A system dynamics model for assessing the UK carbon market

Laura M. Cárdenas, Carlos J. Franco and Isaac Dyner

CeiBA, Universidad Nacional de Colombia – Sede Medellín,
lmcardenasa@unal.edu.co
cjfranco@unal.edu.co
idyner@unal.edu.co

Prepared for the
29th International Conference of the System Dynamics Society
Washington, DC, 24 – 28 July, 2011

ABSTRACT

The emissions of greenhouse gases have become a great worldwide concern due to their effects on climate change. This led to determine, through the Kyoto Protocol, goals to decrease at least 5% of the GHGs by 2012, with respect to the 1990 levels. This agreement established three explicit mechanisms: joint implementation, clean development mechanism and emissions trading. In this context, the European Union created an Emissions Trading Scheme – EU ETS (EU Emissions Trading Scheme) – that committed 73% of the global carbon market in 2009.

Given that the electricity sector is the main contributor of GHGs, it is important to assess the impact of the EU ETS on this sector. This article undertakes this task with the support of a system dynamics model, using the United Kingdom as a case study. Preliminary results indicate that even under a scenario of low prices for emission allowances this would induce significant changes in the installed capacity of the electricity sector, replacing fossil-based technologies by cleaner ones, such as wind and nuclear energy; and also significant reductions of CO2 emissions.

KEYWORDS

System dynamics, emissions trading, energy sector, clean technologies, simulation model, emission allowances.

1. INTRODUCTION

Climate Change has become a major global concern in recent years. The public is becoming increasingly aware of this given the magnitude of droughts, glaciers melting, hurricanes and floods, as well as the extent of their effects, as these are just some of the manifestations in all continents worldwide (Comisión Europea 2006; UNFCCC 2005).

Since the 1990s, initial global agreements (the Kyoto Protocol) have been made to face the problems, based on studies by the Intergovernmental Panel on Climate Change (IPCC), and others (Vitousek 1994; Feenstra, et al. 1998). Perhaps the main clear commitment of the industrialized world has been to reduce by 2012 their GHGs emissions, by at least a 5% with respect to those registered in 1990 - "first commitment period" (PNUMA and UNFCCC 2002).

This protocol proposes three mechanisms – joint implementation, clean development mechanism and finally, the emissions trading – that seek to reduce emissions in the home country or putting in place projects that increase carbon capture elsewhere (UNFCCC 2005). To implement these three mechanisms, some regions created "Carbon Markets".

Despite that the Kyoto Protocol is in progress, progress is still limited. It is worth noting the effort of the European Union through the emissions trading scheme – EU ETS – that committed 73% of the global carbon Market in 2009, which represented 86% of the allowances markets (World Bank Institute 2010). The emission transactions by this scheme are made via EUAs (European Union Allowances), which are equivalent to one ton of carbon dioxide (World Bank Institute 2008) – the electricity sector contributes to 60% of these (Zachmann and Von Hirschhausen 2008).

During the Kyoto Protocol first commitment period, which would correspond to the second phase of the EU ETS, a free EUAs assignation system was used. This system is known as National Allocation Plan (NAP) and it is equivalent to the 90% of the total number of permissions (Comisión Europea 2003). This allocation of EUAs establishes a maximum limit to installations that generate carbon dioxide emissions.

The problem appears when these installations produce more emissions, exceeding the established limit. In the case of the electricity sector, for instance, the cost of fines to companies is being passed on to consumers, increasing the cost of the electricity (Chen, et al. 2008) and generates a new dynamics in the European economy (Kara, et al. 2008; Sijm, et al. 2005; Gullì 2008).

Several researchers have analyzed such dynamics through different methodologies, mostly statistical and econometrical (Alberola, Chevallier and Chèze 2009; Oberndorfer 2009; Laurikka and Koljonen 2006). Topics of research have included aspects such as: assessment of investments in the electricity sector, the effect of EUAs on the electricity price, and this effect of EUAs on other sectors. With SD there are some studies with Carbon Markets in USA (Ford 2008; Ford, Vogstadb and Flynn 2007; Ford 2010).

This paper assesses the consequence of EUAs on the electricity market structure in the UK, based on a systems dynamic model that runs under different scenarios, facilitating an assessment of the emission commerce. We chose the United Kingdom case, because this may help us understand what might be the dynamics of power capacity and the CO2 emissions in this country, as well as the dynamics of capacity investment and divestment.

This article is organized as follows: first an analysis of the European Union emissions trading scheme is presented, then we present the model that was created for the evaluation of the consequences of this scheme over the electricity sector in the United Kingdom. Section 3 shows simulation results and finally, in section 4, conclusions are shown.

2. THE EU SCHEME AND THE PROBLEM OF REDUCING CO2 EMISSIONS

In its Directive 2003/87/ce the European Parliament and Council created a GHG emission rights Market. This was implemented in 2005 aiming at meeting the goals established in the Kyoto Protocol (KP), consisting on reducing 8% emissions by 2012 (PNUMA and UNFCCC 2002; Bayón 2004; Zhang, Yue-Jun and Wei. 2010). This reaches the 27 member states of the European Union and some neighboring countries including Iceland, Liechtenstein and Norway.

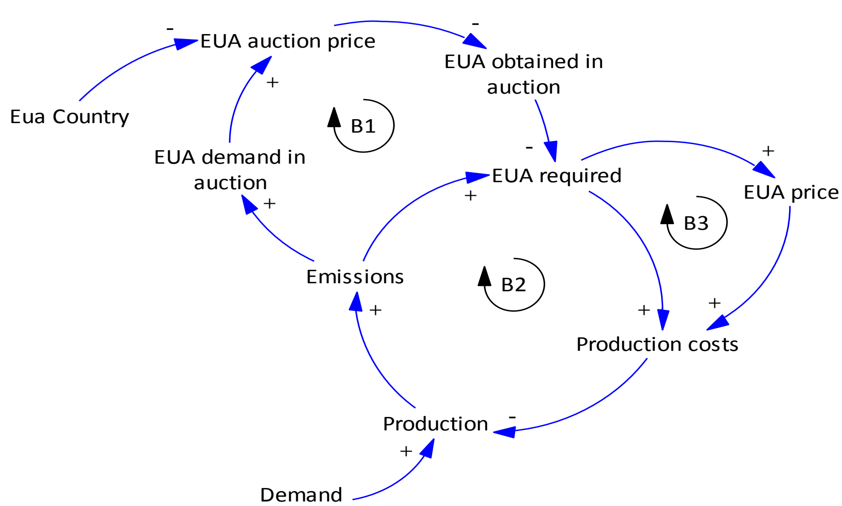

Figure 1. European Union Emissions Trading Scheme

The EU ETS aims to require allowances to companies that emit GHG emissions from the following sectors (combustion plants, oil refineries, coke ovens, iron and steel plants and factories making cement, glass, lime, bricks, ceramics, pulp and paper). Depending on the production that each company will determine the emissions during the year and based on these emissions, each of the companies need a certain number of allowances (EUA: 1 EUA equals 1 ton of CO2) if the company increased production, higher emissions and greater number of EUA's required. The acquisition of these allowances is a cost to the company so that affect its production. The allocation of these EUA's is given initially by auction, the bids are the number of allowances that companies will require and the number of allowances each government provides will be the supply in the auction, determining a price for auctioned EUA's. In a second opportunity is given a secondary market, represented by companies that for some reason have allowances to sell and the companies that couldn't acquire allowances in the auction and need them for their emissions. In the event that the EUAs are not submitted in the corresponding amounts, the company will be penalized as follows: first, they will have to get the missing EUAs; second, the name of the installation will be published in a list of offenders and, third, they will have to pay a 100 Euros fine per extra ton produced (Comisión Europea 2003).
This scheme has the following phases:

I Phase (2005-2007)	II Phase (2008-2012)	III Phase (2013-2020)
Free Allocation (95%)	Free allocation (90%)	Free allocation for energy sector 0%
Auctions (5%)	Auctions (10%)	Auctions (100% energy sector)

Table 1. Allocation in the EU ETS

According to what was observed between the first and second phases of the National Allocation Plans, the percentage of allocations decreased, in line to what was expected, as the aim is to decrease the emissions, inducing all installations to reduce their emissions in the long term.

This paper focuses on assessing the possible consequence of the CO2 market adopted by the EU on the electricity market structure and its reduction of CO2 emissions. For this we built an sd model which is presented next.

3. MODEL DESCRIPTION

To study the effect of the European Union emission trading scheme on the electricity sector, a model was build. The corresponding dynamic hypothesis for the system's problem is shown in Figure 2.

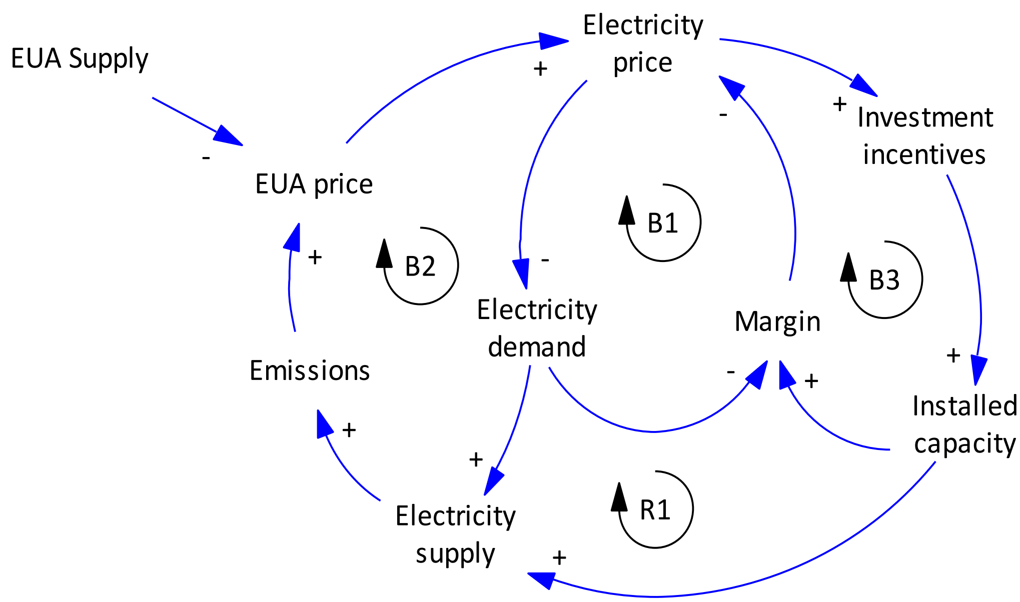

Figure 2. Dynamic hypothesis

Figure 2 represents the EU ETS and the dynamics of the electricity sector. This figure has 4 loops: B1, B2, B3 and R1. Depending on the difference between electricity demand and capacity we obtain the margin of the system, which establishes the price of electricity, this affects the demand because of the elasticity between these variables and thus gets the balance cycle B1. Also, the price shows signals to the model to invest in capacity, determining the balance cycle B3. Besides, installed capacity determines the electricity supply, which sets emissions at fossil fuel-based technologies, and it affects the price of electricity with the addition of EUA price or Carbon price and finally obtains cycles R1 and B2. sector".

Model components:

The model has four feedback loops included in the dynamic hypothesis (Figure 2). These are presented in figures 3, 4, 5 and 6.

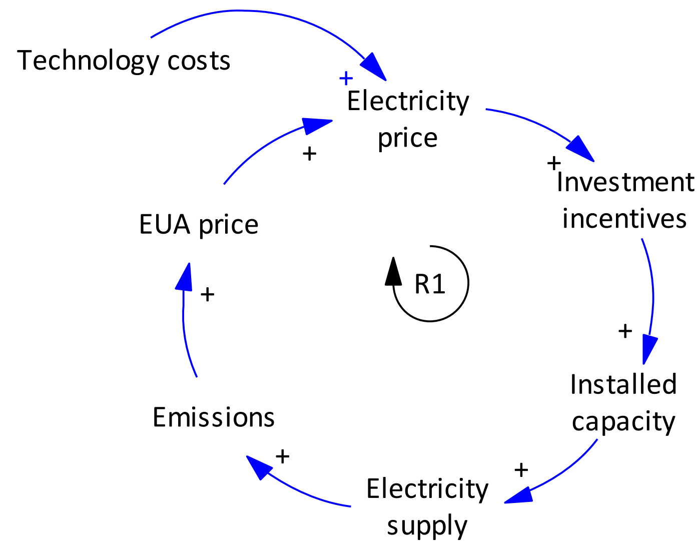

Figure 3. Carbon price loop

The carbon price loop R1 (Figure 3), indicates that higher electricity supply induces higher emissions, so EUAs price raises. This EUAs price increases the cost of electricity generation, incentivizing new power capacity (although not explicitly indicated here, this is conducted by generation technology – e.g. coal, gas, nuclear renewables).

The margin loop B1, includes the margin variable (the difference between supply and demand - peak demand) and how this affects electricity price and consequently decreases electricity demand (Figure 4). The electricity demand loop B2 represents how emissions from electricity supply influences EUAs price, and this raises electricity price, so this decreases electricity demand (figure 5). Also electricity demand is affected by GDP.

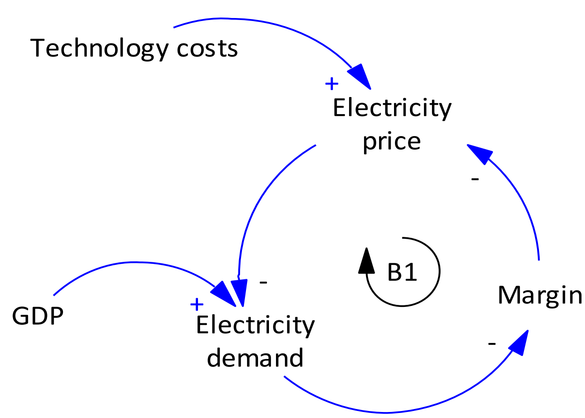

Figure 4. Margin loop

Note that as more EUAs are required, the price of EUAs increases, which constitutes a cost to those installations that generate GHG. This cost will be reflected on the generation supply by technology which determines emissions.

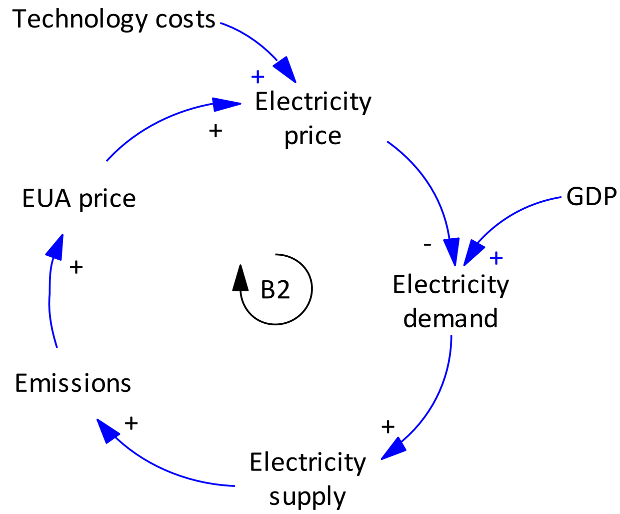

Figure 5. Electricity demand loop

The installed capacity loop B3·shows how the electricity sector operates (see Figure 6). Here the electricity price incentivizes new capacity, which increases the margin, affecting the electricity price.

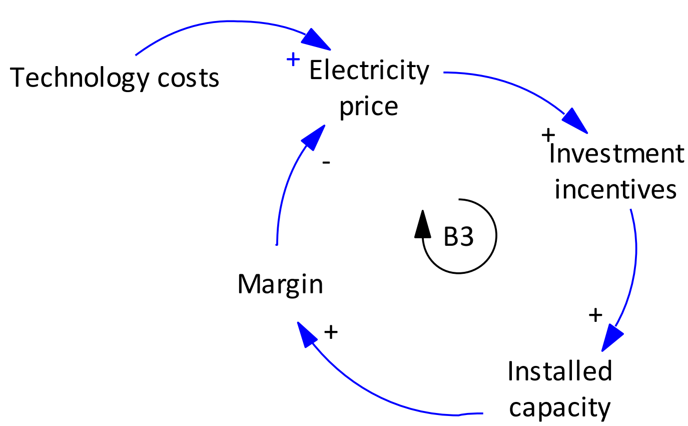

Figure 6. Installed capacity loop

Next, we present simulation data and assumptions used in the model.

4. DATABASE AND VALIDATION

The model developed is multidimensional; it is divided by the main technologies of the country's power sector studied. In the UK these technologies are: gas, coal, fuel oil, nuclear, wind and hydro. Also, Interconnections are added by the significant contribution they make to the electricity production.

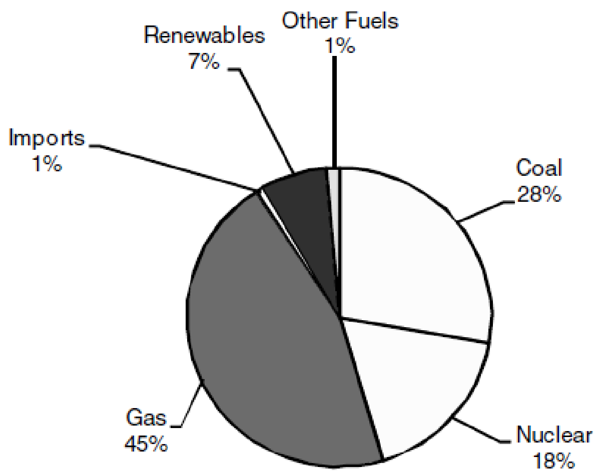

Figure 7. Installed capacity in UK in 2009 (Department of Energy & Climate Change, 2010)

The information used to feed and classify the costs into the model was taken by the Mott MacDonald report (Mott MacDonald, 2010). This report sets out the capital costs and operating costs. Operating costs are fixed operating costs, fuel cost, emission cost, variable operating cost and decomm and waste fund. Within the model remained the classification capital costs and operating costs, but the latter were called cost of generation without carbon cost. Fuel costs (see table 2) were taken from the Department of Energy & Climate Change (Department of Energy & Climate Change 2009)**.**

	Gas price (p/therm)	Oil price ($/bbl)	Coal price (£/tonne)
2007	32,0	77,7	47,3
2008	60,7	106,3	83,1
2009	31,0	62,6	45,0
2010	59,6	71,6	70,3
2011	61,8	72,6	66,5
2012	62,5	73,6	62,6
2013	63,3	74,6	58,8
2014	64,0	75,7	55,0
2015	64,8	76,7	51,1

2016	65,5	77,7	51,1
2017	66,3	78,7	51,1
2018	67,0	79,8	51,1
2019	67,8	80,8	51,1
2020	68,5	81,8	51,1

Table 2. Fuel cost for UK (Department of Energy & Climate Change 2009)

The expansion plans were taken from (National Grid Electricity Transmission plc, 2010) and the data for electricity demand was taken from the Department of Energy and Climate Change in the UK (Department of Energy & Climate Change, 2009) and U.S Energy Information Administration (EIA). Finally, the information on the number of allowances and rules of the EU ETS were taken from the "National Allocation Plan approved for Phase II of the United Kingdom" (Department for Environment, Food and Rural Affairs, 2007).

In the model delays are very important because for each of the technologies we have established a different time of construction that determines when new capacity enters depending on the profits of each technology, and the output of each capacity is determined by life cycle of each technology. These delays are in the following Table and were supplied by the study conducted by The Royal Academy of Engineering for the costing of electricity generation in the UK (PB Power, 2004).

Technology	Time of construction (years)
Gas-fired	2
Coal-fired	4
Nuclear	5
Wind turbines	2

Table 3. Time of construction for each technology (PB Power 2004)

5. SIMULATION RESULTS

The described model was parameterized using United Kingdom data; the model timeline is determined by the different phases of the European Union scheme, between 2008 and 2020. Note that in the second phase (2008-2012) 93% of the EU ETS are free, and in the third phase (2013-2020) 100% is allocated through auctions.

To analyze results, we constructed three scenarios: a base case that shows investment using historical investment rates, and two allocation policies, i.e. from 2008 until 2012 7%

auctions and from 2013, 100% auctions; a second stage with an accelerated investment and 7% auctions; finally, a third stage with an accelerated investment and 100% auctions since 2008.

5.1 Base Case:

This scenario presents a simulation very close to its real operation, i.e. with 100% EUA auctions from 2013. For investment and divestment we use historical tendencies together with planned expansions. Fuels prices are projections of the Energy and Climate Change Department in the United Kingdom. Note that 2500 MW of nuclear capacity is due to retired by 2015.

Clean technologies (wind power, nuclear, hydro-thermal) do not have a big variation in their generation costs due to: first, they do not use fossil fuels and second, these technologies are not affected by the emission cost. Electricity price is then determined by coal, gas and fuel oil. Note that carbon price can change the "merit order" between coal and gas technologies.

Figure 8 shows simulation results under the conditions of the base-case scenario. We remark important increases in gas and wind power; this contrasts with decreases in coal, hydro, coal and fuel oil power. Nuclear energy has a tendency less marked because it is decreasing its capacity until 2016 (because several plants are due to shut-down soon). In 2019, we observe reductions in gas capacity at the expense of coal and wind power.

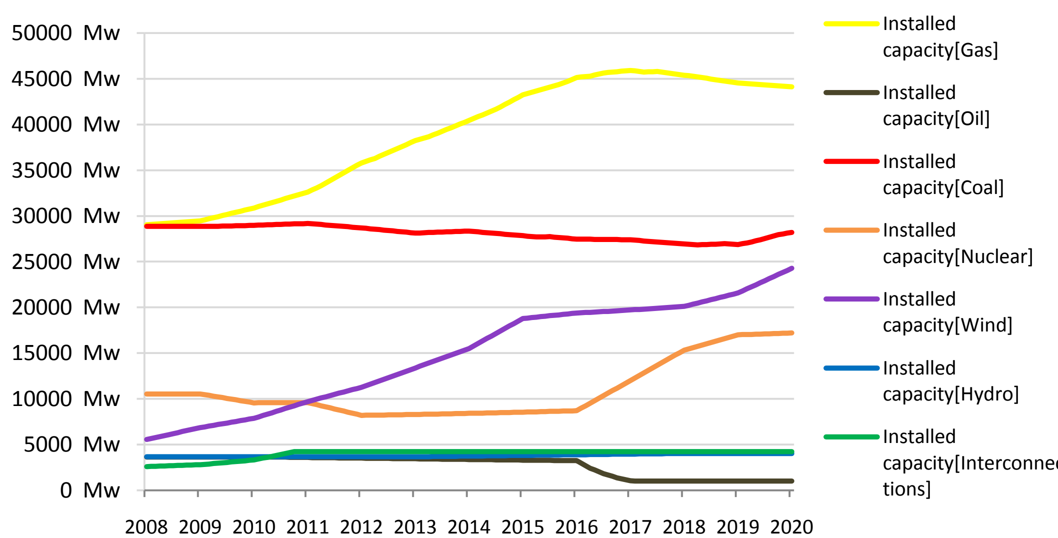

Figure 8. Installed capacity for base case

Figure 9 reports simulations of total emissions of electricity generation in the UK. According to the results of this scenario, reductions in emissions are achieved during the first few years but they increase again. By 2020 CO2 reduction reaches 21.5%- however it fails to meet its goal set at 30% by 2020 (i.e. to reach the 1990 level). Thus, other mechanisms and policies need to be established to reach this goal.

From 2016 a EUA price can be established in approximately 14 Euros/ton, but such price is not high enough to boost the technological changes in the electrical sector to cleaner or lower emission technologies.

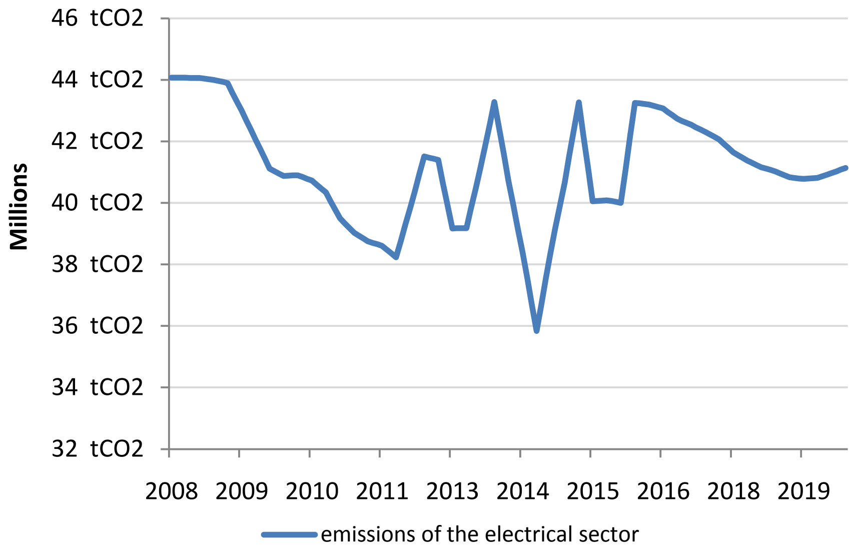

Figure 9. Emissions of the electrical sector for base case

5.2 Scenario 2: accelerated infrastructure with free allocation:

This scenario is based on the following assumptions:
• During this scenario the free allocation policy reaches 93% of the total; with 7% auctions
• The costs will consider the fuel price projections made by the DECC
• Generation and auctions will be conducted by merit order
• The determination of the secondary market price is established by demand and supply
• Investment and divestment in capacity is undertaken according to financial criteria
• 2500 MW of nuclear capacity gradually retires by 2015

In this scenario, wind power takes a big portion of the market (see Figure 10). Unlike the previous scenario, there is remarkable decrease of fossil fuels technologies: Coal-based and gas-based technologies loose grounds. Nuclear power remains with the same behavior as in previous scenario.

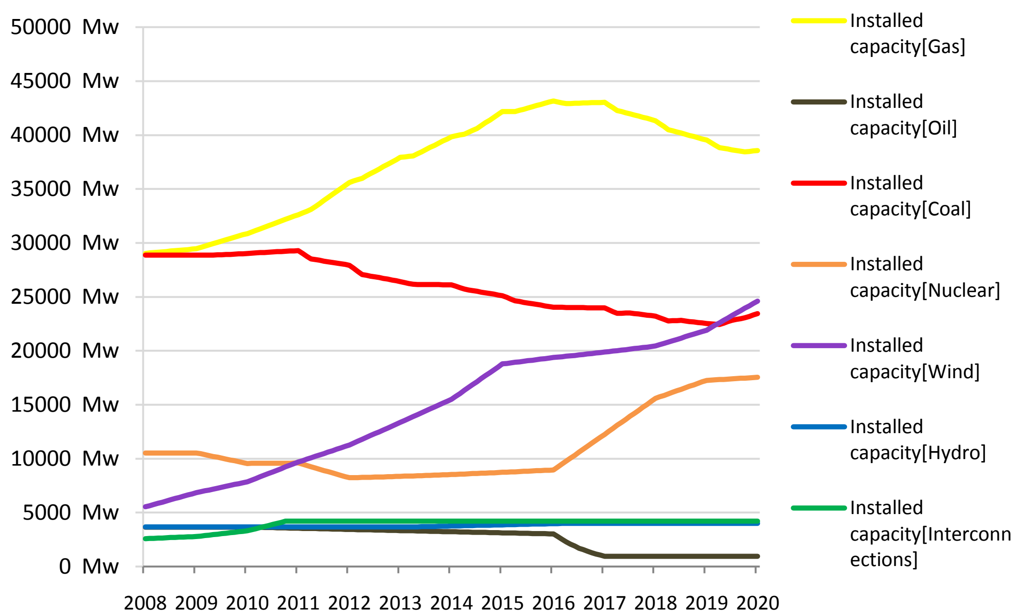

Figure 10. Installed capacity with free allocation policy

In figure 11 we can observe emissions under this scenario. Unlike the previous scenario, the tendency here is more encouraging, despite some oscillations. This is mainly due to big divestment of fossil fuels technologies and increases of clean technologies, which reduce considerably emissions in electricity generation by about 28,4% (just missing the goal).

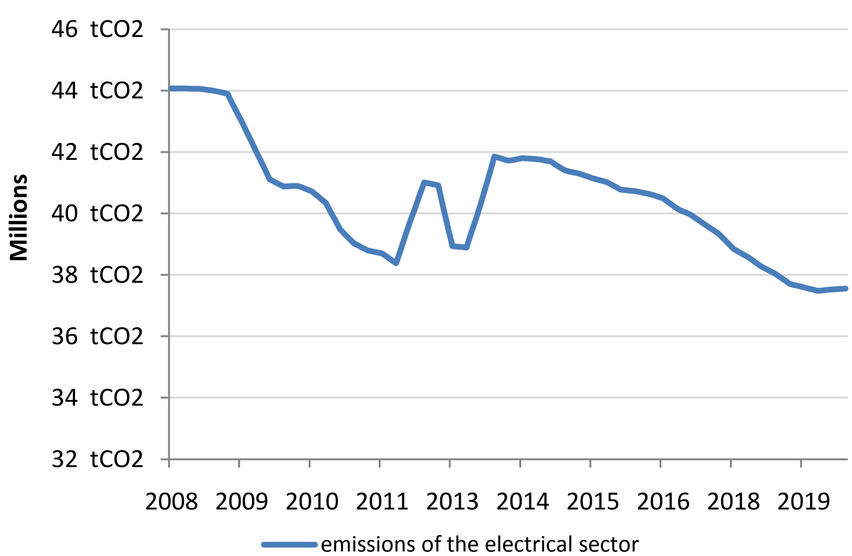

Figure 11. Emissions of the electrical sector with free allocation policy

5.3 Scenario 3: accelerated infrastructure with 100% auctions:

This scenario is based on the following assumptions:

- During this stage 100% auctions policy is analyzed
- The costs will take into account the projections of fuel prices made by the DECC
- Generation and auctions by merit order
- The determination of the secondary market price is established by supply and demand
- Investment and divestment in capacity is undertaken according to financial criteria
- 2500 MW of nuclear capacity gradually retires by 2015

Figure 12 presents the results of this scenario. This scenario exacerbates results shown in the previous case as conditions here are slightly more aggressive.

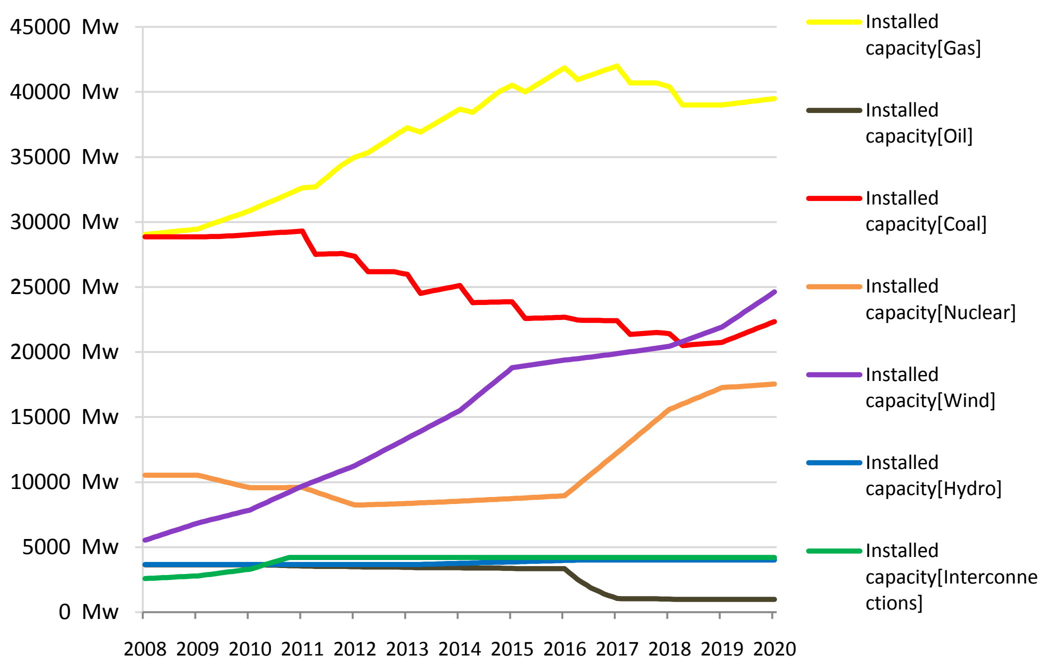

Figure 12. Installed capacity with a 100% auctions policy

As long as electricity demand is met, it becomes harder for gas and coal technologies to maintain their market share, as the high costs of emission do not favor profitability on these technologies, leading to more rapid divestment.

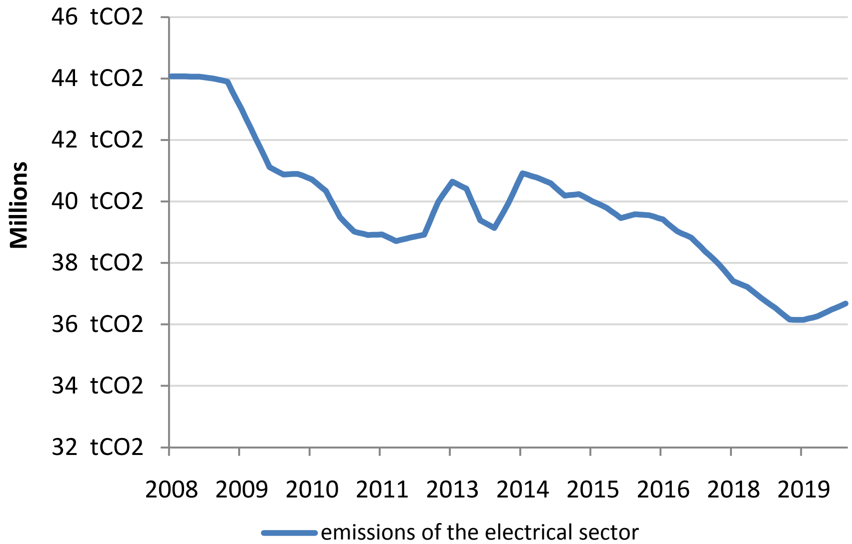

Figure 13. Electrical sector emissions with 100% auctions policy

Regarding emissions, the behavior here is similar to the one observed in the previous scenario, only that at a faster rate. Reductions of emissions have a marked tendency, maintained once again by decreases of fossil fuel generation. In this scenario the 30% reduction is attain.

6. CONCLUSIONS

Results indicate that the United Kingdom will meet the 12.5% goal established by the Kyoto Protocol during the first commitment period. CO2 reduction will be of the order of 25% by 2012. This will mainly attain as a consequence of the liberalization of its electricity sector in the 90's, which led to replace coal based technologies by gas generation – a "dash for gas".

Additionally, the carbon market contributes to the penetration of clean technologies, such as wind power. The role of gas-based technology is also remarkable as this reduces GHG emissions.

The methodology used – a combination of scenarios and sd – proved to be helpful for assessing the impact of the CO2 market on a technology shift in the UK, which contributes to reduce emissions at a level that will meet the goal established by the Kyoto protocol. The lessons, in the case of the United Kingdom, is that in relatively short periods it is possible to achieve transformations in the composition of the generation capacity of the electricity generation, first by liberalizing its market, and once again by creating an emissions trading market.

The three scenarios for simulations suggest a revision in the quantity of emission allowances to be auctioned during the third phase of the scheme. The model assumes similar quantities as established in the second phase. The corresponding auction may be unsuccessful as the total volume of bids might fall short of the volume of auctioned allowances.

Results observed in this article show that the 100% auction policy tends to produce promising effects regarding emissions in the electricity sector and a shift towards efficiency. It is observed that such policy may lead heavily divest fossil-based technologies. However, further research is needed to assess the efficiency and effectiveness of auctions as the ones proposed by the EU.

REFERENCES

Alberola, E, J Chevallier, y B Chèze. «Emissions Compliances and Carbon Prices under the EU ETS: A Country Specific Analysis of Industrial Sectors.» *Journal of Policy Modeling* 31, nº 3 (2009): 446-462.

Bayón, Ricardo. «Hacer que funcionen los mercados ambientales: lecciones de la experiencia inicial con el azufre, el carbono, los humedales y otros mercados relacionados.» 2004.

Bode, S. «Multi-period emissions trading in the electricity sector — winners and losers.» *Energy Policy* 34, nº 6 (April 2006): 680-691.

Chen, Y, J Sijm, B F Hobbs, y W Lise. «Implications of CO2 Emissions Trading for Short-run Electricity Market Outcomes in Northwest Europe.» *Journal of Regulatory Economics* 34, nº 3 (2008): 251-281.

Comisión Europea. «Acción de la UE contra el cambio climático: El régimen de comercio de derechos de emisión.» 2008.

Comisión Europea. «Directiva 2003/87/CE del Parlamento Europeo y del Consejo del 13 de octubre de 2003.» 2003.

Comisión Europea. *El cambio climático: ¿qué es? Introducción para jóvenes.* Material. Oficina de Publicaciones Oficiales de las Comunidades Europeas. Luxemburgo, 2006.

Convery, F, D Ellerman, y C De Perthuis. «The European Carbon Market in Action: Lessons from the First Trading Period.» *Journal for European Environmental & Planning Law* (Martinus Nijhoff Publishers, an imprint of Brill) 5, nº 2 (Agosto 2008): 215-233(19).

Department for Business Enterprise & Regulatory Reform. *Digest of United Kingdom Energy Statistics 2008.* London : National Statistics, 2008.

Department of Energy & Climate Change . *Digest of United Kingdom Energy Statistics 2009.* London: National Statistics, 2009.

Department of Energy & Climate Change. «Annex F - Fossil fuel and retail price assumptions.» *Department of Energy & Climate Change Web Site.* July de 2009. http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx (último acceso: 13 de Junio de 2010).

—. *Digest of United Kingdom Energy Statistics 2010.* London: National Statistics, 2010.

Feenstra, Jan F, Ian Burton, Joel B Smith, y Richard S.J. Tol. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies.* Amsterdam: United Nations Environment Programme, Vrije Universiteit Amsterdam, Institute for Environmental Studies, 1998.

Ford, Andrew. «Global Warming and System Dynamics.» *Proceedings of the 25th International Conference of the System Dynamics Society.* 2007.

—. «Greening the Economy with New Markets: System Dynamics Simulations of Energy and Environmental Markets.» *Proceedings of the 28th International Conference of the System Dynamics Society.* Seoul, Korea: System Dynamics Society, 2010. 26.

Ford, Andrew. «Simulation scenarios for rapid reduction in carbon dioxide emissions in the western electricity system.» *Energy Policy*, 2008: 443-455.

Ford, Andrew, Klaus Vogstadb, y Hilary Flynn. «Simulating price patterns for tradable green certificates to promote electricity generation from wind.» *Energy Policy*, 2007: 91-111.

Gullì, Francesco. *Markets for Carbon and Power Pricing in Europe.* Milan: Edward Elgar, 2008.

Kara, M, et al. "The impacts of EU CO2 emissions trading on electricity markets and electricity consumers in Finland." *Energy Economics* (Elsevier) 30, no. 2 (Marzo 2008): 193-211.

Laurikka, H, y T Koljonen. «Emissions trading and investment decisions in the power sector—a case study in Finland.» *Energy Policy* 39, nº 9 (2006): 1063-1074.

Oberndorfer, U. «EU emission allowances and the stock market: evidence from the electricity industry.» *Ecological Economics* (Elsevier) 68, nº 4 (2009): 1116–1126.

PB Power. *The Costs of Generating Electricity.* Report, London: The Royal Academy of Engineering, 2004.

PNUMA y UNFCCC. «Para comprender el Cambio Climático: Guía Elemental de la Convención Marco de las Naciones Unidas y el Protocolo de Kyoto.» 2002.

Sijm, J P, S J Bakker, Y Chen, H W Harmsen, y W Lise. «CO2 price dynamics: The implications of EU emissions trading for the price of electricity.» Energy Research Centre of the Netherlands, 2005.

Sterman, J D, y L B Sweeney. «Cloudy skies: Assessing public understanding of global warming.» *System Dynamics Review* 18, nº 2 (2002): 207-240.

UNFCCC. *Cuidar el clima, Guía de la Convención Marco sobre el Cambio Climático y el Protocolo de Kyoto.* Bonn, Alemania: Secretaría de la Convención Marco sobre el Cambio Climático (CMCC), 2005.

Vitousek, Peter M. «Beyond Global Warming: Ecology and Global Change.» *Ecology* 75, nº 7 (1994): 1861–1876.

World Bank Institute. «State and Trends of The Carbon Market 2008.» Washington, 2008.

World Bank Institute. «State and Trends of The Carbon Market 2010.» 2010.

Zachmann, G, y C Von Hirschhausen. «First Evidence of Asymmetric Cost Pass-Through of EU Emissions Allowances: Examining Wholesale Electricity Prices in Germany.» *Economics Letters* 99, nº 3 (2008): 465-469.

Zhang, Yue-Jun, y Yi-Ming Wei. «An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect.» *Applied Energy* 87, nº 6 (2010): 1804-1814.