Energy xxx (2014) 1–7

Contents lists available at ScienceDirect

Energy

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

Potential of CO_2 (carbon dioxide) taxes as a policy measure towards low-carbon Portuguese electricity sector by 2050

Hana Gerbelová [a,*], Filipa Amorim [a], André Pina [a], Mário Melo [b], Christos Ioakimidis [c], Paulo Ferrão [a]

[a] MIT|Portugal Program – Sustainable Energy Systems, Instituto Superior Técnico, Av.Professor Cavaco Silva, 2744-016 Porto Salvo, Portugal
[b] Escola Superior Náutica Infante D. Henrique, Av. Engenheiro Bonneville Franco, 2770-058 Oeiras, Portugal
[c] Deusto Institute of Technology, DeustoTech, Energy Unit, Avda. de las Universidades, 48007 Bilbao, Spain

A R T I C L E I N F O

Article history:
Received 30 July 2013
Received in revised form
17 December 2013
Accepted 3 January 2014
Available online xxx

Keywords:
Electricity generation
CO_2 emissions
CO_2 taxes
The Integrated MARKAL-EFOM System
Portugal

A B S T R A C T

The European Union proposed the introduction of taxes on emitted CO_2 as an effective policy measure for the reduction of CO_2 emissions in its electricity sector. Applying the TIMES (The Integrated MARKAL-EFOM System) modeling tool, this paper examines the cost effectiveness of different evolutions of CO_2 taxes under the Emissions Trading System in Europe by 2050 in order to analyze the possible roles and limits of different mitigation technologies within the Portuguese electricity supply system. The results were analyzed based on the final year CO_2 emissions of the electricity system when compared to 1990 levels. The results show that when CO_2 prices stay below 50 €/tonne by 2050 there is no reduction in emitted CO_2 emissions when compared to the levels of 1990. For CO_2 prices reaching between 50 and 100 €/tonne there is a clear reduction in CO_2 with the increase in the price, from 7% with 50 €/tonne to 79% with 100 €/tonne. For prices above 100 €/tonne the increased taxation has only a slight impact on the reduction of CO_2 emissions, as even with a 300 €/tonne price the CO_2 reductions achieved are only of 87%.

1. Introduction

The amount of CO_2 present in the atmosphere keeps rising due to the continuous and increasing use of fossil fuels for energy production. Portugal as a member of the EU (European Union) and within the framework of the Kyoto protocol and the UNFCCC (United Nations Framework Convention on Climate Change) must deal with climate change as one of the main factors towards long-term sustainable development [1]. A study by the EC (European Commission) showed that under current policies domestic GHG (greenhouse gas) emissions would be reduced by 60% in 2050 compared to 1990 levels [2]. Therefore in 2011, the European Council proposed an initiative to design policy measures in the energy and transportation sectors to achieve 80–95% GHG emissions reduction by 2050 compared to 1990 domestically [3]. The largest mitigation of CO_2 emissions is expected to be performed in the electricity sector, mainly due to technology innovation and energy efficiency in end-use [4,5]. In practice, the use of some existing supply technologies will have to be expanded and new advanced technologies will have to be introduced and commercialized to meet GHG reductions in the electricity market, especially in the long run [6].

The EU is one of the main actors in the global effort to reduce GHG emissions and proposed various regulatory measures and strategies in order to achieve targets in limiting its emissions [7]. In this context, an EU Directive introduced the EU-ETS (European Union Emission Trading Scheme) as a mechanism towards flexible and efficient reduction of CO_2 emissions [8]. It is a market-based policy instrument based on a cap-and-trade scheme between energy intensive installations, which are allocated an annual number of permits to emit CO_2 [9]. The first trading phase of the Scheme came in force in 2005 when, according to the National Allocation Plan of each EU member states, a certain number of allowances were allocated to the largest carbon intensive industry sectors based on their historical emissions. Gradually, the number of allowances is getting limited and it is up to the strategy of each country whether to invest in reducing national emissions or to buy extra allowances from the international market. Lund [10] argues that the international collaboration under Kyoto Mechanisms can lead to the particular situation where the industrial countries are more involved in the CO_2 emission control of other countries than controlling their own emissions. In any case, the emission trading

* Corresponding author. Tel.: +351 21 040 70 27.
E-mail addresses: hana.gerbelova@ist.utl.pt, gerbelova@gmail.com (H. Gerbelová).

0360-5442/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2014.01.011

system is believed to encourage carbon intensive industries to reduce their CO_2 emissions. As the environment stringency gets tighter, the companies participate more actively in the EU-ETS [11]. Therefore, in the electricity sector, which is responsible for a significant amount of CO_2 released, the EU-ETS is considered to be a key component in order to commercialize low carbon technologies at large scale.

In continental Portugal, large incentives have been used to implement technologies using RES (renewable energy sources) in the electricity sector due to country's favorable location for their use [12–14]. The Portuguese National Renewable Energy Action Plan to the European Commission confirms that nearly 50% of electricity is produced from RES currently and define a goal of 60% share of RES in the electricity generation by 2020 [15]. Further, a larger share of RES would be necessary to reduce CO_2 emissions in the electricity sector to near-zero values. Krajacic et al. [16] showed an example of achieving 100% RES in the electricity supply in Portugal through a large increase of RES in electricity generation coupled with appropriate energy storage systems. However, this study is based only on achieving a sustainable solution, not analyzing the technology cost. Therefore, this approach considers a large expansion in installed capacity of RES technologies, even in those which are at very beginning stage of their development, with much of them providing significant excess of electricity since the fluctuating output of RES might become a main barrier to guarantee the supply of electricity. To ensure a minimum continuous load operation in a cost effective manner, it is also necessary to invest in capacities balancing these fluctuations, such as conventional backup technologies and fossil fuel power plants with CCS (carbon capture and storage) [17]. Vögele and Rübbelke [18] discussed the profitability on investments in PV (photovoltaic) power plants and fossil power plants with CCS since they are both considered as technologies characterizing a low carbon electricity sector. Taking in account the additional costs for additional capacities required for backup of the intermittent energy source, the overall effect on supplier surplus is larger when investing in the CCS. Moreover, Gutiérrez-Martín et al. [19] denoted that sudden increase and decrease in the conventional power generation output for necessary backup leads to inefficient operation of the fossil fuel power plants and higher emission levels. Significant improvements in the operation of RES technologies can be provided by the deployment of demand side management strategies [20]. However, the technology uncertainties regarding demand response are still significant and the analysis of social behavior is out of the scope in this paper.

This paper analyzes interactions between different mitigation technologies within the Portuguese electricity supply system and studies different evolutions of CO_2 taxes which might be applied as a main policy measure to reduce CO_2 emissions in the national electricity sector. The TIMES model tool was used to assess the representative electricity system over the period of 2005–2050. The paper starts with a short description of the Portuguese electricity system, followed by a presentation of the modeling methodology and the assumptions considered. Next, different evolutions of CO_2 taxes were modeled and the reduction of CO_2 emissions by 2050 in the electricity system was compared. Under the most relevant trends of CO_2 prices, the evolutions of the electricity system from 2005 to 2050 were compared in terms of the electricity production mix.

2. Portuguese electricity system

Electricity generation in continental Portugal is divided into two regimes: ordinary and special. Special regime relates to the generation of electricity from RES (except large hydropower plants), subject to different licensing requirements together with benefits regarding tariffs. Although the electricity generation through RES has been growing in recent years, Portugal is still heavily dependent on imported fossil fuels. The ordinary regime includes all other generation units, which function under the Iberian electricity market. The total installed capacity of fossil fuel power plants was around 6680 MW from a total of 18,546 MW installed capacity by the end of year 2012 [21]. As it is shown in Table 1, Portugal achieved a strategic shift from coal power plants to natural gas combustion in the last decade. Several natural gas power plants started their operation recently and two more are expected to enter the electricity system soon.

Table 2 presents the installed power capacity of RES. Clearly, hydropower is one of the principal RES in continental Portugal. In 2012, nearly 30% of electricity production from RES was generated by large hydro plants, supplemented by small hydro which includes run-off-river plants. Lately, Portugal has also extensively invested in wind power plants. The installed capacity increased progressively from 891 MW in 2005 to 4197 MW in 2012. Moreover, the energy mix of the Portuguese electricity system is complemented by biomass, which is mainly used in CHP (Combine Heat and Power) plants, and a small amount of solar energy.

3. Modeling methodology

3.1. Times model

TIMES (The Integrated Markal-Efom System) is an energy/economic/environmental tool developed for ETSAP – Energy Technology Systems Analysis Program [22]. It is used to estimate energy dynamics in local, national or multi-regional energy systems over a long-term, multi-period time horizon [23–25]. TIMES is a bottom-up partial equilibrium optimization model and it is built through a detailed description of technologies and commodities that characterize the energy system. Then, it computes the minimum cost solution that is capable of providing the modeled energy demands by making decisions on equipment investment and operation, primary energy supply and energy trades. It is a partial equilibrium model as the quantities and the prices in each time period are such that the suppliers produce exactly the quantities demanded by the consumers.

In this study, the TIMES simulation tool is designed to represent the Portuguese electricity system and its evolution up to 2050 with annual steps in between. The purpose of the model is to ensure that enough electricity is generated to meet the annual volume of demand. Moreover, the model employs a very detailed time resolution through dynamics within the electricity system to meet the

Table 1
Characteristics of Portuguese centralized fossil fuel power plants.

Power plant location	Combustion technology	Installed capacity (MW)	Start operation	Efficiency (%, LHV)
Sines	PC	1180	1985	39
Pego	PC	628	1993	39
Ribatejo	NGCC	1176	2004	55
Medas	NGCC	990	2000	55
Lares	NGCC	870	2009	55
Pego II 1	NGCC	417	2010	55
Pego II 2	NGCC	417	2011	55
Sines[a]	NGCC	830	2013	55
Lavos[a]	NGCC	830	2017	55
Carregado	Fuel-oil	710	1968	38
Setúbal	Fuel-oil	946	1979	40
Barreiro	Fuel-oil	56	1978	35

[a] Licensed power plants.

Please cite this article in press as: Gerbelová H, et al., Potential of CO_2 (carbon dioxide) taxes as a policy measure towards low-carbon Portuguese electricity sector by 2050, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.01.011