Energy Economics 30 (2008) 3044–3062

Contents lists available at ScienceDirect

Energy Economics

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

White Certificates for energy efficiency improvement with energy taxes: A theoretical economic model

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ARTICLE INFO

Article history:
Received 13 August 2007
Received in revised form 20 April 2008
Accepted 20 April 2008
Available online 26 April 2008

Keywords:
Energy efficiency
White Certificates
Energy taxes

ABSTRACT

In this paper we analyze interactions of two energy policy instruments, namely a White Certificates (WhC) scheme as an innovative policy instrument for energy efficiency improvement and energy taxation. These policy instruments differ in terms of objectives and final impacts on the price of electricity. We examine the effect of these policy instruments in the electricity sector, focusing on electricity producers and suppliers in a competitive market. Using microeconomic theory, we identify synergies between market players and demonstrate the total effect on the electricity price when suppliers internalize the behaviour of producers in their decisions. This model refers to an ideal market situation of full liberalization. The cases we examine consist of electricity producers with and without a carbon tax, electricity suppliers with and without an electricity tax, and with WhC obligations. Furthermore, we present a parallel implementation of WhC for electricity suppliers with carbon tax on electricity producers and an electricity tax with WhC obligations to electricity suppliers. We demonstrate differences in optimization behaviour of producers and suppliers. Based on a couple of cases of WhC with carbon and electricity taxes, various positive and negative effects of both schemes in terms of target achievement and efficiency are present, which can lead to an added value of such schemes in the policy mix, although uncertainties of outcomes are quite high. A basic finding is that in a merit order several parameters can increase final electricity price after the implementation of different policies: demand for electricity and electricity supply cost at a large scale and then follow the level of level of obligation for energy saving, level of penalty, and price of WhC (representing the marginal costs of energy

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0140-9883/$ – see front matter
doi:10.1016/j.eneco.2008.04.005

saving projects). The impact magnitude of parameters depends on the values chosen and on the initial position of suppliers (i.e. if their actual behaviour deviates from full compliance with targets).

1. Introduction

Various national and international policies have been implemented in EU countries targeting energy efficiency (Oikonomou and Patel, 2004). Traditional policy instruments for energy efficiency improvement are energy taxes and energy tax rebates, which have been applied widely in many EU countries under different forms.[1] Next to taxes, a plethora of policy instruments addressing similar issues is present, consisting of voluntary negotiated agreements, standards and labeling, information campaigns, market based mechanisms and so on. In this policy crowded environment, interactions of these instruments take place and lead to complementarities or overlaps in terms of their effectiveness and cost-effectiveness. So far literature in energy efficiency policies has not dealt in depth with addressing clearly distinctions of targets and combinations of such policy instruments. This paper attempts to analyze to a certain extent interactions of financial and market based instruments that address energy efficiency.

Energy taxes cover many economic sectors, mainly energy production (heat and/or power generation), transport, distribution, and electricity and natural gas end uses ranging from large final users (industry) to households. According to OECD/IEA statistics (2005), with regard to energy taxes on energy production and electricity use, the majority of EU countries possess a differentiated tax that consists of the energy tax itself and the VAT. An important distinction of taxes and their effects based on Zhang and Baranzini (2004) differentiates between energy and carbon taxes. Energy taxes are excise taxes aimed at both fossil fuels and carbon free sources of energy production (or consumption) with an exemption of renewable energy sources. They resemble more to sale taxes imposed on energy suppliers (or producers) and do not focus on CO_2 emissions reduction, in fact they rather aim at fostering energy efficiency through increased costs in energy supply and consumption. A carbon tax is also an excise tax imposed on the carbon carbon-content of fossil fuels; therefore, it addresses directly CO_2 emissions. This tax can drive emitters towards internalizing their negative externality and enable other more efficient or 'cleaner' technologies into penetrating in the energy market. In this paper we employ this tax as an input tax (on fossil fuels) for energy producers. An increase in the level of energy tax will be required in order to achieve the same emissions reduction in comparison to a carbon tax. A bottleneck in the EU internal energy market is that energy taxes are basically levied on electricity consumption, rather than on the carbon-content of the fuels used for electricity production (OECD, 2001). Countries that have introduced carbon taxes, although with many exemptions, are Denmark, Finland, Italy, the Netherlands, Norway and Sweden, while electricity taxes can be found in most EU countries.

A relatively new policy instrument is White Certificates (WhC), named also as Energy Efficiency Titles. The basic idea underlying this policy instrument is that specific energy saving targets are set for energy suppliers or energy distributors, which must fulfil these requirements by implementing energy efficiency measures to end users within a specific period. The fulfilment is acknowledged by means of (White) certificates. Energy suppliers or distributors, which overfulfill their targets, can sell their unused energy efficiency equivalents in the form of WhC to suppliers/distributors which have implemented fewer measures than necessary. In the EU, only the UK and recently Italy and France have implemented WhC schemes, with different target and design characteristics.

Literature has dealt in depth with economic analysis of various energy policy instruments (Baumol and Oates, 1988; Boonekamp, 2006; Bovenberg and Gurney, 2005; Ekins and Barker, 2001; Pezzey, 2003; Pizer, 1999, 2002; Weitzman, 1975; Williams, 2002). For WhC most studies deal with analysis of the instrument and possible interactions, basically in the area of implications (Bertoldi and Rezessy, 2006; Bertoldi et al., 2005; EU SAVE "White and Green" project, 2004; EuroWhiteCert project, 2007; Farinelli et al., 2005;

[1] More information on energy taxes in the EU can be found in the following studies: (Alfsen et al., 1995; Baranzini et al., 2000; Birkelund et al., 1994; Bosello and Carraro, 2001; Bovenberg and Gurney, 2005; Christiernsson, 2004; ECOTEC, 2001; EEA, 2004; Ekins, 1999; Fujiwara et al., 2006; Ghalwash, 2007; Johansson and Schmidt-Faber, 2003; Manne and Richels, 1993; OECD, 2001; OECD/IEA, 2005; Pearce, 2006; Quirrion, 2005; Schlegelmilch, 2000; Vehmas, 2005).

Guardiola et al., 2004; International Energy Agency, 2006; Langniss and Praetorius, 2006; Mundaca and Santi, 2004; Pagliano et al., 2003). Nevertheless, with the exception of Quirrion (2005), an economic model of White Certificates with other policy instruments and implications to energy supplier's behaviour is not present. A reason could be found in the fact that this policy instrument is quite new and has not gained so much significance in economic literature in comparison to other policies, namely emissions trading, taxes, subsidies, and other certificate mechanisms.

The purpose of this paper is to create a framework that reveals possible interactions in the market structure and players' behaviour after the implementation of three energy policy instruments, electricity tax on sales, carbon tax on electricity production, and White Certificates. This framework consists of profit maximization decisions of electricity producers and electricity suppliers when facing different policies. Using microeconomic theory, we identify synergies between these market players and demonstrate the total effect on the electricity price when suppliers internalize the behaviour of producers in their decisions. Our focus lies mainly on the parameters that influence final retail electricity price.

In Section 2 we introduce the methodology used, that consists of a microeconomic model alongside with some important assumptions that need to be taken into consideration. In Section 3 we present two cases of electricity producers with and without carbon tax and three cases of electricity suppliers with and without sales tax and with an obligation of WhC. In Section 4 a WhC scheme interacts with a carbon tax on electricity producers and with a sales tax on suppliers. In Section 5 we conduct an assessment of our cases based on criteria and finally in Section 6 discuss our results and present some conclusions.

2. Methodology

We make use of a small microeconomic model depicting the business behaviour of electricity producers and suppliers in response to the actions of other stakeholders in the energy market, when a WhC scheme, an electricity tax on sales, and a carbon tax on input are applied. We depart from the work of Quirrion (2005) with WhC, taxes and standards, and we differentiate ourselves by making use of two different taxes covering the whole energy sector. We try to answer for each case what are the parameters that affect retail electricity market price and at what direction.

The obligation in our WhC scheme is set upon electricity suppliers, which is often the case, with an exception of Italy, where distributors receive targets. This obligation is translated in implementing energy saving projects or purchasing WhC, depending on the marginal costs of each option. WhC are generated when energy savings are realized and certified. In fact, in order to avoid market distortions, policymakers can impose such obligations also on gas, fuel for domestic use and heat suppliers. Furthermore, we do not refer to electricity distributors, which have natural monopoly elements and can be subject to economic regulation. The reason is that we focus on competitive markets and we depict the business behaviour of energy suppliers that is determined by market provisions. We deal with a competitive supply and demand side and render our model tractable and abstract from considerations of market power. Below lay some basic assumptions of our model.

Electricity suppliers under an energy efficiency obligation are assumed to function in a competitive market according to the principles of electricity market liberalization. Similar assumption holds also for electricity producers. We acknowledge that in many countries this is not the case so far, but following the electricity market liberalization targets set by the EU Commission (EC 2003), all EU countries must comply with. Given the reconsolidation tendencies in energy production and supply in the EU the market maintains an oligopoly character with limited production capacity and competitive prices. For the sake of simplicity and detail of analysis, we confine ourselves to competitive energy suppliers and producers.[2] Furthermore, we assume an electricity price regulation set by authorities on electricity producers.

End users' demand function for electricity in the model can also determine the level of energy efficiency due to price changes. Cost functions for producers and suppliers are not presented in detailed components and are aggregated to simple cost parameters. A detailed bottom up analysis can reveal numerous cost elements but our analysis focuses on how these market parties react in a general cost increase induced by policies.

[2] In a different case, the number of cases and the results would double and game theory should be employed, which would change the scope of this paper.

3. Microeconomic analysis without policy interaction

In this section, we analyze the normative behaviour of energy producers and suppliers in three market conditions: a) a policy free environment, b) a carbon tax on fossil fuels as input for the electricity producers and a tax on sales for electricity suppliers (electricity tax), and c) a WhC obligation for electricity suppliers. We treat the behaviour of each player separately and we assume that no interaction of these policies initially takes place.[3]

3.1. Electricity producers under a carbon tax

We start our analysis assuming that a power generator produces electricity with conventional inputs, i.e. fossil fuels; therefore, limited possibilities for substitution of fuels are present at least in the short term. An average load electricity producer (generator) in a competitive market faces the optimization problem of maximizing his profit through selling electricity to energy suppliers at a market price, under fixed, quasi-fixed, and variable costs.[4] Fixed costs include the financing of plant construction and equipment leases, but their contribution to the market price is a small fragment due to their dispersion in the longer term. Nevertheless we acknowledge that depending on specific technologies employed, such costs can vary significantly and can affect directly the market price.[5] Variable costs consist of fuel expenses (namely fossil fuel) and operational costs. Operational costs refer to non-fuel, labor, plant maintenance and other capital costs. Total production cost that affects an electricity producer's profit over a given tie interval is obtained by multiplying the sum of electricity produced in each unit in megawatt hours (MWh) with the operational cost (€/MWh).[6] In this paper we make thus use of fuel expenses and operational costs. The producer's profit function can be presented as:

$$\Pi = PQ_{\mathrm{P}} - \left[\frac{1}{2}C_{\mathrm{F}}Q_{\mathrm{P}}^{2} + C_{\mathrm{V}}Q_{\mathrm{P}}\right]$$

where:

Q_{P}	is MWh of electricity produced from fossil fuels
CF	is the uniform market price of fossil fuels (determined by the efficiency of the plant and quantity of fuels, given that no “two tiered oil pricing” for imported and domestic oil takes place)
C_{V}	is the summation of all operational costs, which we consider linear just for tractability. It is not in the scope of the paper to go into the details in the cost function and therefore we use a general form in order to represent a wide range of technologies for average load production[7]

[3] Furthermore, especially in the case of energy suppliers, we acknowledge that the maximization problem consists also of the sales maximization and market power, as it is revealed in real practice after the unbundling of energy markets in the EU. In this case, a producer or supplier aims at maximizing his output, hence total revenues given the price and the optimal production is different from the market equilibrium point.

[4] We do not refer to peak load producers since the demand in that case is temporary and peak load producers can supply consumers in the market even at very low efficiency, therefore the optimization strategy does not apply. Another distinction can eventually include the quasi-fixed costs that are independent of the level of electricity production, but are paid if the firm produces output (Varian, 2003). Nevertheless, we assume that these costs are integrated in the operational costs.

[5] These costs normally form step functions and they vary according to the size of the plant. We still consider them linear here since we assume that they are valid for a specified range. Some indicative figures in such investment costs in €/kW range from Gas combustion plants (220), Combined Cycle Gas (425), Coal Steam Turbine (900), Combined Cycle CO2 seq. Gas (925), to Wind Onshore (980), Wind Offshore (1570), PV's PV's (2750), Geothermal (4300), and Hydropower (5850) (Dataset of SAGE model, see EIA/DOE, 2003).

[6] Furthermore, as presented in Pepermans and Willems (2003) a clear distinction takes place between the base load plants and peak load plants, based on the highly variable demand and the non-storability of electricity. The former entail low marginal costs of production and high investment costs, while the latter the opposite. In our model we consider base load generation plants, since the analysis in the other case would require extra constraints in the quantity (namely production refrained to peak demand) and would blurry our policy objective.

[7] In another case of quadratic operational costs we must employ specific production technologies with various costs addressing peak and load production. We expect that in general, if a carbon tax is applied to producers under quadratic operation cost functions, peak technologies would be affected and ‘cleaner’ ones could gain a competitive advantage.

We also assume a linear marginal cost function similar to Quirrion (2005), Johnston (1952), and Ciarreta and Espinosa (2005), where plants have diminishing returns, due to limited availability of cheap sources.[8]

In a competitive market with a tax on inputs (fossil fuels), electricity producers optimize their behaviour by internalizing the tax rate in their decisions. The tax increases average and marginal costs of production, given that cost of other production factors remains stable. The producer's new profit function is now:

$$\Pi = PQ_{\mathrm{P}} - \left[\frac{1}{2}(C_{\mathrm{F}} + t_{\mathrm{F}})Q_{\mathrm{P}}^{2} + C_{\mathrm{V}}Q_{\mathrm{P}}\right]$$

where:

t_{F} is the carbon tax.

A producer's profit in the equilibrium market price is zero. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity produced.

$$\frac{\partial \Pi}{\partial Q_{\mathrm{P}}} = 0,\ \text{where } P = C_{\mathrm{F}}Q_{\mathrm{P}} + C_{\mathrm{V}}. \tag{1}$$

Eq.(1) satisfies the first order condition of profit maximization under a competitive market, where price equals marginal profits and also equals marginal costs of electricity production. The second order condition is given by

$$\frac{\partial^2 \Pi}{\partial Q_{\mathrm{P}}^2} = -C_{\mathrm{F}} = \frac{\partial^2 C}{\partial Q_{\mathrm{P}}^2} < 0.$$

This is in accordance with the basic principle that competitive price is determined by market behaviour and an individual producer cannot affect it directly. An increase in the price of fossil fuels will increase marginal costs of production and will lead to profitability loss. We acknowledge however that a standard method in electricity generation is the average cost pricing, but a basic problem in this case is that when electricity demand rises (approximating peak load), average cost is higher than marginal cost. Competition tends to fix rates charged when adjusting supply with extreme demand. Electricity producers eventually will all react to the cost increase and will stimulate an increase in their selling price (possibly through market exit of producers with high cost). Another strategy for producers is to implement energy efficiency or other measures in their own installations, which can reduce their marginal abatement costs. In any case, they can still pass over their extra investment cost of these measures to the electricity price (this issue is also relevant to windfall profits of producers under the EU emissions trading scheme) (Reinaud 2007).

In the case of a carbon tax, through the partial derivative of the profit function with respect to the quantity of electricity produced, the wholesale equilibrium electricity price is

$$\frac{\partial \Pi}{\partial Q_{\mathrm{P}}} = 0,\ \text{where } P = (C_{\mathrm{F}} + t_{\mathrm{F}})Q_{\mathrm{P}} + C_{\mathrm{V}}. \tag{2}$$

In this case, an individual energy producer sells electricity at a market price, which reduces his optimal profits at the level of the tax (higher price than Eq. (1). An increase in the tax level will result in a further loss of profitability in the short run, but electricity producers will all react and increase the market price, since the tax is uniform and does not allow cost competitive positions. Producers in this sense can pass on all or part of their policy induced costs to following market segments (suppliers and consumers). In an open market however, domestic producers face a threat of cheaper imports of electricity (not taxed), reducing hence their domestic market shares. To sum up, a carbon tax can reduce profits from electricity generation especially to producers that cannot cover the increased variable policy induced costs. Sijm et al. (2005) and Reinaud (2007) present also similar results in the sense that whether energy producers are in a competitive market or an oligopoly or monopoly, in principle the pass through rate of increased carbon costs (whether it is tax or emissions trading) from production to supply will be almost 100%. Finally, based on our assumption of electricity price regulation in the market, producers are not allowed to raise the price more than the

[8] This cost structure facilitates the solution of differential equations for electricity generation (Ciarreta and Espinosa, 2005).

cap price (P_{cap}). In this case if P approximates P_{cap} producers are motivated towards energy efficiency actions in their installations that reduce their costs, in order to avoid any profitability loss in the short term (in case that their marginal costs are higher than P_{cap}).

3.2. Electricity suppliers under an electricity tax

Electricity suppliers sell purchased electricity to end users (households, industry and tertiary sector). They differ from distributors and the transmission in terms of network management, since suppliers do not deal with the transport of electricity (given that electricity companies are not vertical) and can function in a competitive environment (while transmission and distribution are mostly natural monopolies). Sale of electricity includes metering, billing, marketing, and can be wholesale (large users) or retail (individual users) (Steiner, 2000). Relevant labour and capital costs during this procedure can be aggregated to energy supply cost (represented as €/MWh) required for electricity sold. The supplier's profit function can be presented as:

$$\Pi = P_S Q_S - \frac{1}{2} C_S Q_S^2$$

where:

P_S is the final price of electricity,
Q_S is the quantity of electricity sold and
C_S is the energy supply cost.

We also assume a linear marginal cost function, where suppliers have diminishing returns, due to a given price received from competitive production markets and lack of substitution possibilities.[9] The quantity of electricity that suppliers purchase from producers Q_P (derived from the Eq. (1) is internalized into their decisions. Moreover due to supplier's demand driven strategy, in excess demand conditions suppliers have to purchase electricity from abroad in order to remain competitive. The ratio of electricity produced/sold is $Q_S = aQ_P$. Parameter a can be also related to the efficiency of the whole electricity system, since grid loss takes place from production to transmission and distribution.[10]

Again through the partial derivative of the profit function with respect to the quantity of electricity sold, we receive the final price of electricity

$$\frac{\partial \Pi}{\partial Q_S} = 0, \text{ where } P_S = C_S \times a \frac{P - C_V}{C_F} \tag{3}$$

which reflects that a supplier's decision incorporates marginal cost and the producer's competitive quantity. If demand rises, supply price rises and if prices of fossil fuels rise then supply price increases, due to the reaction of all producers that increase the price. An individual supplier nevertheless might not prefer to increase the market price due to external factors that determine it (namely behaviour of competitive producers). The basic tool for a supplier is the reduction of supply costs in order to maintain the same margin of profits in case of an increase in the costs of producer and marketing strategies in order to increase his share in the consumers market. Furthermore, since suppliers do not fall under any price cap regulation from the authorities they can opt for increase in their supply price or any other alternative price strategy.

[9] Similar discussions on convexity of cost functions can be found in Baldick et al (2000), Baldick and Hogan (2001), Johnston (1952), Oren (2000) and Ramos-Real (2005). As explained in Baldick et al (2000), linear marginal costs in cases with asymmetric companies (and more than two strategic players) in the electricity sector can lead to more realism.

[10] Parameter a is related to the efficiency of the whole electricity system, since grid loss takes place from production to transmission and distribution. This efficiency loss ratio in transmission and distribution ranges from 7 to 10% (EC, 2006). P and P_s differ in this paper because they belong to different markets in our analysis, where the output of one is the input of the other. We present these prices as separate, since the price P charged by producers in the supply market falls under a domestic price cap and can be substantially different from the price of producers from another country in our open market (similar with quantities). Suppliers can also import electricity from producers with a different price P, but using a common P for both markets can blur our focus on policies upon electricity supply price.

3.2.1. Electricity demand

We assume a residential demand function for electricity where we can extract the market equilibrium. We make use of a demand function from Fischer and Kaysen (1962), where quantity of electricity demanded is a function of retail electricity price, income and stock of household appliances in use. Given that in the short and medium term demand responses to price of electricity are quite low (low elasticity of demand) the function can be written as:

$$Q_D = u(Y, P_S)^*K$$

where:

Q_D	is the quantity of electricity demanded (in equilibrium is the same with Q_S)
u	is the utility rate of household appliances
Y	is the household's income
K	is the stock of appliances in use.

An increase in income is expected to increase the overall increase in energy demand, while an increase in the electricity price (due to the price inelastic demand) will not decrease substantially electricity demand.

In a competitive market with an electricity tax on sales, suppliers optimize their behaviour by internalizing the tax rate in their decisions. The tax reduces the price that a supplier finally receives. The supplier's new profit function can be presented as:

$$\Pi = (P_S - t_F)Q_S - \frac{1}{2}C_S Q_S^2$$

where

t_S is the electricity tax.

A supplier's profit in the equilibrium market price is zero. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity sold.

$$\frac{\partial \Pi}{\partial Q_S} = 0, \text{ where } P_S = t_S + C_S \times a\frac{P - C_V}{C_F} \tag{4}$$

which shows that in equilibrium, electricity market price received by the producers equals their marginal cost of supply (determined by the marginal cost of production) increased by the sales tax (higher price than Eq. (3)).

Similar to the case without tax, if electricity demand rises, supply price rises and if prices of fossil fuels rise then supply price might increase, due to the reaction of all producers that increase the price, but this time at a higher level due to the effect of the tax. An individual supplier might not prefer to increase the price due to external factors that determine it (namely behaviour of competitive producers) and the large numbers of competitors.[11] The average price of electricity can nevertheless increase because of the whole branch reaction, reducing hence the end consumer surplus. Finally, the impact of the tax on sales might stimulate suppliers on shifting their product portfolio towards more profitable products (for instance shifting from electricity sales to integrated energy services, which in turn can stimulate a market of energy efficiency).

3.3. Electricity suppliers with a WhC obligation

A WhC scheme for achieving higher energy efficiency is often imposed on electricity suppliers. Bertoldi et al. (2005) and International Energy Agency (2006) present several variations in terms of design and targets set in Italy, France, and the UK. As far as design is concerned, WhC can function in a simple form (i.e. suppliers fulfil their obligations, receive WhC and can trade them in a certificate market), or more complex,

[11] Actual suppliers' behaviour indicates that due to their market expansive strategy, they trade off their increased costs with maintaining electricity prices in order to preserve or increase their market share.

involving also financial mechanisms, such as taxes and subsidies, for stimulation of energy efficiency actions and involving more actors. Potential actors are Energy Service Companies (ESCO) that receive WhC originating from their day-to-day activity and sell them in a certificate market to the obliged actors, such as energy distributors or suppliers. The scheme presupposes an obligation imposed on energy suppliers that must implement energy efficiency projects to their customers and by doing so they fulfil their target and receive WhC.

Target allocation can be uniform (same for all suppliers) or differentiated (individual for each supplier). In both cases, moreover a target can be absolute (i.e. fixed amount of energy savings) or relative to electricity sales (i.e. proportioned to the sales of the supplier, considering the weight of the supplier in ratio with the national amount of energy sold yearly by all the national suppliers). The price of WhC in theory reflects the marginal costs of implementing energy efficiency projects (shadow price) or the relevant value of energy saved.

In our model, we assume a uniform target relative to electricity sales, where energy efficiency actions must take place among domestic end users. We further assume that accompanying information diffusion policies targeting end users are at place, in order to facilitate the demand for energy efficiency projects. A supplier can sell electricity but a proportion of these sales must correspond to implementation of energy saving projects (obligation), where he receives WhC, after projects are accredited. We assume that suppliers prefer implementing energy efficiency projects mainly to their own electricity customers, since already established relationships exist and information, communication and negotiation costs can thus be lower. Furthermore, a supplier's implementation of specific energy efficiency projects can create a market lock-in for other suppliers that will shift their investments towards similar competitive products.[12] The actual percentage of electricity that a supplier sells on the market can differ from his obligation, depending on market strategies and profitability margins. A supplier faces hence two options: a) purchasing WhC in order to fulfil his target or b) implementing energy efficiency projects to end users. If the target is overfulfilled, the supplier can finance part or all the cost of his energy efficiency projects by selling WhC to suppliers that cannot meet their targets. If a supplier cannot fulfil his target or purchase WhC, a sanction in the form of financial penalty is imposed. In theory, that penalty should be higher than WhC market price, in order to induce supplier's behaviour towards implementing energy saving projects or purchasing WhC.[13]

The supplier's revenues and costs from electricity sales (modified from Eq. 2) are:

$$P_S(1-\beta)Q_S - \frac{1}{2}C_S(1-\beta)Q_S^2$$

where the new parameters are:

- β is the baseline percentage of electricity sales upon which the mandatory energy efficiency target is set,
- $(1-\beta)$ is the percentage of energy saving that is required for the fulfilment of the target (represents the actual target).

The supplier's revenues and costs from the WhC obligation are:

$$P_{\mathrm{WhC}}\delta_1(1-\beta-\gamma)Q_S - P_{\mathrm{PEN}}\delta_2(\gamma-(1-\beta))Q_S$$

where:

- P_{WhC} is the price of WhC as a shadow cost of energy efficiency projects,
- P_{PEN} is the level of penalty and
- γ is the actual sales behaviour of the supplier

[12] Energy Service Companies can also realize energy saving projects and economies of scale but they can act as a counteracting force to electricity suppliers. The latter can have major profit loss consequences from this competition (some empirical evidence about this can be found in the Italian WhC scheme, where distributors though –and not suppliers– were involved).

[13] Nevertheless, the penalty can take various forms, as a fixed ceiling price or as a percentage of a supplier's supplier's turnover (Energy Efficiency Commitment in the UK). In the first case it acts as an upper bound of the WhC market price, while on the latter is a means of compliance.

δ_1 is the supplier's opportunity cost on buying/selling WhC
δ_2 is the supplier's opportunity cost on paying the penalty.

The supplier's new profit function can be presented as:

$$\Pi = P_S(1-\beta)Q_S + P_{WhC}\delta_1(1-\beta-\gamma)Q_S - \frac{1}{2}C_S(1-\beta)Q_S^2 - P_{PEN}\delta_2(\gamma-(1-\beta))Q_S.$$

The first two elements in this equation are the revenues from electricity and from WhC sales and the last two are costs of the supplier (supply costs and penalties). As can be understood, if a supplier cannot fulfil his target, the second element is negative and transforms to cost, through purchasing WhC. We distinguish three cases of compliance:

- if $1-\beta>\gamma$ the target is lower than the actual level of electricity sales, then the target is overfulfilled, i.e. generated energy savings provide a surplus of WhC that can be sold
- if $1-\beta<\gamma$ the target is higher than the actual level of electricity sales, meaning that a supplier needs to implement more energy efficiency projects, purchase WhC or pay the penalty
- if $1-\beta=\gamma$ then the target is achieved, so all WhC acquired from energy efficiency actions are redeemed and no surplus or shortage is present.

A basic conceptual difference between β and γ is that the former is imposed by government while the latter demonstrates the supplier's strategy.[14] In one more detailed step, we express furthermore the tradeoff of a supplier on buying WhC (alternatively implementing energy efficiency projects) or paying the penalty with the symbols δ_1 and δ_2 ($\delta_1=1-\delta_2$, with values 0 to 1). If $\delta_1=1$ the supplier prefers to cover his obligation with WhC and avoid paying penalty, while if $\delta_2=1$ he does not participate in the process of implementing energy saving projects and prefers to pay the penalty.[15] When there is a surplus of WhC, where the target is lower than the actual level of electricity sales, the δ_2 equals to zero, which renders the last part of the equation to zero.

In a competitive market, market equilibrium is where profit derivative equals to zero, which leads to the equation of supplier's marginal costs with a competitive market price. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity sold.

$$\frac{\partial \Pi}{\partial Q_S} = 0, \text{ where } P_S = C_S \times a\frac{P-C_V}{C_F} + \frac{\delta_2(\gamma-(1-\beta))P_{PEN} - \delta_1(1-\beta-\gamma)P_{WhC}}{1-\beta}. \tag{5}$$

We can deduce from this relationship that if demand rises (i.e. higher a) or other costs rise, supply price rises as a result of the reaction of all producers that increase their price. A supplier cannot affect directly the market price due to the external factors that determine it (namely behaviour of competitive producers). With a WhC scheme, price of supplied electricity is also determined by the relative difference of penalty with certificate price, level of target (β), and tradeoffs of purchasing WhC (δ_1) or paying the penalty (δ_2).

When a supplier meets his energy efficiency target up to the level of the obligation, it is clear that no extra costs are incurred. If all suppliers manage to achieve this result, then price of electricity is in equilibrium and no pressing effect is present. In this situation, no trade of WhC takes place since the targets are achieved (i.e. there is no demand or supply for WhC), and the added value of the scheme towards an obligation without trading is not present anymore. If an energy efficiency obligation is lower than a supplier's actual electricity sales, then he can decide to sell more electricity up to the maximum allowed level, or sell electricity more than his target because his opportunity cost of paying the penalty (for not complying with the obligation) is lower than selling more electricity, or to achieve more energy savings than his target, which grants him with a surplus of WhC that can be sold in the market. If an obligation is

[14] An important remark here is that γ at this stage is considered as independent variable for our example; it is influenced by external factors, e.g. price of energy efficiency goods as they are produced in the exogenously given energy efficiency products market.

[15] Another strategy for the supplier, in theory, could be the partial fulfilment of the target through purchase of WhC and the remaining part through paying the penalty. In reality nevertheless that WhC trading periods are relatively short (yearly basis), a supplier chooses the lowest compliance price and decides to cover his obligation with the same cost. Still, a tradeoff between these two options can take place and a supplier can choose a portfolio of options (e.g. $\delta_1\delta_1$ and δ_2 simultaneously at a certain rate).

higher than actual electricity sales, then a supplier faces the option of reducing his electricity sales while performing energy efficiency projects to achieve the target, maintain his relatively high electricity sales and purchasing WhC, or paying the penalty.

At an initial phase, when no-regret energy efficiency potentials exist, energy efficiency projects are expected to carry a low cost. This cost in a competitive energy efficiency products market will determine also the price of WhC (as a marginal shadow price of the next least expensive energy saving project). A low P_{WhC} influences moderately the optimal price. When P_{WhC} increases it presses P_{S} upwards, which in fact can increase the incentive for energy efficiency actions, since financing of such projects can be fulfiled through an increased market electricity price (given that suppliers will react and formulate a new market equilibrium). An increase in penalty price will also press P_{S} upwards, while it will have no effect if a supplier fulfils his obligation solely through WhC trading. Furthermore, an increase of the target can lead to an increasing effect to the equilibrium price of electricity, assuming that suppliers cannot comply with the new target. A failure of compliance, (reflected in high values of γ) affects P_{S} positively, while an overcompliance lowers the P_{S}. A fulfilment of the target (either with energy efficiency measures or purchase of certificates) in equilibrium can affect P_{S} in both directions, depending on the initial point of a supplier. We could expect that most probably, suppliers should increase P_{S} in order to carry over increased policy costs.

Nevertheless, in all the above-mentioned effects, an individual supplier's competitive position does not allow him to raise the price and therefore he can optimize his revenues or cost parameters or combinations of them. More specifically, supplier's extra costs should be financed through his increase in sales (Q_{S}), his implementation of least cost energy efficiency projects, his lowering of inputs cost (Q_{P}), by choosing the least cost producer who sells below market price), his lowering supply costs (C_{S}), or by selecting a network with the least grid loss (minimize a). Another strategy a supplier can follow is the contracting of Energy Service Companies (ESCO's) or other market parties in order to implement energy saving projects in a more profitable way and increase his share in the energy service market. Such projects consist of technologies with a high market potential and cost cost-effectiveness.[16]

Based on the residential demand function we expect that an energy efficiency obligation will change the quality of the stock of appliances in use (K), while an increase in P_{S} will not have a strong effect on their utility rate (u). The net total effect in this case will be a reduction in the quantity of electricity demanded. Nevertheless, we must take into account the rebound effect (originating from an income effect), where the relative increase of income (due to lower electricity bill) can possibly stimulate a higher utility rate and the positive effect can be reduced. The price effect can be a small fraction in the total effect, hence it cannot explain by itself a big rebound effect. It can also be an autonomous increase in income without electricity bill. Finally, if we consider information campaigns as an extra measure implemented by electricity suppliers, this can stimulate a more energy efficient behaviour of the end users, which leads to a lower u and hence a lower electricity demand.

4. Microeconomic analysis with policy interaction

In this section, we analyze the normative behaviour of electricity suppliers under a WhC scheme when incorporating in their decisions a carbon tax imposed on electricity producers, and when facing an electricity tax on sales. We treat each case separately and identify interactions of these policies. At a next step, we demonstrate the degree of significance of each parameter on the final decisions of the market, as reflected by their impact on the final price of electricity. Finally, we present potential behaviours of electricity suppliers given their expectations on policy costs.

4.1. Electricity suppliers with WhC obligation with electricity producers with carbon tax

In a competitive market with a carbon tax on production, electricity producers optimize their behaviour by internalizing the tax rate in their decisions (Eq. 2). An electricity supplier under an energy efficiency obligation in a WhC scheme can sell electricity and must fulfil an energy efficiency obligation as a

[16] In reality, a typical measure that dominates market potential in such schemes (especially in the UK) is insulation, see for instance OFGEM (2003).

proportion to his electricity sold through setting up energy efficiency projects to end users, purchasing WhC, or paying the penalty (Eq. 5). In the case where both instruments are implemented simultaneously, a supplier's profit function, when taking into account the effect of the tax on producer, is:

$$\Pi = P_S(1-\beta)aQ_P + P_{WhC}\delta_1(1-\beta-\gamma)aQ_P - \frac{1}{2}C_S(1-\beta)aQ_P - P_{PEN}\delta_2(\gamma-(1-\beta))aQ_P.$$

A supplier internalizes the producer's tax burden in his decision and sells electricity at the competitive price. We extract this result through the partial derivative of the profit function with respect to the quantity of electricity sold.

$$\frac{\partial \Pi}{\partial Q_S} = 0, \text{ where } P_S = C_S \times a\frac{P-C_V}{C_F+t_F} + \frac{P_{PEN}\delta_2(\gamma-(1-\beta)) - \delta_1(1-\beta-\gamma)P_{WhC}}{1-\beta}.$$

Similar to the previous cases, we demonstrate that if demand raises supply price rises. With higher prices of fossil fuels due to the carbon tax, supply price in this case will definitely increase, due to the reaction of all producers. A supplier cannot affect directly the market price due to external factors that determine it (namely behaviour of competitive producers). An increase in producer's fossil fuel cost will tend to increase the price of final electricity sold in the retail market or increase imports from cheaper sources.

When P_{WhC} increases it presses the optimal market P_S even more upwards, which jeopardizes the incentive for energy efficiency actions. A counterargument is that if supplier's market positions are guaranteed then they could indeed reduce their electricity sales and promote energy efficiency.[17] In all senses this behaviour depends on the level of the price increase due to the carbon tax and on the supplier's initial position. Furthermore, a determinant parameter is the difference of carbon tax with price of WhC in the market. If prices of WhC are higher than the tax, then the tax acts as a lower bound price for energy efficiency, which is not necessarily favourable, since energy efficient solutions that are initially economically efficient might be locked out. In this case, a carbon tax could distort the market for energy efficiency stimulated by WhC. If prices of WhC are lower than the tax, then the increase in the costs will stimulate a lot of cost cost-effective energy efficiency actions in a merit order, which could exhaust the low hanging fruits, but most probably the allocation of costs would not be efficient. Finally, another determinant parameter is the difference of the penalty with the level of carbon tax. When the tax is much lower than the penalty, the relative impact on the price of electricity will not be substantial and energy efficiency projects can be locked up due to their lack of competitiveness. If the tax is higher then eventually energy efficiency actions will be stimulated and become profitable, as long as their costs for the suppliers still remain under the level of the penalty. If finally, the carbon tax is higher than the penalty, then the price of electricity can rise a lot and suppliers might just pay the penalty and maintain their profits (through higher revenues).

An increase in penalty price will press also P_S upwards, while it will have no effect if the supplier fulfils his obligation solely through WhC trading. A failure of compliance, (reflected in high values of γ) affects P_S positively, while an overcompliance lowers P_S. Through the imposition of a carbon tax on the producer, electricity supplier's input is more expensive, therefore a percentage of this cost will be passed on to energy efficiency projects or directly to electricity price, based on cost pricing. Since supplier's input is already more expensive, his extra costs should be financed through increasing sales (Q_S), or P_S if his competitive position allows it, implementing least cost energy efficiency projects (e.g. contracting ESCO's), lowering of inputs cost (aQ_P), choosing the least cost producer who sells below market price, lowering supply costs (C_S), or by selecting a network with the least grid loss (minimize a). In all cases, the increase of P, as a result of carbon tax, can range within an expected range, given the existence of P_{cap} in the market.

As far as electricity demand is concerned, we expect that an increase that no substantial added value will take place from the introduction of a carbon tax upon the electricity consumption, given that a WhC obligation also takes place. This is due to the fact that price elasticity of demand for electricity is rather low in the short term and hence the effect on a price increase cannot stimulate only by itself an extra energy

[17] This argument can be valid also if market concentration of suppliers is quite high, leaving hence only a fringe market to non-dominant suppliers.

efficient behaviour. This gap can be covered by energy efficiency measures implemented through a WhC scheme.

4.2. Electricity suppliers with WhC obligation and with electricity tax

An electricity supplier under an energy efficiency obligation in a WhC scheme that is also burdened with a tax on sales receives a double regulation that significantly restricts his profits and business strategies (Eqs. 4, 5). Under WhC obligation a supplier must fulfil a percentage of his electricity sales in energy efficiency and with the imposition of a sales tax, the price of electricity he receives on the market is further on reduced at the level of the tax. Under these market conditions a supplier's new profit function is:

$$\Pi = (P_S - t_S)(1-\beta)Q_S + P_{WhC}\delta_1(1-\beta-\gamma)Q_S - \frac{1}{2}C_S(1-\beta)Q_S^2 - P_{PEN}\delta_2(\gamma-(1-\beta))Q_S.$$

A supplier internalizes the producer's tax burden in his decision and sells electricity at the competitive price. Once more the partial derivative of the profit function with respect to the quantity of electricity sold gives us the equilibrium retail price.

$$\frac{\partial \Pi}{\partial Q_S} = 0, \text{ where } P_S = C_S \times a\frac{P - C_V}{C_F} + t_S + \frac{\delta_2 P_{PEN}(\gamma-(1-\beta)) - \delta_1(1-\beta-\gamma)P_{WhC}}{1-\beta}.$$

Similar as the previous case, if electricity demand rises supply price rises and if prices of fossil fuels rise then supply price might increase, due to reaction of all producers that increase the price. An individual supplier cannot affect directly market price due to external factors that determine it (namely behaviour of competitive producers). The level of electricity tax can determine the final price of electricity and its changes affect P_S on the same direction.

A basic characteristic of sales tax is that it increases the cost of supply, which affects the actual share of electricity sold $(1-\beta)$ and presses therefore towards fulfilment of the WhC target. An argument against this scheme can be on the grounds of fairness, because electricity suppliers are in fact restricted twice, since they are obliged to reduce their quantity sold and are taxed on the top of this reduced quantity. If a WhC obligation is higher than a supplier's actual sales, then an increase of P_{WhC} presses the market P_S upwards, which can increase the incentive for energy efficiency actions, since the financing of projects can take place through an increased electricity price. Given the imposition of electricity tax, the electricity price will increase further on, reflecting hence a higher amount than the shadow price of energy efficiency projects. An increase in the penalty price will press also the P_S upwards, while it will have no effect if the supplier fulfils his obligation solely through WhC trading. Furthermore, an increase of the target can lead to an increasing effect to the equilibrium price of electricity, assuming that the supplier cannot comply with the new target. A failure of compliance, (reflected in high values of γ) affects P_S positively, while an overcompliance lowers P_S. Through the imposition of a sales tax, a supplier has an extra incentive to comply with the obligation and even more to overcomply, since he can generate an income from WhC trading that can finance the extra tax burden. This relationship depends on the magnitude of the cost shares of electricity tax and shadow prices of energy efficiency projects (as reflected by price of WhC) on the average costs of supplier. Since an individual supplier's competitive position does not allow him to raise the price, his extra costs should be financed through implementing least cost energy efficiency projects (e.g. contracting ESCO's), lowering of inputs cost (Q_P, by choosing the least cost producer who sells below market price), lowering supply costs (C_S), or by selecting a network with the least grid loss (minimize a). In this scheme, consumers pay the increased P_S due to electricity tax but they can also balance it through decreasing end-use costs from installing energy efficiency equipment. This scheme creates limited awareness, since electricity taxes do not provide a clear signal of correcting environmental externalities, as in the case of carbon taxes.

4.3. Influencing factors on the price of electricity

As depicted in this section, different sorts of taxation when combined with WhC lead electricity suppliers to different optimizing behaviours. Electricity suppliers in a competitive environment receive

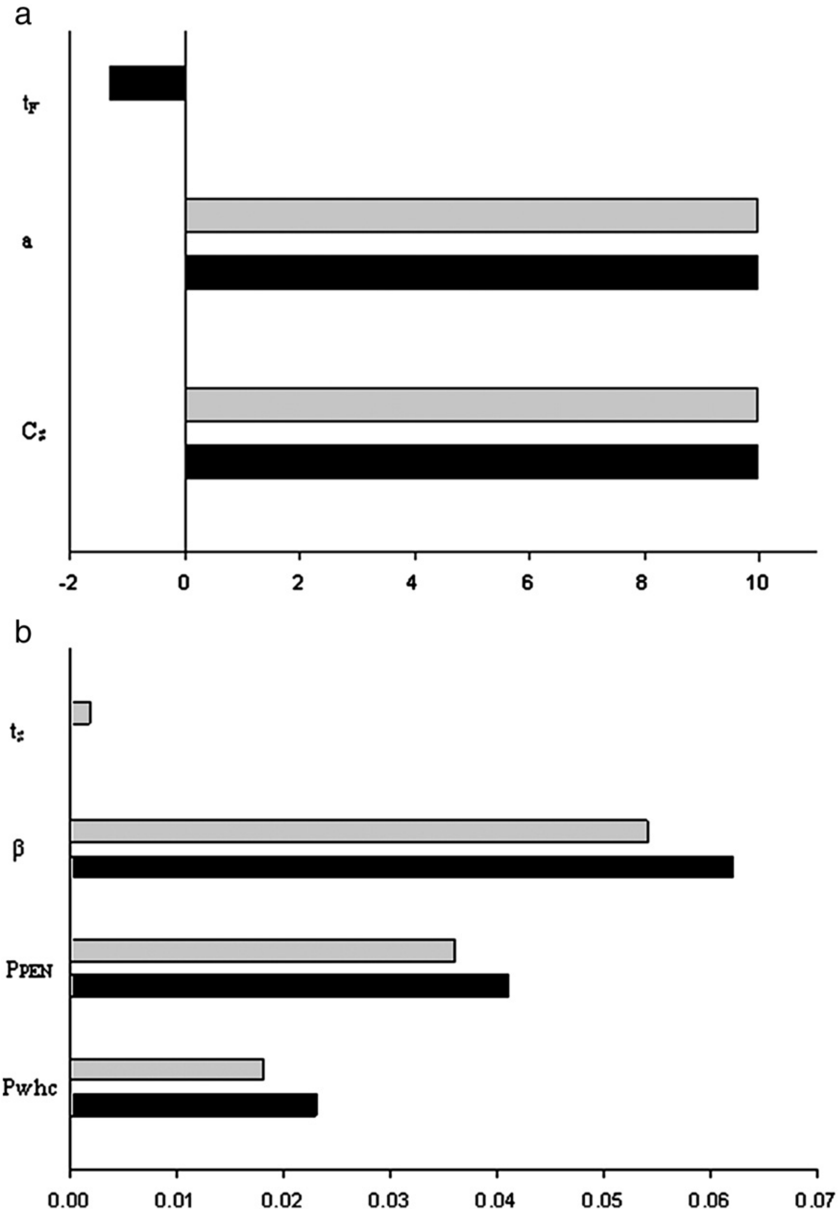

Fig. 1. Parameters affecting the final electricity price under taxes and WhC.

market signals and incorporate prices, taxes and their energy efficiency obligations to their decisions. Due to the nature of the market, they cannot determine the price individually. Based on the equations in the previous two sections, we identify some parameters that influence the final market price. These are namely: price of WhC, level of obligation, actual percentage of electricity sold, level of sales tax, level of penalty, electricity demand, and cost of supply.

For demonstrative purposes we test these parameters and their significance, through data application from various sources. We assume annual quantities produced and sold in the market of 3000 MWh and 2790 MWh respectively (given a transmission loss of 7%). Furthermore, electricity generation costs are split

Table 1
Parameters affecting price of electricity, price and volume of WhC

	P_{WhC}	P_S	β	a	C_S	t_S	t_F
P_{WhC}	X	+	−	+	−	−	+
P_S	+	X	+	+	+	+	+
WhC	−	−	+	−	+	+	−

into fixed and stranded costs (7.5–8 €/kWh), operation and maintenance costs (9 €/kWh) and fuel (coal) costs (12.75 €/kWh) (OECD, 2005; The Royal Academy of Engineering, 2004). Electricity supplier's costs are estimated around 0.02 €/MWh. Concerning policy instruments applied we assume a price of WhC at 5 €/MWh, a penalty at 20 €/MWh (similar to the French WhC scheme), an electricity tax on sales at 0.001 €/MWh and a carbon tax at 0.002 €/MWh. Fig. 1a and b incorporates these values, where we present the significance of these parameters through a sensitivity analysis. We increase the values of all parameters by 10% (x-axis) and we extract the following bars representing the percentage change of final electricity market price (y-axis), when all suppliers react to the market signals. We assume in this case that electricity suppliers fulfil their obligations through purchase of WhC (or through implementing energy efficiency projects at a cost reflected by the shadow price of WhC) and by paying the penalty ($\delta_1 = \delta_2$). In this case, we can attest that electricity demand and supply cost affect P_S significantly, independent thus of other policy parameters (i.e. level of obligation and taxes). In Fig. 1a, a change in transmission effectiveness (a) and electricity supply costs affects electricity price at a great extent (9–10%). Furthermore, in Fig. 1b, at a much lesser extent the level of the obligation, the level of penalty, and the price of WhC are determinant factors for the price of electricity as induced by policy (in a range of 0.02–0.07%). Another factor influencing electricity price is the level of electricity tax, but its effect is minor. Some important remarks are that an increase in the level of fossil fuel tax without an electricity tax in a WhC scheme can press towards reduction of electricity price. Overall, our analysis demonstrates that in a competitive market, price of electricity can be more sensitive in changes of company's own costs than policy variables. The study of Quirrion (2005) also confirms that, where electricity price rises despite policies applied since suppliers adapt their prices according to marginal cost pricing.

In Table 1 we present the influence of the above-mentioned parameters on the price of the WhC, on the price of electricity, and on the volume of WhC that is an inverse factor of realization of energy efficiency projects (less demand for certificates because obligations are achieved through projects). In terms of policy interaction, we identify that a carbon tax on fossil fuels on producers provides a better incentive for energy efficiency than a tax on sales to suppliers that cover policy costs with an increase of electricity market price. An increase of the level of the obligation under WhC or of the cost of electricity supply will reduce P_{WhC} and suppliers will prefer to purchase certificates than implementing projects. The magnitude of impacts of parameters depends on the values chosen and on the initial position of suppliers (i.e. if their actual behaviour deviates from full compliance with targets).[18]

4.4. Expected supplier's behaviour based on policy costs

An individual electricity supplier modifies his behaviour based on current and expected fluctuations of policy parameters, namely price of WhC, electricity and carbon taxes, and penalty for non-compliance. In principle, a tax can be a clearer sign for adapting market behaviour and long run energy efficiency investments than WhC, since suppliers are aware of a level of tax that remains stable in the short medium run, while price of WhC fluctuates depending on market forces and this can lock out sensible investments.[19] Due to the competitive position of a supplier in our model, he cannot affect the electricity price directly in the short term and therefore we consider it exogenously given.

In Table 2, we demonstrate possible variable scenarios in the short and long run and market response of electricity suppliers. A high price of WhC represents expensive energy efficiency actions (hence no more low hanging fruits) and leads to a disincentive for such actions, while a high price in the future signals the

[18] We have identified some threshold values in the model, which can act as restrictions, for instance very low prices of electricity result in negative WhC prices. In a follow up paper, we will incorporate the market of energy efficiency products and will make use of these restrictions.
[19] This could be a separate factor in the model but we disregard it at this stage of analysis.

Table 2
Supplier's responses to market signals

Prices	Short run	Long run (expected)
$P_{PEN} > P_{WhC} > t_S$	More electricity sold and less energy efficiency actions	Less electricity sold (uncertain) and more energy efficiency actions
$P_{PEN} > P_{WhC} > t_S$	Less electricity sold (uncertain) and more energy efficiency actions	More electricity sold and less energy efficiency actions
$P_{PEN} > P_{WhC} < t_F$	More electricity sold and less energy efficiency actions	Less electricity sold (uncertain) and more energy efficiency actions
$P_{PEN} > P_{WhC} = t_F$	Less electricity sold (uncertain) and more energy efficiency actions	More electricity sold and less energy efficiency actions
$P_{PEN} > P_{WhC} = t_S$	An added value of both policies is lost, uncertain outcome. Possible motivation for energy efficiency	An added value of both policies is lost, uncertain outcome
$P_{PEN} > P_{WhC} = t_F$	An added value of both policies is lost, uncertain outcome. Possible motivation for energy efficiency	An added value of both policies is lost, uncertain outcome. Supplier gains through price increase and selling of WhC (windfall profits danger)
$P_{PEN} \approx P_{WhC} \approx t_S$ or t_F	Less energy efficiency actions, penalty preferable	Less energy efficiency actions, penalty preferable

market that cheaper options are available and by acquiring WhC, they can be sold at high price in the long run, paying back current project costs. The opposite situation occurs when prices of WhC are low. A high electricity tax in the short run reduces the incentive of selling more electricity and leads to other market options (e.g. energy services), while a high tax in the future can press towards more electricity sales currently. Finally, a high carbon tax in the short run can have the same effects of an electricity tax, while a high tax in the future leads to uncertain behaviour, since suppliers are granted with more market options (e.g. purchasing cheaper imported electricity, shifting to energy services etc.). These effects can take place, under the precondition that taxes or prices of WhC cannot reach the level of the penalty. If this is the case then the above-mentioned trade offs shift and a disincentive of pursuing energy efficiency projects can arise, since suppliers might opt in paying the penalty.

5. Assessment of policy interactions

In this section, we evaluate interactions of electricity and carbon taxes and WhC for electricity suppliers in an integrated scheme, from a policy maker's perspective, as analyzed in Section 4.

Our evaluation is based on a list of criteria that refer to the triptych: energy, environment, and society (IPCC 2001, 2007; OECD 1997, 2001). We sort out six general categories, which consist of several specific criteria, based on a study by Oikonomou and Jepma (2006, 2007). These categories are in principle: effectiveness, efficiency, innovation process, impacts on society, and market effects.

The evaluation procedure takes place in the form of a baseline setting and an additional (positive or negative) impact of our combined policies. More specifically, baseline is determined as when WhC, carbon, and electricity taxes are stand alone measures and assessed according to the aforementioned criteria. An integrated scheme of WhC with electricity and carbon taxes is assessed on top of the baseline with the same criteria and the added value of the new scheme is demonstrated. Through this approach, assessment of an integrated scheme is conducted on the grounds of positive or negative effects for the achievement of various objectives (as represented by each criterion).

In this context, WhC, energy, and carbon taxes are initially assessed individually in Table 3. Their evaluation is based on results from several studies on general or specific case studies, where some similar criteria are also addressed. The bundle of studies consists of: (Alfsen et al., 1995; Birkelund et al., 1994; Bosello and Carraro, 2001; Bovenberg and Gurney, 2005; Boyd and Uri, 1991; Ekins and Barker, 2001; Heijdra and van der Horst, 2000; Hoeller and Coppel, 1992; Manne and Richels, 1993; Pearce, 2006; Pezzey, 2003; Quirrion, 2005; Speck, 1999; Zhang and Baranzini, 2004). In the last two columns of Table 3, both integrated schemes (WhC with electricity tax and WhC with carbon tax) are assessed on the grounds of our analysis with all assumptions made, given the absence of similar studies.

Table 3
Assessment of integrated schemes

	WhC	Electricity tax	Carbon tax	WhC/electricity tax	WhC/carbon tax
Effectiveness					
Reduction of GHG emissions	+	×	+	↑	↑
Security of supply	+	+	×	↑	↑
Dynamic effectiveness	+	×	+	↑	↑
Avoidance of negative effects (free riders, Baumol and rebound)	−	+	+	×	×
Efficiency					
Low compliance costs	+	−	−	↓	↓
Low transaction costs	−	×	×	↓	↓
Low administrative costs	−	−	−	↓	↓
Flexibility in exogenous changes	+	−	−	×	×
Innovation process					
Invention/innovation/diffusion of new technologies	×	×	+	×	↑
Diffusion of existing technologies	+	×	×	↑	↑
Impacts on society					
Equity and fairness for direct parties	+	?	?	?	?
Equity and fairness for indirect parties	?	−	×	↓	×
Employment	+	×	−	↑	×
Increase in environmental awareness	+	×	+	↑	↑
Political acceptability	×	−	−	↓	↓
Market effects					
Trading and business opportunities	+	×	+	↑	↑
Competition in energy market	×	×	−	×	↓
Competitiveness (prices)	+	×	−	↑	×

+, −, ×: Positive/negative/neutral impact on criterion. ↑, ↓: Strong positive/negative added value of integrated instruments.
?: Uncertain effect dependant on design. ↑, ↓: Minor positive/negative added value of integrated instruments.

5.1. Basic findings

According to our evaluation, both combined schemes present various positive and negative effects depending on their goals as expressed by criteria. Our results are generally in accordance with the outcome of the study of Quirrion (2005), where WhC are "interesting to reach a certain level of energy savings while limiting distributional effects, thus to limit oppositions to its implementation". In this study, WhC with taxation present an advantage concerning equity and acceptability.

In terms of effectiveness, in general a WhC/carbon tax scheme is slightly superior to a WhC/electricity tax especially on the grounds of reduction of GHG emissions and dynamic effectiveness, while less effective in guaranteeing security of energy supply. Achievement of various targets nevertheless can be ensured by both schemes in comparison to the case where these policy instruments are stand alone.

In terms of cost minimization, a WhC/carbon tax and WhC/electricity tax prove to be not equally highly efficient, given the extra costs incurred by administration and transactions in order to implement these policies. In this case however, uncertainties are quite high since the level of taxes with the design characteristics of schemes play a predominant role.

Innovation towards more energy efficient technologies can be enhanced through a WhC/carbon tax scheme given the extra incentives for such investments from market actors, while existing technologies can be easier diffused in both schemes in contrast to stand alone policies.

Both schemes can influence various impacts on society positively or negatively, given that uncertainties are quite high also in this case. We could estimate that equity and fairness for directly and indirectly affected market parties remains the same in both combined schemes, while they can both face a political opposition due to the mandatory character of taxation and energy efficiency obligations. Furthermore, increase in employment opportunities are present more in a WhC/electricity tax. A more certain outcome refers to the increase of environmental awareness, which is stimulated clearly more from a WhC/carbon tax.

Finally, both combined schemes generate in general positive market effects in terms of trading and business opportunities, competition in energy market and market competitiveness (as price stimulations of various technologies and energy sources). Especially for trading possibilities, a WhC/carbon tax can be highly significant, while for the process of market liberalization and competition both schemes do not present any added value according to our baseline.

6. Discussion and conclusions

In this paper we have analyzed interactions of two energy policy instruments, namely a WhC scheme as an innovative policy instrument for energy efficiency improvement and existing energy taxation. Due to the multiplicity of energy taxes, we confine ourselves to a tax on fossil fuels as an input for electricity production (carbon tax) and a tax on electricity sales (electricity tax). These policy instruments differ in terms of objectives and final impacts on the price of electricity. WhC are implemented recently in the UK, France and Italy, under various forms, and energy taxes in most EU countries, with different rates and rebates.

We examine the effect of these policy instruments in the electricity sector, focusing on electricity producers and suppliers in a competitive market. All other market parties (e.g. electricity end users) are considered exogenous to our analysis. Using microeconomic theory, we identify synergies between these market players and demonstrate the total effect on the electricity price when suppliers internalize the behaviour of producers in their profit maximization decisions. Our focus lays mainly on the parameters that influence final electricity price that electricity suppliers charge on the market.

The cases we have examined consist of electricity producers with and without a carbon tax, electricity suppliers with and without a sales tax, and with WhC obligations. In the second step, we present a parallel implementation of WhC for electricity suppliers with a carbon tax on electricity producers and a sales tax with WhC obligations to electricity suppliers. In all these cases, we present the differences in optimization behaviour of producers and suppliers and how the optimal decisions of electricity producers are incorporated in the decisions of electricity suppliers. Given also that WhC refer to undertaking of energy efficiency actions, we present possible tradeoffs in business strategies between reducing electricity supply costs and implementing energy saving projects. According to a general evaluation of a couple of cases of WhC with carbon and electricity taxes, various positive and negative effects of both schemes in terms of target achievement and efficiency are present, which can lead to an added value of such schemes in the policy mix, although uncertainties of outcomes are quite high.

A basic finding is that in a merit order several parameters can increase final electricity price when different policies are implemented: demand for electricity and electricity supply cost at a large scale and then follow the level of sales tax, level of obligation for energy saving, and price of WhC (representing the marginal costs of energy saving projects). Some parameters that influence positively the price of WhC are: price of electricity, level of demand, and the level of fuel tax, while negative impact is found on the level of obligation, supply cost, and the level of sales tax. Finally, energy savings (represented indirectly by quantities of WhC traded) are affected positively by the level of obligation, cost of electricity supply, and level of sales target, while negatively by the price of WhC, price of electricity, level of electricity demand, and the level of carbon tax. The magnitude of impacts of parameters depends on the values chosen and on the initial position of suppliers (i.e. if their actual behaviour deviates from full compliance with targets).

Acknowledgements

The authors would like to thank Paul Baudry and Magali Tarbe (EDF) for their valuable support in the early stages of this paper. Finally, a short preliminary version of this paper has been peer reviewed and published in the European Council for Energy Efficient Economy Summer Study 2007 'Saving Energy — Just do it'.

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