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On the impact of CO_2 emission-trading on power generation emissions

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ABSTRACT

Under the Kyoto Protocol, governments agreed on and accepted CO_2 reduction targets in order to counter climate change. In Europe one of the main policy instruments to meet the agreed reduction targets is CO_2 emission-trading (CET), which was implemented as of January 2005. In this system, companies active in specific sectors must be in the possession of CO_2 emission rights to an amount equal to their CO_2 emission. In Europe, electricity generation accounts for one-third of CO_2 emissions. Since the power generation sector, has been liberalized, reregulated and privatized in the last decade, around Europe autonomous companies determine the sectors' CO_2 emission. Short-term they adjust their operation, long-term they decide on (dis) investment in power generation facilities and technology selection. An agent-based model is presented to elucidate the effect of CET on the decisions of power companies in an oligopolistic market. Simulations over an extensive scenario-space show that there CET does have an impact. A long-term portfolio shift towards less-CO_2 intensive power generation is observed. However, the effect of CET is relatively small and materializes late. The absolute emissions from power generation rise under most scenarios. This corresponds to the dominant character of current capacity expansion planned in the Netherlands (50%) and in Germany (68%), where companies have announced many new coal based power plants. Coal is the most CO_2 intensive option available and it seems surprising that even after the introduction of CET these capacity expansion plans indicate a preference for coal. Apparently in power generation the economic effect of CO_2 emission-trading is not sufficient to outweigh the economic incentives to choose for coal.

1. Introduction

Under the Kyoto Protocol, governments agreed on and accepted CO_2 reduction targets in order to counter climate change [1]. In Europe one of the main policy instruments to meet these reduction targets is CO_2 emission-trading (CET), which was implemented as of January 2005 [Directive 2003/87/EG; [2]. In this system, companies active in specific sectors must be in the possession of CO_2 emission rights that equals the amount of CO_2 emitted [3]. Any surplus can be sold; any deficit must be compensated for by acquiring rights. Effectively, by economic pricing of CO_2 emission the external effects are partly internalized to the economy. By limiting the total amount of rights – the cap – the EU and its Member States must make sure a suitable price of rights is formed and that trade amongst the parties involved emerges. The magnitude of the CO_2 cap determines the scarcity of rights. A major argument to introduce tradable emission rights, instead of, for instance, taxes, has been that "the invisible hand" of the market would lead to emission reduction by those who can achieve reduction at the lowest cost [4–7].

In Europe, electricity generation accounts for one-third of CO_2 emissions; in the Netherlands this is more than 50% of the sectors under CET [8]. It may thus be seen the power sector is pivotal to CET. In the past decade this sector has been liberalized, regulated and privatized in the last decade. Today power generation is separated from electricity transport and retail and supply.

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Relatively few, autonomous companies are in the business of large-scale power generation. They must survive in oligopolistic but competitive market-conditions. Options to reduce their CO_2 emission include short-term adjustment of their operation, medium-term revamp and long-term they may decide on investment and divestment in power generation facilities and technology selection.

Although the operational flexibility of power generation facilities designed for base-load operation is limited, CET will certainly stipulate further optimisation of power plant optimization. The net effect on CO_2 emission is important, but an order of magnitude smaller than the possible effect of (dis)investment decisions: a coal-fire power plant emits 2.5–3 times the amount of CO_2/MWh of a gas-fired plant. The CO_2 emissions of wind-farms and nuclear plants are negligible. Moreover, all of these capital-intensive facilities currently have technical and economic life-spans of 25–40 years, so decisions today will determine CO_2 emissions for decades. Markets served by capital-intensive facilities are known to be cyclic; the investment in a large-scale power plants may require an investment between 500 and 1500 Million Euros. Switching cost thus are high. While an emission market arguably would lead to reduction at the lowest cost, it remains to be seen whether sufficient emission reduction is achieved long-term.

The central question in this paper therefore is:

> What long-term impact of CO_2 emission-trading on CO_2 emissions can be expected in electric power generation?

In this paper, the effect of CET on the emissions in electric power generation is quantified with an agent-based simulation model. The paper is structured as follows. First, emission-trading, electric power production and the system perspective used are elaborated upon. Subsequently, the agent-based model setup and implementation are explained in detail. Third, model validation, assumptions and limitations are given. Fourth, the simulation results are presented and analysed. Finally, conclusions are drawn.

2. Background and system perspective

The electricity sector has been liberalized in the last decade; power generation, transport over the national grid, regional distribution, retail and supply have been unbundled. Consecutively, the EU implemented an emission-trading scheme, by which electricity generating companies are obliged to have emission right to cover their emission.

This paper focuses on the electric power generation sector. A socio-technical systems-perspective is adopted to analyze the long-term effect of CET on this system [9]. In this perspective, the sector is viewed as a single system that consist of a technical and social subsystem. The technical subsystem contains physical apparatus, such as power generation facilities, electricity grids and consumer equipment; the laws of physics apply to this subsystem and its components. The social subsystem contains actors who engage in contracts with each other on the exchange of fuel, electricity and emission-rights. Some of these actors own and operate components of the physical subsystem. This social system is subject to a regulatory regime and market competition. To survive and make sufficient profits the actors must decide on the operation of their assets, secure fuel at a suitable price, make or defer investment decisions and select the technology they want to use. In Fig. 1 an overview is given of the electricity generation system, including emission-trading, using this socio-technical perspective.

A limited number of companies are active in (large-scale) electric power generation: in many a country a tight oligopoly is in place [10]. In the Netherlands, mainly facilities use natural gas and coal. To a lesser extent other sources are used, such as nuclear, wind and biomass [3]. In Table 1, the main characteristics of the energy sources are stated.

CO_2 emissions are energy source dependent: coal is the most CO_2 intensive; gas is less CO_2 intensive nuclear and wind are essentially CO_2-free. Contrary to the carbon-intensity, coal is a relatively cheap fuel compared to natural gas. Uranium can be acquired at even lower cost, if compared on an energy basis. When it comes to investment, on a per MW basis a world-scale gas-fired power plant has the lowest investment; a modern coal plant requires is about twice as expensive, a modern nuclear plant is more than 5 times as expensive.

Biomass is the subject of an intense debate wherein its carbon-neutrality is questioned [11]. Under the current EU CET biomass is considered to be carbon-free, on the basis of the notion that firing biomass implies that only short-cycle carbon is used and the carbon uptake of the biomass chain equals the carbon emission. Recently, however, it has been concluded by a variety of researchers and the Cramer Commission [12] that first generation biomass use does have a carbon footprint of 30 to 70% of the carbon in the biomass used. Technology used is similar to a coal-fired plant, so also the per MW investment of a biomass plant is similar.

Electricity is transported long-distance over a high voltage transport grid that is owned and controlled by system operators. Medium voltage distribution grids are used for local distribution. Ownership and control of these networks varies throughout Europe. Households buy electricity from retail companies that are active on power markets in order to buy the contracted electricity. Some large industrial consumers buy their electricity on the market themselves, mainly through engaging in bilateral contracts with electricity generators. It is this bilateral market which is the main power market in the Netherlands, where 80% of the electricity is exchanged. The rest is sold on the spot market.

Although many incremental innovations drive-down the CO_2 intensity of electricity generation (in Mton CO_2 per kWh electricity produced), it may be seen that a net reduction of emission from the sector is hard to achieve. The reasons for this are the following:

- The demand for electricity has been rising steadily by 2% per year on average for the last decades. The continuous increase in population and living standards are the main underlying reasons. The growth reflects the ongoing electrification of society.