Energy Policy 51 (2012) 164–171

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

Viewpoint

The impact of transmission constraints on the emissions leakage under cap-and-trade program ☆

Enzo Sauma *

Industrial and Systems Engineering Department, Pontificia Universidad Católica de Chile, Santiago, Chile

HIGHLIGHTS

- We study conditions under which the CO_2 leakage would happen under a C&T program.
- Conditions relate to transmission capacity, merit order change and production cost.
- Transmission congestion interacts with environmental regulations.
- CO_2 leakage would likely occur when there is surplus transmission capacity.
- Power grid management and operations decisions should be carefully scrutinized.

ARTICLE INFO

Article history:
Received 30 November 2011
Accepted 24 August 2012
Available online 18 September 2012

Keywords:
Carbon leakage
Emissions trading
Power system economics

ABSTRACT

Several regional cap-and-trade (C&T) programs are considered or implemented in the United States to control greenhouse gas emissions from the power sector. One concern is the possibility of emissions leakage due to a lack of coherence in the geographic scope of the regional electricity market and the C&T program. Leakage in the context of regulating CO_2 emissions is defined as the short-run displacement of CO_2 emissions from the capped region to other uncapped regions due to the imposition of a regional C&T scheme. However, the presence of transmission congestion could interact with regulations in an unanticipated way to determining whether leakage would occur and its magnitude if happens. In this paper, we use a two-node network to study the conditions under which the CO_2 leakage would happen in a radial network under a C&T program. These conditions are related to transmission capacity, merit order change, and relative production cost between capped and uncapped regions. Since CO_2 leakage would likely occur in a radial network during the time when there is surplus transmission capacity, if regional CO_2 policies could influence power grid management and operations decisions, then there might be space for a better multi-objective coordination.

1. Introduction

Cap-and-trade (C&T) program emerges as a preferred approach used by government to control for greenhouse gas emission from the power sector and other energy-intensive sectors. Although emissions trading is not a new concept, it is expected to have significant economic impact on the power sector in part because now both base-load and peak-load units would incur substantial CO_2 emissions costs, effectively elevating electricity prices in the competitive markets (Chen et al., 2008). One emerging concern is the incoherence of the geographic scope of the regional electricity market and the regional greenhouse gas mitigation initiative that would lead to "CO_2 leakage", which is defined as the short-run displacement of CO_2 emissions from the capped region to the uncapped region due to the imposition of a regional C&T scheme.[1] Here, we refer CO_2 leakage as a short-run phenomenon associated with pollution displacement when firms are unable to relocate their polluting facilities to the un-regulated regions. Its long-run counterpart is called "pollution haven hypothesis", which states that firms migrate their polluting activities to regions where the environmental standards are less strict.

☆The work reported in this paper was partially funded by the CONICYT, FONDECYT/Regular 1100434 grant.

* Tel.: +56 2 354 4272; fax: +56 2 5521608.
E-mail address: esauma@ing.puc.cl

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http://dx.doi.org/10.1016/j.enpol.2012.08.057

[1] For example, more than 20% of California electricity consumption relies on the generators located in New Mexico, Arizona, and other neighboring states, which produce power dominantly from coal-fired plants. Thus, CO_2 leakage is expected to occur if an emissions-trading policy is only applied to the California facilities. More recently, the RGGI experienced a further setback when the governor of New Jersey announced his intention to withdraw from the RGGI (http://www.state.nj.us/governor/news/news/552011/approved/20110526a.html). It is unclear how this action is going to affect the RGGI after 2012, but clearly the emission leakage could become a serious concern.

On the other hand, it is a well-known fact that power grid management and operations procedures typically aim to reduce network congestion and enhance reliability without considering emission implications (Sauma and Oren, 2006). Congestion cost and congestion revenue are good signals for network operations and investments since congestion both increases electricity price and reduces system reliability. The common knowledge is that the network must be operated not to exceed an "acceptable" level of congestion in the network. However, in general, this "acceptable" (or the "optimal") level of congestion does not consider the potential implications on CO_2 leakage under a C&T program.

In this paper, we use a two-node network to study the conditions under which CO_2 leakage would happen in a radial network under a C&T program.[2] In particular, we show that when the transmission line is congested prior to the emissions trading in the direction of uncapped to capped region, there would be no CO_2 leakage effect since no surplus transmission capacity can support incremental exports. However, if the condition is not satisfied (i.e., if the transmission line is not congested prior to the emissions trading in the direction of uncapped to capped region), there might be a carbon leakage effect.

The main contributions of this paper are:

- To provide an explicit analysis of the conditions for the occurrence of CO_2 leakage in a radial network under a C&T program,
- To explain the way in which transmission capacity, merit order change, and relative production cost between capped and uncapped regions may influence the occurrence of CO_2 leakage, and
- To point out that if regional CO_2 policies could influence power grid management and operations decisions, then there might be space for a better multi-objective coordination.

The rest of the paper is organized as follows. First, we give a summary of the current literature concerning CO_2 leakage in Section 2. In Section 3, an analytically tractable model is presented to derive conditions under which the leakage would occur and to demonstrate how transmission congestion interacts with a regional C&T scheme and creates the leakage effect. We illustrate our results using a simple numerical example in Section 4. Section 5 concludes the paper.

2. Most relevant literature

The pollution haven hypothesis, which concerns the permanent migration of energy-intensive industries under local strict environmental regulations, has been an active research area for several decades (Eskeland and Harrison, 2003; Henderson, 1996; Greenstone, 2003; Millimet and List, 2004). For instance, using a panel data for industrial plant sitting from 1977 to 1987 in US, Henderson (1996) showed that the exit of polluting industry when a county's ozone status is changed from attainment to nonattainment under the Clean Air Act is statistically significant. In Eskeland and Harrison (2003), the authors examined the pollution haven hypothesis from a global perspective, showing that whether strict domestic environmental regulation would lead to an efflux of polluting activities depends on the possible complementarities between capital and pollution abatement. However, overall, weak evidence was found to support the pollution haven hypothesis. Greenstone (2003) referred emissions leakage as "regulation-induced substitution", distinguishing two effects associated with the leakage effect: output reductions and inputs substitutions. In the context of electricity generation, inputs substitution in the short-run is equivalent to "merit order" changes due to the inclusion of emissions costs, whereas output reduction could be induced by demand response and inclusion of emissions costs results in a decline in output.

The research concerning the short-run CO_2 leakage or displacement in electricity industry is scarce, partly because the programs are either national in their scope (e.g., SO_2 Acid Rain Program) or its coverage overlaps with the majority of the regional electricity markets (e.g., NO_x State Implementation Plan Call). Some exceptions are the works by Fowlie (2008) and Chen (2009). Fowlie (2008) defined the term "leakage" as the difference in the emissions under incomplete and complete regulation. The paper showed that when environmental regulation is incomplete, the existence of forward markets would amplify emissions leakage. When the model is applied to the simulation of the California market, the paper estimated that CO_2 leakage amounts to 11.1 and 12.3 t or 62% and 65% of emissions reduction from regulated facilities with and without forward markets, respectively. However, how the CO_2 leakage would interact with transmission congestion between capped and uncapped regions is not addressed.

In Chen (2009), the author empirically examined the CO_2 leakage and SO_2 and NO_x emissions spillover in the RGGI (regional greenhouse gas initiative). The paper concluded that the possibility of CO_2 leakage and NO_x and SO_2 emissions spillover are directly associated with the level of CO_2 allowance prices. Additionally, demand elasticity can effectively attenuate the effect of a regional C&T scheme on leakage and emissions spillover. Although transmission constraints are implicitly included in Chen (2009), the paper does not include an analytical investigation about the conditions for the occurrence of leakage.

The present paper adds to the current literature on CO_2 leakage mainly by explicitly analyzing the conditions for the occurrence of CO_2 leakage in a radial network under a C&T program, illustrating the way in which transmission capacity, merit order change, and relative production cost between capped and uncapped regions may influence the occurrence of CO_2 leakage. Our approach uses a simple two-node network to represent transmission network constraints, which are crucial in examining the substitution of outputs among generators with heterogeneous fuel costs and emissions rates when they face environmental regulation.

Nevertheless, this paper's work has some limitations that are worth-noting. On one hand, the results obtained in the simplified radial network can be generalized to the extent that the capped and uncapped regions are interconnected by transmission lines with a limited capacity. However, loop-flow effects in a more complex network topology might complicate the system in some surprising ways. On the other hand, the market power potentially exercised by generation firms in competitive markets may also interact with network congestion (Sauma and Oren, 2006) and C&T policy, leading to some unintended consequences, as shown in Downward (2010). We leave these considerations to our future research.

3. The analytical model

In this section, we present an analytically tractable model to determine the conditions under which the CO_2 leakage would occur. The parameters are represented with capital letter and variables are with small case. The dual variables associated with

[2] Although the current paper focuses on C&T, the emission tax might also lead to emission leakage if a region is subject to an emission tax while other regions also produce substitute goods and are allowed to sell to the tax-levied region.