Utilities Policy 28 (2014) 28–41

Contents lists available at ScienceDirect

Utilities Policy

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

The dynamic impact of carbon reduction and renewable support policies on the electricity sector

Riccardo Fagiani*, Jörn C. Richstein, Rudi Hakvoort, Laurens De Vries

Faculty of Technology, Policy and Management, Delft University of Technology, Jaffalaan 5, 2600 GA Delft, The Netherlands

A R T I C L E I N F O

Article history:
Received 1 August 2013
Received in revised form
19 November 2013
Accepted 29 November 2013

Keywords:
Electricity sector
EU ETS
Renewable energy policy
Dynamic policy interaction

A B S T R A C T

Carbon reduction and renewable energy policies are implemented in Europe to improve the sustainability of the electricity sector while achieving security of supply. We investigate the interactions between these policies using a dynamic investment model. Our analysis indicates that both policies are necessary to achieve a sustainable power sector. However, renewable energy generation significantly affects carbon markets and could lead to very low prices. These would attract investments in carbon intensive technologies, locking the sector into future higher emissions. To contrast this effect, policy makers may introduce a floor price in the carbon market or adjust the emissions quota periodically.

1. Introduction

The European Union set an ambitious target to lower the emissions of greenhouse gases (GHG) and established challenging goals for the production of energy from renewable energy sources (RES). An Emissions Trading Scheme (ETS) was established at the European level while mechanisms supporting investments in RES are implemented at a national level. A significant sector affected by these policies is the power industry, since it is one of the primary sectors emitting GHG and many RES technologies are electricity generators.

In this paper we investigate the dynamic interactions between carbon reduction and renewable energy policies. Both policies affect operational and investment decisions concerning renewable and conventional generation in the electricity market. Carbon policy adds to the variable cost of conventional generators. This affects their revenue streams and may change the merit order. Renewable energy producers also affect generation dispatch and thus the (future) revenues of the other generators in the market.

While interactions have been studied for equilibrium conditions, the dynamic feedback loops between the two policies over time have been less investigated. Jensen and Skytte (2003) discuss the impact of the correlation between the consumer price and the renewable energy quota on the interactions between carbon reduction and green certificate markets. Linares et al. (2008) present an oligopolistic partial-equilibrium model simulating the Spanish electricity sector under different energy policy scenarios. Amundsen and Nese (2009) investigate the interaction between carbon and renewable energy policies in the Scandinavian region implementing an analytical equilibrium model. De Jonghe et al. (2009) use a welfare maximization simulation in order to find equilibrium states for combinations of renewable and carbon policy in a three zone system.

This paper presents a bottom-up investment model which simulates the evolution of a hypothetical electricity sector, with characteristics close to the Spanish system, under different policy scenarios. This work addresses the following research question: *In which manner do CO_2 reduction policies and renewable energy support mechanisms dynamically affect each other?* This research adds insights to the analysis of the interactions existing between carbon reduction and renewable energy policy.

We apply a simulation approach that combines elements of agent-based and system-dynamic modeling. The purpose of our model is to analyze how energy policy instruments affect the investment decisions of generating companies by changing the profit and risk profiles of investment projects (Gross et al., 2010). We apply the notion of bounded rationality (Simon, 1957), recognizing that investors are not fully rational when making decisions and do not necessarily optimize but rather satisfice. This means that investors' decisions may not be optimal, but adequate to comply with their expectations. This reflects the fact that investors have

* Corresponding author. Tel.: +31 655795492.
E-mail addresses: r.fagiani@tudelft.nl, riccardo.fagiani@mail.polimi.it (R. Fagiani).

0957-1787/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jup.2013.11.004

informational, intellectual, and computational limitations. Hence, in our model the agents base their investment decisions on available information and on expectations, trying to maximize the trade-off between risks and profits. Agent behavior is also limited by their past investment choices, which affect their current generation portfolios, balance sheets and cash positions, reflecting path dependency. By simulating the impact of carbon reduction and renewable energy policies on investors' choices, we model how energy policy shapes the evolution of the electricity sector (Chappin, 2011).

Our results indicate that while both carbon reduction and renewable support policies are necessary for improving the sustainability of the electricity sector, an aggressive renewable energy policy may reduce the effectiveness of a carbon market in attracting investments in carbon-intensive technologies. Renewable electricity generation reduces carbon emissions and may therefore lead to lower carbon prices; this is part of the reason by the EU ETS is currently experiencing a period of low prices (in addition to a decline in energy demand and industrial activity) (Rathmann, 2007; Lecuyer and Quirion, 2013). If this causes generation companies to invest in coal-fired generators, this may lock the system into higher emissions in the future. In the opposite direction, the EU ETS does not impose negative side-effects on the national renewable support mechanisms; rather, a higher CO_2 price reduces the need for RES subsidies.

This paper is organized as follows. Section 2 provides an overview of policy instruments for supporting renewable energy and reducing carbon emissions, and describes how these are implemented in Europe. Section 3 presents the details of the model. Section 4 describes and discuss the results of the simulations. Finally, Section 5 concludes with policy recommendations.

2. Renewable and carbon policy in the European power sector

Carbon reduction and renewable energy policy mechanisms can be categorized into price-based and quantity-based policies, a distinction made by Weitzman (1974) in a seminal paper on the generic case of regulating a particular economic variable. In quantity-based instruments, the desired level of outcome is set and an artificial market is created in which participants trade certificates to fulfill the policy target. This yields a price for the regulated variable. Examples are the emission trading schemes (ETS) for GHG, in which emitters buy emission allowances (and therefore need to pay for emissions) and tradable green certificates (TGC) for the promotion of RES, which are sold by power producers. In price-based policies, on the other hand, the regulator sets a price for a specific variable, thus, levying a tax on or paying a subsidy to a producer. Ideally, this is a Pigovian tax, which means it is equal to the externality cost of the variable. Examples are technology-specific feed-in tariffs for RES technologies and a carbon tax on GHG emissions. Combinations of these policy instruments are possible as well; however, they represent an increased level of complexity (Hepburn, 2006).

While many publications compare TGC markets with feed-in tariffs (FITs), the question of which policy leads to preferable results for society is still debated. Feed-in tariffs have proven to be effective in reaching policy targets but they suffer from poorer cost-effectiveness (Menanteau et al., 2003). They can be used to stimulate technological change, as they can be designed to have a technological specific component. This can be used to promote technologies in their early stages of development, which may possibly lead to higher dynamic efficiency by inducing technological learning (Del Rio, 2012). Feed-in tariffs may also limit the windfall profits that cheaper RES generators experience in a TGC scheme (Haas et al., 2011) (since cheap RES technologies receive the same remuneration as the marginal technology), and do not cause generators to charge a risk-premium as they do in a TGC market due to the volatility of the green certificate price. This was investigated in a precursor to this study which incorporated generator's risk attitudes and that found that the efficiency of TGC schemes' depended on the risk attitudes towards RES technologies (Fagiani et al., 2013).

The general arguments made by Weitzman (1974) were applied to carbon policy by Grubb and Newberry (2007). They concluded that while a well-set, slowly rising carbon tax would probably be more efficient because it provided more investment certainty (temporal price stability), only a CO_2 market in the form of the European ETS was politically viable and credible for such a large area, due to easier negotiations on quantities than prices and because it offered a better promise for global integration. Chappin et al. (2010) presented an agent-based simulation in which they found that a carbon tax was more efficient in reducing emissions at similar costs to an ETS. Both studies also conclude that setting an appropriate tax is very difficult, due to lack of information. Nonetheless, Chappin et al. (2010) suggest a relatively low starting tax, with a commitment that it will only be adjusted upwards periodically, to provide policy flexibility while limiting investor uncertainty.

In the tradition of Tinbergen (1952), the European Union implemented different policy instruments for the different policy goals. The establishment of the EU ETS, which was established by Directive 2003/87/EC, has involved three trading phases, from 2005 to 2007 (Phase I), 2008–2012 (Phase II), and Phase III since in 2013. The main difference between the phases was in the increasing number of sectors that were covered and the allocation of allowances, freely or in an auction. While the banking of allowances was not allowed between Phase I and Phase II, from Phase II they may be taken over to Phase III. Renewable energy policy, on the other hand, developed at the initiative of member states. Directive 2009/28/EC imposed legally binding national renewable targets for 2020, which differ between the states and were implemented via National Renewable Action Plans (NREAP) (European Commission, 2009; European Commission, 2010). However, no instruction was provided as to the choice of policy instrument for reaching these targets (Haas et al., 2011). In addition, targets for both carbon reduction and renewable energy were established for 2050 (European Commission, 2011).

3. Model description

Our model simulates the evolution of a hypothetical power sector with characteristics similar to the Spanish system from 2012 to 2050. The model is written and run in Matlab R2011a and comprehends elements of agent-based and system-dynamics methodologies. A previous version of the model was used to evaluate renewable energy support mechanisms, confronting price-based and quantity-based mechanisms under different risk-aversion investors' behavior (Fagiani et al., 2013). That analysis did not consider the interaction between carbon and renewable policies; instead, an increasing pigovian tax on carbon emission was defined as an exogenous variable. Also, the green certificate market was modeled assuming a steady state equilibrium with its price reflecting the difference between the average total generation cost of the marginal renewable plant in the market and the average electricity price.

For the purpose of this analysis, we added to the model a carbon market which covers the power sector exclusively, introducing the carbon price as an endogenous variable. The green certificate and carbon prices are modeled to reflect both short-term and long-term expectations of the generation companies in order to better reflect