Design under uncertainty of carbon capture and storage infrastructure considering cost, environmental impact, and preference on risk

Suh-Young Lee a, Jae-Uk Lee a, In-Beum Lee a, Jeehoon Han b,*

a Department of Chemical Engineering, POSTECH, Pohang, Republic of Korea
b School of Chemical Engineering, Chonbuk National University, Jeonju, Republic of Korea

HIGHLIGHTS

• A stochastic decision-making algorithm for CCS networks incorporating tolerance on risk is provided.
• Optimization and modeling of CCS networks is performed.
• Economic and Life Cycle Assessment of CCS networks is conducted.
• A case study based on power-plant CO2 emission in Korea is presented in this study.

ARTICLE INFO

Article history:
Received 25 October 2016
Received in revised form 9 December 2016
Accepted 12 December 2016

Keywords:
CCS
Optimization
Life Cycle Assessment
Stochastic model
Downside risk

ABSTRACT

We present a stochastic decision-making algorithm for the design and operation of a carbon capture and storage (CCS) network; the algorithm incorporates the decision-maker’s tolerance of risk caused by uncertainties. Given a set of available resources to capture, store, and transport CO2, the algorithm provides an optimal plan of the CCS infrastructure and a CCS assessment method, while minimizing annual cost, environmental impact, and risk under uncertainties. The model uses the concept of downside risk to explicitly incorporate the trade-off between risk and either economic or environmental objectives at the decision-making level. A two-phase-two-stage stochastic multi-objective optimization problem (2P2SSMOOP) solving approach is implemented to consider uncertainty, and the ε-constraint method is used to evaluate the interaction between total annual cost with financial risk and an Eco-indicator 99 score with environmental risk. The environmental impact is measured by Life Cycle Assessment (LCA) considering all contributions made by operation and installment of a CCS infrastructure. A case study of power-plant CO2 emission in Korea is presented to illustrate the application of the proposed modeling and solution method.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Carbon capture and storage (CCS) technologies capture the carbon dioxide (CO2) emitted by burning fossil fuels and by industrial processes, and store it in underground geological formations and aquifers. These technologies have been considered as the most promising to mitigate CO2 released from large-scale fossil fuel use [1–3]. On a global basis, if large-scale CCS is to considerably contribute to reducing CO2 emission, it must operate at a massive scale, on the order of 3.5 billion tons of CO2 per year [4]. Today, it operates on the scale of millions of metric tons (MT) of CO2 per year [5]. The recent literature of CCS focuses on large-scale (>1 MT CO2 per year) CCS systems, which are strongly favored by the economics of scale. The U.S Department of Energy planned to develop of large-scale CCS projects in 2018 [6,7], and many studies have been conducted to evaluate the potential of nation-wide [8–11] and Europe-wide CCS projects [12]. In this situation, establishing optimized CCS networks and developing effective algorithms to formulate networks is crucial to enable large-scale CCS systems that encompass a wide range of industrial clusters from capture facilities to sequestration sites [13,14].

Although the technology at each step of the process has been in use for many decades, large-scale commercialized CCS projects are very expensive and are composed of complex networks that may be susceptible to breakdown, so because of these uncertainties, no such projects have been developed [15,16]. The major complications in the planning of CCS networks are various sources of uncertainty, such as permeability and porosity of reservoir, fluctuation of CO2 emission level of each source, variability of construction and
### Notation

**Indices**
- \( b_i \): environment burdens from operation
- \( b_j \): environmental burdens from installation
- \( c \): type of capture facility
- \( d \): pipeline diameter
- \( g \): geographical region
- \( g' \): geographical region \((g' \neq g)\)
- \( I \): physical form of CO\(_2\)
- \( k \): technology set
- \( l \): type of transport mode
- \( n \): damage category
- \( p \): type of utilization facility or production facility
- \( s \): type of sequestration facility
- \( si \): type of source industry
- \( sp \): source plant name
- \( t \): impact category
- \( sc \): scenarios

**Parameters**
- \( C_{CC}^{i,c,s} \): capital cost of building CO\(_2\)-capture facility type \( c \) capturing in source plant \( sp \) of industry type \( si \) in region \( g \), $/t-CO\(_2\)
- \( CCR_{pipe} \): capital charge rate of pipelines – the rate or return required on invested capital cost, \( 0 \leq CCR_{pipe} \leq 1 \)
- \( CCR_{facility} \): capital charge rate of facilities – the rate or return required on invested capital cost, \( 0 \leq CCR_{facility} \leq 1 \)
- \( Loff_{i,l,g,g} \): average delivery distance between regions \( g \) and \( g' \) by transport mode \( l \) offshore, kmtrip\(^{-1}\)
- \( Lon_{i,l,g,g} \): average delivery distance between regions \( g \) and \( g' \) by transport mode \( l \) onshore, kmtrip\(^{-1}\)
- \( LR \): learning rate—cost reduction as technology manufacturers accumulate experience, \( 0 \leq LR \leq 1 \)
- \( SCC_{i,g} \): capital cost of establishing CO\(_2\) sequestration facility type \( s \) sequestrating CO\(_2\) in physical form \( i \) in region \( g \), $/t-CO\(_2\)
- \( TPCI_{off} \): total capital cost of installing pipeline with pipe diameter \( d \) offshore, $/km
- \( TPCI_{on} \): total capital cost of installing pipeline with pipe diameter \( d \) onshore, $/km
- \( TPOCI_{off,ci,d} \): total operating cost of pipeline with pipe diameter \( d \) offshore in each scenario \( sc \), $/km\( \cdot \)t-CO\(_2\)
- \( TPOCI_{on,ci,d} \): total operating cost of pipeline with pipe diameter \( d \) onshore in each scenario \( sc \), $/km\( \cdot \)t-CO\(_2\)
- \( UCC_{i,c,s} \): unit capture cost for CO\(_2\) captured in physical form \( i \) by capture facility type \( c \) in source industry \( si \) in each scenario \( sc \), $/t-CO\(_2\)
- \( USC_{i,c,s} \): unit sequestration cost for CO\(_2\) sequestered in physical form \( i \) by sequestration facility type \( s \) in each scenario \( sc \), $/t-CO\(_2\)
- \( w_{i,b}^{l_i} \): entry of emission inventory from operation \( b_i \) associated with the capture per unit of CO\(_2\) by capture facility type \( c \) in each scenario \( sc \), kg/t-CO\(_2\)
- \( w_{i,b}^{l,i} \): entry of emission inventory from operation \( b_i \) per one unit of CO\(_2\) mass transported one unit of distance by transport means \( l \) in each scenario \( sc \), kg/km\( \cdot \)CO\(_2\)
- \( w_{i,b}^{l,s} \): entry of emission inventory from operation \( b_i \) associated with the sequestration of one unit of CO\(_2\) by sequestration facility type \( s \) in each scenario \( sc \), kg/t-CO\(_2\)
- \( v_{c,r,n,b} \): damage factor of environment burden \( b_i \) in terms of damage category \( n \) and impact category \( x \)
- \( w_{b_i}^{l_i} \): entry of emission inventory from installation \( b_i \) from installing one capture facility of type \( c \), kg
- \( w_{b_i}^{l,i} \): entry of emission inventory from installation \( b_i \) per unit of distance from installing transportation means \( l \), kg/km\( \cdot \)

**Binary variables**
- \( BC_{i,c,i,s} \): investment of capture facility type \( c \) capturing \( CO_2 \) in physical form \( i \) in source plant \( sp \) of industry type \( si \) in region \( g \)

**Integer variables**
- \( NS_{i,g} \): number of well or injection facilities of type \( s \) sequestering \( CO_2 \) in region \( g \)
- \( NTP_{on,gi,d} \): number of pipelines with diameter \( d \) for transporting \( CO_2 \) in physical form \( i \) between regions \( g \) and \( g' \) onshore
- \( NTP_{off,gi,d} \): number of pipelines with diameter \( d \) for transporting \( CO_2 \) in physical form \( i \) between regions \( g \) and \( g' \) offshore

**Continuous variables**
- \( C_{CC}^{i,c,s} \): amount of \( CO_2 \) in physical form \( i \) captured by capture facility type \( c \) in source plant \( sp \) of industry type \( si \) in region \( g \) in each scenario \( sc \), $/t-CO_2$
- \( FCC \): facility capital cost, $/y\(^{-1}\)
- \( FOCC \): facility operating cost in each scenario \( sc \), $/y\(^{-1}\)
- \( Q_{pipeline}^{i,c,s} \): flow rate of \( CO_2 \) in physical form \( i \) transported by pipelines with diameter \( d \) between regions \( g \) and \( g' \) in each scenario \( sc \), $/t-CO_2$
- \( S_{i,c,s} \): amount of \( CO_2 \) in physical form \( i \) sequestered by sequestration facility type \( c \) in region \( g \) in each scenario \( sc \), $/t-CO_2$
- \( TAC_{c} \): total annual cost in each scenario \( sc \), $/y\(^{-1}\)
- \( TCC \): transport capital cost, $/y\(^{-1}\)
- \( TC_{offshore} \): transport capital cost for \( CO_2 \) offshore, $/y\(^{-1}\)
- \( TC_{onshore} \): transport capital cost for \( CO_2 \) onshore, $/y\(^{-1}\)
- \( TOC_{c} \): transport operating cost in each scenario \( sc \), $/y\(^{-1}\)
- \( IO_{i,c,s} \): environment impact of operation of technology set \( k \) in terms of damage category \( n \) and impact category \( x \) in region \( g \) each scenario \( sc \), impact\(^{-1}\)
- \( D_{i,g} \): environment damage score of the damage category \( n \) in region \( g \) in each scenario \( sc \), damage\(^{-1}\)
- \( Eco99_{c} \): total environment impact score in each scenario \( sc \), score\(^{-1}\)
- \( \delta_{im} \): positive deviation from the cost target \( \xi^{Fin} \) for design \( x \) under scenario \( sc \)
- \( \delta_{im}^{En} \): positive deviation from the cost target \( \xi^{En} \) for design \( x \) under scenario \( sc \)

**Functions**
- \( FDRisk(x, \xi^{Fin}) \): financial downside risk of solution \( x \) at a cost target \( \xi^{Fin} \)
- \( EDRisk(x, \xi^{En}) \): environmental impact downside risk of solution \( x \) at an Eco99 score target \( \xi^{En} \)
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات