economic benefits (revenues) from incremental oil production that puts EOR as a potential early option for carbon geological storage, especially being Brazil a large oil producer with mature oil fields already presenting high declining production rates (Ferreira, 2016).[2]

Brazil stands out as one of the major ethanol producers in the world. According to studies previously developed by Rochedo et al. (2016), Merschmann et al. (2016) and Silva et al. (2017), carbon capture from ethanol fermentation in Brazilian distilleries faces challenges for the deployment of the CO_2 transportation network due to disperse, small-scale distilleries (resulting in small volumes of CO_2 captured), and to the seasonable character of ethanol production. To address those limitations, this study considers the possibility of incorporating new CO_2 emission sources, in order to assure that the pipeline network functions with adequate operational flows throughout the year.

Co-processing of biomass with fossil fuels is considered a viable mitigation approach (Steinberg et al., 1993), as has been extensively discussed in the literature. Several articles address this mechanism and attempt to evaluate its development in combining biomass and fossil sources, mainly in energy-intensive industries such as oil refining and power generation (Lappas et al., 2009; Liu and Larson, 2014; Ng et al., 2015). In this perspective, this study proposes an innovative alternative since it considers biomass and fossil energy integration not at the point of the energy conversion, but in the downstream CO_2 transportation infrastructure.

The ethanol production is geographically concentrated in the Center-South region in Brazil, in the vicinity of the country's largest oil refineries and gas-fired power plants (potential new emission sources), and close to important oil and gas fields (suitable for carbon storage and enhanced oil recovery − EOR). Hence, through the inclusion of fossil-derived CO_2, this study aims to increase the total volume of transported CO_2 and to optimize the use of the pipeline network, minimizing idleness and reducing transportation costs. As the carbon capture from fossil-fuel processing facilities is more expensive than from ethanol production facilities, this study tests if the inclusion of fossil-fuel units in the carbon capture and transportation network leads to a cost reduction in the transportation network that more than compensates the increase in carbon capture costs, which are typically higher in those kinds of installations.

Fig. 1 provides the location of existing ethanol distilleries and suitable alternative emission sources (nearby oil refineries and fossil-fuel power plants), as well as oil and gas fields, suitable for carbon storage and enhanced oil recovery (CO_2-EOR).

It is also worth noting that the importance of improving CO_2 flow regularity is associated with two main objectives: guaranteeing capital expenditure recovery and adjusting the CO_2 mass flow to EOR operation characteristics. Firstly, from a capital expenditure perspective, capital costs in carbon capture, transportation and storage systems are a critical factor for the large scale deployment of these systems (Tapia et al., 2015). Furthermore, from the EOR operation characteristics perspective, there are various studies available in the scientific literature working with the assumption of a constant injection rate for CO_2-EOR operations (Choi et al., 2013; Abedini, 2014; Mazzetti et al., 2014; Brownsort, 2015; Tapia et al., 2015; Tapia et al., 2016). Therefore, improving flow regularity, through the reduction of seasonality issues related to the sugarcane industry, is important for correctly adjusting the CO_2 flow to the characteristics of the EOR operations.

This study is structured as follows. Section 2 presents the methodological procedure developed and applied in this study. Section 3 presents the case studies, detailing the results of the different scenarios of carbon capture according to the kinds of emission sources included in the carbon transportation network. Section 4 discusses and compares these results in terms of abatement costs and abatement potentials. Finally, Section 5 provides final remarks, with main achievements and future work suggestions.

2. Methodology

In order to evaluate the optimum carbon transportation network design through the integration of new emission sources (other than the ethanol fermentation process), this study followed four basic steps: (i) mapping the distilleries, (ii) selecting nearby potential emission sources, (iii) estimating CO_2 availability and capture costs related to the selected new emission sources, and (iv) calculating the total abatement costs for each of the stablished scenarios (including both capture and transportation costs) (see Fig. 2).

2.1. Mapping existing distilleries

All 236 selected ethanol distilleries in the Center-South region of Brazil were mapped using the ArcMap 10.1 software. Following the path led by the work previously conducted by the same authors in Silva et al. (2017), the selection criteria intended to exclude plants considered isolated (without at least 10 other plants around a 100 km radius) in order to avoid long-distance pipes operating with low capacity.

2.2. Selecting new emission sources

New emission sources were selected according to their proximity

[1] Even though there is evidence of suitable aquifer storage beneath the State of São Paulo (Moreira et al., 2016), there are several issues concerning this storage option, including (i) geological uncertainty, with limited seismic and well data available (unlike data on oil and gas reservoirs), (ii) lack of industry experience (unlike the vast experience shared in the oil and gas industry for EOR), (iii) difficulties in assessing CO_2 storage capacity in deep saline formations, and (iv) difficulties in assessing risks of leakage (which could result in groundwater contamination, impacting wildlife habitats and restricting or eliminating agricultural use of land) (IPCC, 2005). Therefore, this option has not been contemplated by this study. However, this study acknowledges the need to include such storage options in future studies, since they could be an important opportunity to reduce costs of transportation.

[2] Even though we cannot consider EOR operations to be widespread in Brazil, it is fair to say that Petrobras, the Brazilian oil company, has some experience with these operations, including thermal, chemical and miscible recovery processes. In what regards CO_2-EOR (miscible process), Petrobras has accounted for 3 pilot projects from which one has been successfully implemented and two have been interrupted mostly due to problems with the supply of CO_2. Nowadays, Petrobras is working with WAG-EOR (alternate injection of water and gas − in this case CO_2) in the pre-salt Lula field. Preliminary results have been promising so far, according to the company (Petrobras, 2017).