University of South Florida

Power Generation Expansion under a CO_2 Cap-and-Trade Program

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Description: The objectives of the proposed research are to 1) develop a comprehensive generation technology based portfolio optimization (GTPO) model and its solution algorithm, and 2) develop educational resources to enhance training of scientific workforce for the state of Florida. The research will directly address three major challenges: fulfillment of the growing power demand, meeting the emissions targets, and supply of technology workforce. The potential economic impact of the proposed research on the State of Florida is expected to be very high, since an energy-secure environment is a basic necessity to support the current trend of explosive growth both in industry and human resources.

Budget: $71,906
Universities: USF
External Collaborators: Argonne National Lab

Progress Summary

During the initial phase of the project, our efforts were focused on developing a generation capacity expansion model that incorporates the implications of the implementation of a CO2 cap-and-trade program in the U.S. A CO2 cap-and-trade program will change the way generators make capacity expansion decisions, especially if the allowances (or pollution permits) created with the program are distributed via auction (as opposed to be given away for free based on historical emissions). In fact, the profitability of a particular expansion plan is measured by adding the profits obtained by the generator in the allowance and electricity markets. Furthermore, the generators' bids and profits in the electricity market are directly impacted by the additional cost generators incur in purchasing allowances.

This year, we have expanded our problem scope by including the issue of optimal redistribution of the revenue collected from the CO2 allowances. It is anticipated that the implementation of a CO2 emissions control scheme, either a cap-and-trade program with auctioned permits or a carbon tax, will provide the government with an important new source of revenue. Several economists advocate for the redistribution of this carbon revenue i.e., for the emissions control schemes to be revenue neutral. We have developed an optimization model to obtain redistribution strategies of the carbon revenue collected by an electricity sector emissions control scheme. We consider two types of subsidies through which the redistribution is accomplished: i) bid subsidies for low-emission generators, which are directed at lowering locational marginal prices throughout the power network, and ii) R & D subsidies, whose purpose is to improve the competitiveness of low-emission generators against fossil-fuel generators. We use empirical curves found in the literature to model the potential effect of R & D subsidies on the cost reduction of low-emission technologies. The optimization model that we have developed attempts to strike a balance between the allocations of these two types of subsidies for a given planning horizon. In addition, by considering the OPF as the basis for our formulation, we intend to address some of the regional (locational) equity issues that may arise if an equal per capita revenue redistribution rule (as proposed in the literature) is implemented.

We demonstrated the use of the mathematical model via a 4-node sample problem. With the objective of examining the effect of network location in the results, we considered two subsidy-scenarios:

discriminatory and non-discriminatory allocation. Finally, we compared the above results with the Business as usual scenario (no emissions control in place) and the scenario with no revenue redistribution.

2010 Annual Progress Report

The following paper provides a detailed report.

Carbon Revenue Redistribution Strategies in Deregulated Electricity Markets

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1. Introduction

In recent years the U.S. and other countries have reduced or at least have started to debate about reducing greenhouse gas emissions, CO_2 dominant among them. There is agreement as to the market-based nature of the approach that should be taken, a cap-and-trade program or a carbon tax, as opposed to direct intervention by the government. However, the disagreements are vast with regards to which approach is better suited to achieve emissions reductions at a reduced cost for the economy and what design features must be considered in the selected approach (the latter is particularly true for the cap-and-trade approach).

A design feature that is common to both market-based emissions control scheme, is the possibility of returning to the market participants the revenue raised by selling allowances (in the cap-and-trade case) or by collecting the tax (in the carbon tax case). This paper is concerned with developing strategies to redistribute this carbon revenue.

The amount of revenue collected by CO_2 emissions control schemes can be significant. Metcalf et al. in [1] compile estimates of the potential revenue that could be collected through several carbon tax bills proposed in the U.S. Congress. The estimates range from $69 billion to $126 billion in the first period of a carbon tax program, gradually increasing throughout the years. Paltsev et al. in [2] estimates that the revenue collected by auctioning allowances in some cap-and-trade proposals for the U.S. range from $130 to $366 billion during the first period of implementation. It may be noted that the revenue collected in a cap-and-trade program depends on the number of allowances that are auctioned (in some designs, such as the initial stage of the European Union Emission Trading System, all allowances can be given away for free and no revenue is collected). The only CO_2 cap-and-trade program currently functioning in the U.S., the Regional Greenhouse Gas Initiative (RGGI), has collected proceeds that range from $38 million to $117 million in the auctions run so far [3].

Several economists [4, 5, 9] are in favor of redistributing (recycling) the carbon revenue, in other words, of developing emissions control schemes that are *revenue neutral*. The market participants that are most often mentioned as the potential recipients for the revenue are households and low-emission companies. Some of the means to achieve the redistribution of revenue include lump-sum distribution to households [4], reducing labor or capital taxes, and spending the funds for other purposes such as R & D in low-carbon technologies and energy efficiency [5]. The case for redistributing carbon revenue back to households is based on the assumption that electricity companies will pass on to the consumers the cost of allowances or carbon tax, therefore increasing the electricity prices. In [4], it is estimated that households will spend an additional $1,158 to $4,119 annually (in 1999 dollars) if a carbon tax is implemented. The case for redistributing part of the revenue to low-emission companies, on the other hand, is based on the need to increase the market share of low-emission generation. The European Union, for instance, have set targets for renewable-based generation (21 %) for the next decade [6]. This will demand a great deal of innovation from renewable-based generation companies which could potentially be achieved through R & D investment (according to [7], emissions pricing alone might not be enough to improve renewable technologies).

In this paper, we present a mathematical model to develop revenue redistribution strategies for a cap-and-trade or a carbon tax program among market participants in a power market. The model is a multi-year version of the DC-based Optimal Power Flow (OPF) problem modified to accommodate carbon revenue constraints and subsidies. We focus on deregulated electricity markets that are subjected to emissions control schemes, similar to the case of several existing markets under the Regional Greenhouse Gas Initiative (RGGI) [8].

2. Background

In this paper, we consider two types of subsidies through which the carbon revenue redistribution is accomplished: bid subsidies for low-emission generators and R & D subsidies for low-emission generators. Since the supply bids of fossil-fuel generators are increased due to the price put on carbon emissions, the purpose of the first type of subsidy (bid subsidies) is to lower the LMPs throughout the network. This would allow customers to pay lower prices for electricity (in comparison with the case where no bid subsidies are allocated) and have more money at their disposal for other activities. In this regard, the effect of the bid subsidies is comparable to that achieved through the lump-sum redistribution via rebates. Simultaneously, the bid subsidies accomplish the objective of increasing the market share of low-emission generators.

The second type of subsidy that we consider, subsidies for R & D of low-emission generators, have a more lasting effect on reducing production costs than the bid subsidies, which only increase production during the year they are allocated. Subsidies for R & D are common in several parts of the world with major programs implemented in the United States, the United Kingdom, Denmark, Ireland, Germany, Japan, and The Netherlands [7]. Subsidies for R & D, as part of carbon revenue redistribution strategies, have been included in recent emission control bills introduced in the U.S. Congress. In [10], for example, a portion of the 25% of revenue collected in the allowance auction is targeted for investments in clean energy.

3. Mathematical Formulation

The mathematical formulation is a quadratic non-convex problem optimization problem and is as follows,

$$\max \sum_t \sum_h \sum_i (a^t_{i_h} - \frac{b^t_{i_h}}{2} d^t_{i_h}) d^t_{i_h} - \sum_t \sum_h \sum_j (e^t_{j_h} + \frac{f^t_{j_h}}{2} q^t_{j_h}) q^t_{j_h}, \tag{1}$$

$$- \sum_t \sum_h \sum_k (e^t_{k_h} - s^t_{k_h} - \alpha_{k_h} \frac{Y^{t-1}_{k_h}}{Y^0_{k_h}} + \frac{f^t_{k_h}}{2} q^t_{k_h}) q^t_{k_h},$$

subject to:

$$Q^t_h - D^t_h - \sum_{l \in l(h)} (m^t_{hl} - m^t_{lh}) = 0 \ \ \forall \ \ \text{node} \ \ h, t \tag{2}$$

$$\sum_{hl \in A(v)} R^t_{hl} (m^t_{hl} - m^t_{lh}) = 0 \ \ \forall \ \ \text{voltage loop} \ \ v, t \tag{3}$$

$$Y^t_{k_h} - Y^{t-1}_{k_h} - y^t_{k_h} = 0 \ \ \forall \ \ k, h, t \tag{4}$$

$$Y^T_{k_h} \geq \beta_{k_h} \ \ \forall \ \ k, h \tag{5}$$

$$\sum_h \sum_k q^t_{k_h} s^t_{k_h} + \sum_h \sum_k y^t_{k_h} \leq Z^t \ \ \forall \ \ t \tag{6}$$

$$m^t_{hl} \leq M^t_{hl} \ \ \forall \ \ \text{arc} \ \ hl, t \tag{7}$$

$$m^t_{hl} \geq 0 \ \ \forall \ \ \text{arc} \ \ hl, t \tag{8}$$

$$q^t_{j_h} \leq \ \ Q^t_{j_h} \ \ \forall \ \ j, h, \quad q^t_{k_h} \leq \ \ Q^t_{k_h} \ \ \forall \ \ k, h \tag{9}$$

$$q^t_{j_h}, q^t_{k_h} \geq 0 \ \ \forall \ \ j, k, h \tag{10}$$

where

$d^t_{i_h}$	quantity demanded by load i at node h during year t (decision variable)
$q^t_{j_h}$	quantity of electricity (in MW) produced by fossil-fuel generator j located at node h during year t (decision variable)
$s^t_{k_h}$	bid subsidy (per MW produced) for low-emission generator k at node h during year t (decision variable)
$q^t_{k_h}$	quantity of electricity (in MW) produced by low-emission generator k located at node h during year t (decision variable)
$Y^{t-1}_{k_h}$	cumulative stock of R & D of low-emission generator k located at node h at the beginning of year t (decision variable)
$y^t_{k_h}$	R & D subsidy for low-emission generator k located at node h during year t (decision variable)
$a^t_{i_h}$, $b^t_{i_h}$	intercept and slope of demand bid curve submitted by load i located at node h during year t

$e_{j_h}^t$, $f_{j_h}^t$	intercept and slope of supply bid curve submitted by fossil fuel generator j located at node h during year t
$e_{k_h}^t$, $f_{k_h}^t$	intercept and slope of supply bid curve submitted by low-emission generator k located at node h during year t
α_{k_h}	learning coefficient due to cumulative stock of R & D of low-emission generator k located at node h
Q_h^t	total quantity produced at node h during year t
D_h^t	total demand at node h during year t
m_{hl}^t	power flow on arc hl during year t (decision variable)
R_{hl}^t	reactance of link hl during year t
β_{k_h}	minimum required amount of cumulative stock of R & D at end of planning horizon for low-emission generator k located at node h
Z^t	available revenue for redistribution during year t
M_{hl}^t	transmission limit of link hl during year t
$Q_{j_h}^t$	production limit of fossil-fuel generator j located at node h during year t
$Q_{k_h}^t$	production limit of low-emission generator k located at node h during year t

The first term in the objective function (1) corresponds to the total benefit to consumers, the second term stands for the total cost to the fossil-fuel generators, and the third term corresponds to the total cost to the low-emission generators minus the bid subsidy ($s_{k_h}^t$) and the expected cost reduction due to cumulative R & D stock ($\alpha_{k_h} \frac{Y_{k_h}^{t-1}}{Y_{k_h}^0}$). Constraint sets (2) and (3) enforce Kirchhoff's laws in the DC linearized load flow model; constraint set (4) establishes the relationship between the cumulative stocks of R & D and the yearly subsidies for R & D of each generator while the set (5) ensures that each generator achieves a minimum target of cumulative R & D stock at the end of the planning horizon. This latter set is required to guarantee that after the last year of the planning horizon generators have reached a level of R & D that allows them to compete against fossil fuel generators without bid subsidies. Constraint set (6) ensures that the revenue redistributed among the market participants is not greater than the forecasted revenue collected through the emissions control scheme in place; and constraints sets (7), (8), (9), (10) enforce transmission and generation limits.

4. References

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