ARTICLE IN PRESS

Journal of Cleaner Production xxx (2016) 1–9

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Multi-period carbon integration

Dhabia M. Al-Mohannadi [a, b], Sabla Y. Alnouri [a], Sumit K. Bishnu [a], Patrick Linke [a, b, *]

[a] *Department of Chemical Engineering, Texas A&M University at Qatar, PO Box 23874, Doha, Qatar*
[b] *Qatar Energy and Environment Research Institute (QEERI), P.O. Box 5825, Doha, Qatar*

ARTICLE INFO

Article history:
Received 18 December 2015
Received in revised form
28 February 2016
Accepted 4 March 2016
Available online xxx

Keywords:
Climate footprint reduction
Carbon integration
Multi-period planning
Eco-industrial parks

ABSTRACT

Carbon integration has recently been proposed for the identification of low cost carbon footprint reduction strategies through optimal matching of carbon dioxide sources and sink in industrial clusters. Previous work has laid out the general representation and approach to develop economically optimal carbon dioxide networks that achieve a specified footprint target for the cluster. This work presents an extension to enable transition planning over a time horizon. This is important because climate footprint reduction policies are typically proposed with a view of achieving certain emission cuts by future dates. The proposed approach aims to enable planners and policy makers to systematically assess different emission reduction policies and to explore concrete solutions for carbon dioxide reduction targets. It is illustrated with an example to compare two footprint reduction cases. The results for the case study show that, for the required carbon emissions reduction by the target date, a phased footprint reduction is associated with higher costs relative to the case of no specific reduction requirements in any but the last time period.

1. Introduction

The threat of dangerous climate change has led to calls for drastic carbon dioxide emission reductions (Fischedick et al., 2014). This would require significant emissions cuts across most industry sectors. The processing industries and the utility sectors are associated with significant carbon dioxide emissions, which will need to see significant reductions as a consequence. Recently, carbon integration has been proposed as a systematic approach to carbon dioxide management within industrial clusters (Al-Mohannadi and Linke, 2016). Carbon integration allows the systematic screening of options for achieving an overall carbon emissions reduction target through carbon dioxide allocations across stationary emissions points in the cluster and carbon dioxide sink options such as conversion processes or geological storage. The work introduces a network design representation to consider multiple sources, carbon dioxide enrichment, transmission and sink process allocations. An optimal search is performed to identify the lowest cost carbon dioxide integration network to achieve a specified net carbon emissions reduction for the industrial cluster.

Multi-period planning problems are common in process systems engineering and include problems such as reactor design (Rooney and Biegler, 2000), hydrogen network design (Heever and Grossman, 2003), heat exchange network synthesis (Isafiade and Fraser, 2007) and water network synthesis (Bishnu et al., 2014). Heat and power production with carbon reduction over a time horizon was analyzed by Rong and Lahdelma (2007) using a stochastic optimization approach, while Mirzaesmaeeli et al. (2010) proposed power planning for a specific regional expansion plan. Carbon reduction planning over time horizons have previously been investigated, with a focus on reducing energy use and designing Carbon Capture and Storage (CCS) networks. Zhang et al. (2012) studied the impact of different policies for carbon targets on China's power sector. Kemp and Sola Kasim (2010) studied the optimization of carbon dioxide allocation network in storage sites on a specific region. Spatial multi-period optimization of carbon networks was also explored by Johnson and Ogden (2011). Multi-period planning also has useful applications in carbon dioxide storage allocation studies (He et al., 2013). Elahi et al. (2014) explored multi-period CCS network optimization with simultaneous consideration of transportation and source sink matching. Graphically, Diamante et al. (2014) applied a pinch approach for CCS targeting while considering multiple time periods and regions. While, Pourhashem et al. (2016) studied the time effect of mitigation strategies have on biofuels production. However, this work is

* Corresponding author. Department of Chemical Engineering, Texas A&M University at Qatar, Doha, Qatar.
E-mail address: patrick.linke@qatar.tamu.edu (P. Linke).

http://dx.doi.org/10.1016/j.jclepro.2016.03.027
0959-6526/

Please cite this article in press as: Al-Mohannadi, D.M., et al., Multi-period carbon integration, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.03.027

the first work that considers multi-period carbon integration in industrial parks.

The proposed work extends the carbon integration approach presented in Al-Mohannadi and Linke (2016) to enable multi-period planning. The ability to consider a planning horizon is important, because carbon dioxide emission reduction policies and strategies advocate cuts (or sequences of cuts depending on the reduction strategy) over a time horizon so as to have achieved a certain emissions reduction at a future date, which is typically many years into the future. Therefore, besides identifying a network that can achieve a certain emissions cut at low cost, it is equally important to consider the network transitions of the original carbon integration network into the future network with a reduced footprint that corresponds to the target. A multi-period planning approach would enable the assessment of different carbon dioxide reduction options that may be applied to guiding transitions to a future target emission.

The remainder of this paper presents the problem statement and representation for multi-period carbon integration planning for an industrial cluster, followed by the formulation of the optimization problem. The optimization problem is then solved for an illustrative case study.

2. Problem statement

This work builds upon the problem statement and representation for carbon integration in a single period presented in Al-Mohannadi and Linke (2016). Fig. 1 summarizes the network representation. A stationary carbon source can be captured and processed in its original composition (untreated source), or processed through a carbon dioxide separator to obtain an enriched carbon dioxide stream (treated source). Each untreated and treated source can be allocated to any of the carbon dioxide sinks that may exist or may be added to the industrial cluster. Carbon dioxide transmissions from source to sink involve compression and pipeline placement.

Fig. 2 illustrates the multi-period carbon integration planning problem. A given industrial cluster (at time period tp = 0) needs to be carbon integrated to meet a given carbon emissions constraint at the end of the planning horizon (final time period tp = TP). Additional, intermediate carbon emissions constraints may be applied in each intermediate time period tp = 1, …, TP−1.

The goal of the proposed approach will be to determine the lowest cost carbon source-sink allocation network transition in compliance with emissions reduction requirements in each time period, given the following information:

- A set of carbon emitting plants and power plants with known locations and point source emissions in each time period
- The planning horizon together with a number of defined time periods
- Carbon emissions limits for the industrial cluster in each time period or over a time planning horizon
- All carbon dioxide source flows, pressure and composition in each time period
- A number of carbon sinks with known carbon dioxide capture capacity, fixation efficiency, pressure and composition requirements in each time period
- Plants and associated sources and sinks and alterations in existing plants of the corresponding sources and sinks in each time period
- Distances of the shortest connections between all sources and sinks in the industrial cluster
- Data on the considered carbon treatment technology in terms of capture efficiency, energy use footprint, capital and operating cost
- Capital and operating costs of compression, pumping and pipelines
- Carbon dioxide emissions from electricity and heating required in carbon dioxide compression and transportation

3. Model formulation

Let there be the following sets:

$$S\{s|s = 1, 2, 3, \ldots, N_{sources}|\ S \text{ is a set of carbon sources}\}$$

$$K\{k|k = 1, 2, 3, \ldots, N_{sinks}|\ K \text{ is a set of carbon sinks}\}$$

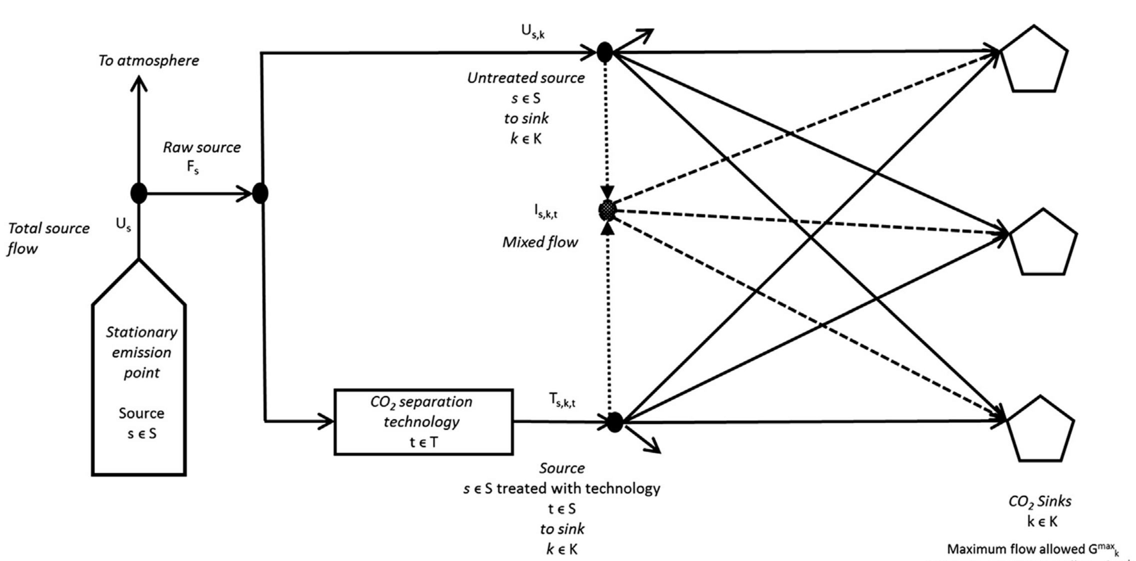

Fig. 1. Carbon integration problem representation based on previous work (Al-Mohannadi and Linke, 2016).