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An optimization model for carbon capture utilization and storage supply chain: A case study in Northeastern China

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HIGHLIGHTS

- Carbon capture utilization storage (CCUS) supply chain problem is studied.
- All stages for carbon capture, transport and storage are taken into account.
- The model is applied to a realistic case study of Northeast China.
- Scenarios assessing toward different CO_2 reduction level are implemented.
- The intermediate sites for CCUS supply chain lessen transportation and total costs.

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ABSTRACT

In recent years, several strategies have been developed and adopted in a bid to diminish the carbon dioxide (CO_2) released into the atmosphere. Carbon capture, utilization and storage (CCUS) system is one of the options. In this paper, we develop a CCUS supply chain superstructure by introducing more comprehensive transportation routes as well as the resultant system deployment schemes. A mixed integer linear programming (MILP) model is proposed to optimize the strategic CCUS deployment in Northeast China by making simultaneous selection of emission sources, capture facilitates, CO_2 pipeline, intermediate transportation sites, utilization and storage sites. The CCUS cost includes the cost of flue gas dehydration, CO_2 capture, transportation and injection, and revenue from CO_2 utilization through enhanced oil recovery (CO_2-EOR). The overall network is economically optimized over a 20 years' life span to provide the geographic distribution and scale of capture, utilization and sequestration sites as well as the transportation routes for different scenarios. The results suggest that it is economic feasible to reduce 50% of the current CO_2 emissions from the stationary sources at a total annual cost $2.30 billion accompanied with $0.77 billion of revenue generated annually through CO_2-EOR. Overall, the optimal CCUS supply chain network correspond to a net cost of $23.53 per ton of CO_2. The results are compared with source-sink model and it can be observed that the total annualized net cost is reduced from $1.62 billion to $1.53 billion and the transportation cost are reduced from $0.27 billion to $0.19 billion.

1. Introduction

Increasing emissions of greenhouse gas (GHG) by fossil fuels have been recognized as the major contributor to global warming and significant changes in climate [1]. Carbon dioxide (CO_2) is one of the primary anthropogenic GHG, and its global emissions have reached a historic high of 32.5 Gt in 2017 [2]. Studies by the International Energy Agency (IEA) indicate that the mean concentration of CO_2 in the earth's atmosphere has nearly reached 404 ppm and caused almost 1 °C increase compared with pre-industrial levels [3]. China has overtaken the United States as the world's biggest producer of CO_2 since 2006 with 5.95 billion tons of CO_2 from fuel combustion [4]. In the last decade, China's energy use has doubled, amounting to 3.13 billion tons oil equivalent in 2017. Large stationary industries contribute the most CO_2 emissions as they are the major energy consumers of the nation. To control CO_2 emissions, Chinese government has launched *The Thirteenth*

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Nomenclature

Sets

G	set of all the nodes (emission sources, intersection sites, storage sites, utilization sites)
I	set of stationary source sites
K	set of capture facilities
N	set of intersection sites
U	set of geological storage sites and utilization sites

Parameters

E_i	total CO_2 emissions available at site i, ton/year
F_T	terrain factor according to the location
Ft_i	total feed flue gas flowrate from site i, mol/s
l	planning horizon for CCUS supply chain, years
Lat_i	latitude of site i
$L_{i,j}$	pipeline distance from node i to j, km
$Long_j$	longitude of site j
$M_{well,j}$	maximum injection capacity if an injection well at site j
$O\&M_{pipeline}$	operation and maintenance percentage factor for CO_2 pipeline
$O\&M_{well}$	operation and maintenance percentage factor for CO_2 injection well
P	CO_2 selling price for CO_2-EOR, \$/ton CO_2
$Smax\ i$	maximum storage capacity of storage site i, ton
T_{min}	minimum overall reduction target of CO_2 emissions, ton/year
xh_k	higher allowed CO_2 composition bound for capture and compression facility k, mol%
x_i	composition if CO_2 in the flue gas from site i, mol%
xl_k	lower allowed CO_2 composition bound for capture and compression facility k, mol%

Variables

c_i	amount of CO_2 captured at site i, ton/year
$CIC_{i,k}$	capture and compression investment cost for site i with facility k
$COC_{i,k}$	capture and compression operation cost for site i with facility k
DC_i	dehydration cost for site i with TEG - absorption
$F_{i,j}$	amount of CO_2 transported from site i to site j, ton/year
$FR_{i,k}$	fraction of captured CO_2 from flue gas
$IAIC_i$	CO_2 injection well annual investment cost in site i
IIC_i	CO_2 injection well investment cost in site i
IOC_i	CO_2 injection well annual operation and maintenance cost in site i
$n_{well,j}$	injection well number at site j
$PAIC_{i,j}$	CO_2 pipeline annual investment cost from site i to site j
$PIC_{i,j}$	CO_2 pipeline investment cost from site i to site j
$POC_{i,j}$	CO_2 pipeline annual operation and maintenance cost from site i to site j
TAC	total annual cost of the CCUS supply chain
TAR	total revenue from CO_2-EOR
u_i	amount of CO_2 sequestrated or utilized at site i, ton/year
$y_{i,k}$	1 if site i captured CO_2 with capture and compression facility k, 0 otherwise
$z_{i,j}$	1 if a pipeline is constructed from site i to site j, 0 otherwise

Five-Year Plan forward to increasing the proportion of non-fossil energy in primary energy consumption to about 15% of the total in 2020, and a peaking target of the national CO_2 emissions by 2030 has been also proposed [5]. This intense demand of CO_2 mitigation by China and other industrialized countries opens challenges and opportunities as well for the development of the approaches aiming at CO_2 emissions reduction.

Efforts to diminish CO_2 emissions while meeting increasing worldwide energy demand can be achieved by implementing a comprehensive portfolio of strategic options that include (a) apply geoengineering approaches (e.g. afforestation and reforestation), (b) enhance the efficiency of energy, (c) develop alternative fuels with lower CO_2 levels, and (d) low carbon technologies [6]. One of the long-term contributing technologies is CO_2 capture, utilization and storage (CCS or CCUS) system. On one hand, CCS has inspired both the environmental and economic interests, making it possible for deployment in the

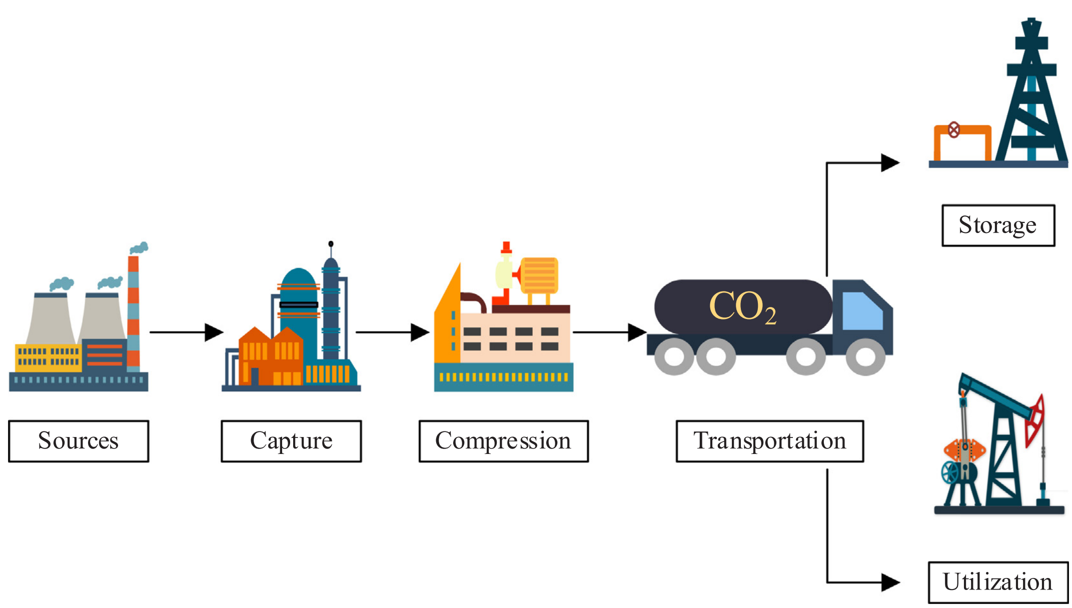

Fig. 1. CCUS supply chain scheme.