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Abstract

Effects of renewable support legislation on electricity prices have been analyzed with a plethora of models. However, these models neglect at least one of the following aspects which we take into account in our analysis: oligopolistic market behavior of dominant firms, emission trading, restricted electricity trade and production capacities, and effects on producer prices and firm profits. In this paper we use the electricity market model EMELIE and decompose the impact of the feed-in of renewable energy in Germany into two effects: a substitution effect triggered by the displacement of conventional sources and a permit price effect induced via the ETS. We find that the renewable support increases consumer prices slightly by 0.1 Eurocent/kWh, while the producer price decreases by 0.4 Eurocent/kWh. In addition, emissions from electricity generation in Germany are reduced by 32 Mt CO_2, but are hardly altered if we consider the European electricity sector in total. Finally, the profits of most firms are significantly reduced by the support policy unless the firms combine relatively carbon intensive production equipment with a loose connection to the German grid.

1 Introduction

Today, in most of the industrialized countries in the world, renewable energy is supported by policy schemes in order to bring this favorable option to the market. Major advantages attributed to renewable energies include their low carbon emissions and their sustainability when compared with fossil sources. Furthermore, renewable energy can enhance security of supply. But, with the exception of long established large hydro power, renewable energies come at a high price. The hope of the industrial policy makers are that the renewable energy technologies can break even once they are more developed and the external effects of CO_2 emissions are priced in. Therefore, in Germany – as in many other European countries – a so called feed-in tariff is granted to electricity from certain renewable energy technologies. Additionally, the European Emission Trading System (ETS) has been introduced and creates a price for carbon emissions. Both instruments act not independently of each other and the impact of this policy mix on the electricity prices are under discussion. Amundsen (2001) investigates the interaction of green certificates, which implement a certain renewable energy quota by a market system with the ETS in a partial equilibrium model, derives comparative static results and shows that trade in electricity matters for the effects of a tightening of the ETS on green certificate prices. Mordhorst (2001) develops a framework in which he analyzes effects of internationally tradable green certificates and interactions with an ETS. He finds that in the absence of an ETS, international trade in green certificates will be biased towards domestic capacity expansion if a national value is attributed to the induced emission reduction. In a similar three country model, Mordhorst (2003) analyzes the promotion of renewable energy usage by alternative instruments and derives results which suggest that renewable energy support schemes are questionable climate policy instruments when an ETS is present. He suspects that a coordinated policy would be more efficient, i.e. the ETS should be tightened if more renewable electricity is produced. Jensen and Skytte use static models for the analysis of the impact of green certificates on electricity prices (2002) and the combination of green certificates with an ETS when an emission and a renewable energy goal is simultaneously targeted (2003). They find that the effect of a simple green certificate market on electricity prices is ambiguous and that the optimal combination of instruments to reach two goals simultaneously depends on the cost structures. Recently, Rathmann (2007) used a model for the analysis of the support for renewable energy by the German feed-in tariff in order to show that it can reduce electricity prices for certain parameter values. Altogether, these models neglect at least one of the following aspects which we take into account in our analysis: oligopolistic market behavior of dominant firms, emission trading, restricted electricity trade and production capacities, and effects on producer prices and firm profits. We, therefore, apply a computable partial equilibrium model with strategic behavior of dominant firms which has been developed on the basis of the original model by Kemfert documented in Kemfert (2007). Following this model, a whole family of models has been applied, among others, to the analysis of behavioral assumptions and environmental impact, and of environmental impacts of demergers (Lise et al. 2006). Two major refinements of the latter model have been achieved for the present analysis. On the one hand, the model has been enlarged to cover the complete European electricity market while, on the other hand, the impact of the cross subsidy induced by the support for renewable energy has been implemented. In the next section, we introduce an algebraic formulation of the model which is followed by a description of the data concerning the transmission capacities between countries and the largest players on the electricity market in Europe: plant types as well as cost- and emission functions. In section three, we present results concerning producer and consumer prices, emissions and the profits of the largest fifteen firms in Europe with regard to installed capacity.

2 The Model

We model the European electricity industry consisting of n conventional electricity producers indexed i which in total form the set I. Each country r is member of the set of countries R. Each production level y^i of the firm i corresponds to a cost and emission level according to the following marginal cost and emission functions: $c_y^i\left(y^i\right)$ and $e_y^i\left(y^i\right)$. The production y^i of each firm is restricted by its installed capacity $\overline{y}^i$ and may be supplied to the home country r or to the foreign country $r*$ such that $y^i = \sum_{r\in R} s^{i,r}$. To put it differently, we assume that the supply of a firm is completely covered by its production. Furthermore, the total electricity export from the home country r to the foreign market $r*, Ex^{r,r*}$, depends on the price for transmission service and is restricted by the transmission restriction $\overline{Ex}^{r,r*}$ between the respective countries. We assume that the market for transmission service clears at the nonnegative price for transmission capacity $\tau^{r,r*}$ such that: $\overline{Ex}^{r,r*} \geq Ex^{r,r*}\left(\tau^{r,r*}\right)$ and $\tau^{r,r} = 0$ for transmission service inside a country. The permit price σ is determined on the emission market which is restricted by the total emission cap $\overline{E}$ and depends on the total demand for emission permits of the electricity sector $E(\sigma)$ and of the non electricity sectors that are included in the ETS: $E^{nely}(\sigma)$. Market clearing on the emission permit market results in $\overline{E} = E(\sigma) + E^{nely}(\sigma)$ and a nonnegative permit price that is set to zero if the market does not clear. The producer price of electricity in each country is denoted by P_S^r. The consumer price $P^r\left(Q^r\right)$ equals the sum of the producer price P_S^r for conventional production plus the average extra costs of the tariff $\varsigma : P^r\left(Q^r\right) = P_S^r + \left(\varsigma - P_S^r\right)\frac{Z^r}{Q^r}$, which yields after rearranging the producer price: $P_S^r = P^r\left(Q^r\right)\frac{Q^r}{S^r} - \varsigma\frac{Z^r}{S^r}$.

The problem of firm i can be stated as the following Lagrangian of the Kuhn-Tucker type:

$$L^i = \sum_{r\in R}\left(P^r\left(Q^r\right)\frac{Q^r}{S^r} - \varsigma^r\frac{Z^r}{S^r}\right)s^{i,r} - C^i\left(y^i\right) - \sigma E^i\left(y^i\right) + \kappa^i\left(\overline{y}^i - y^i\right) - \sum_{r*\neq r}\tau^{r,r*}s^{i,r*} \tag{1}$$

The first term on the right hand side of equation (1) sums up the revenues from supply in all countries, the second term accounts for the production costs, the third for costs of emission permits, and the fourth for the shadow price of the production capacity, while the last sum accounts for the transmission costs for the restricted supply in foreign countries. The optimality conditions to the problem can be summarized in the following way:

$$\frac{\partial L^i}{\partial s^{i,r}} \leq 0, \qquad s^{i,r} \geq 0\,, \qquad \frac{\partial L^i}{\partial s^{i,r}} s^{i,r} = 0\,,$$

$$\frac{\partial L^i}{\partial \kappa^i} \tfrac{\partial L^i}{\partial \kappa^i} \geq 0\,, \qquad \kappa^i \geq 0\,, \qquad \frac{\partial L^i}{\partial \kappa^i} \kappa^i = 0\,,$$

$$\forall r \in R, \forall i \in I$$

The main driver of the model is the derivative of the Lagrangian w.r.t. the supply of the firm in a certain region: $\frac{\partial L}{\partial s^{i,r}}$, which is dependent on the assumed market behavior. In our model we represent two behavioral assumptions attributed to -firms: price taking behavior of minor actors and strategic behavior of dominant firms à la Cournot, giving rise to a situation of imperfect competition. We start with the analytically simpler case of price taking behavior.

The derivative of the problem of the price taking firm w.r.t. supply can be written as:

$$\frac{\partial L^i}{\partial s^{i,r}} P^r\left(Q^r\right) + \left(P^r\left(Q^r\right) - \varsigma^r\right)\frac{Z^r}{Q^r} - C^i\left(y^i\right) - \sigma E^i\left(y^i\right) - \kappa^i - \tau^{r,r*} \tag{2}$$

Under Cournot behavior of the firms, the effect on the revenue caused by the choice of output is taken into account by the firms. If we write the residual demand elasticity[2] as $\in^r = \left| \frac{dQ^r}{dP^r} \frac{P_0^r}{Q_0^r} \right|$ and the regional market share of firm i: $\vartheta^{i,r}$, the derivative of the problem (1) w.r.t. the supply in a Nash equilibrium can be expressed as:

$$\begin{aligned}\frac{\partial L^i}{\partial s^{i,r}} = {} & P^r\left(Q^r\right) + \left(P^r\left(Q^r\right) - \varsigma^r\right)\frac{Z^r}{Q^r} - C^i\left(y^i\right) - \sigma E^i\left(y^i\right) - \kappa^i - \tau^{r,r*} \\ & - \vartheta^{i,r}\left(\left(P^{r*}\left(Q^{r*}\right) - \varsigma^{r*}\right)\frac{Z^r}{Q^r} + \frac{P^r\left(Q^r\right)}{\in^r}\right).\end{aligned} \tag{3}$$

If we compare the optimality conditions under the Cournot-Nash assumption with those of the price taking case, it is apparent that only a term which depends on the market share is added

---

[2] The residual demand elasticity refers to the demand elasticity after the supply of the price taking firms is subtracted.

in equation (3). This last term includes the Mark-up $\vartheta^{i,r}\frac{P^r(Q^r)}{\in^r}$, known from conventional oligopoly models, and a term induced by the feed-in tariff ς which reduces the mark-up if the feed-in tariff is greater then the market price $P^r : \vartheta^{i,r}\left(P^r\left(Q^r\right)-\varsigma^r\right)\frac{Z^r}{Q^r}$. The latter term results from the firms conjecture about a constant output of the rivals in the Nash-equilibrium with regard to a marginal change in own output. Consequently, the firm's burden on production induced by the feed-in tariff is diminished by an own,- hence total-, output increase. We can now represent the complete model with price taking behavior of minor actors and strategic behavior of dominant firms à la Cournot. Therefore, we introduce the binary variable l^i which is set to zero in the case of price taking firms and to 1 in the case of dominant firms. The combined optimality condition for price takers and strategic firms can be expressed as:

$$\frac{\partial L^i}{\partial s^{i,r}} = p^r\left(Q^r\right)+\left(P^r\left(Q^r\right)-\varsigma^r\right)\frac{Z^r}{Q^r}-C^i\left(y^i\right)-\sigma E^i\left(y^i\right)-\kappa^i-\tau^{r,r*}$$

$$-l^i\vartheta^{i,r}\left(\left(P^{r*}\left(Q^{r*}\right)-\varsigma^{r*}\right)\frac{Z^r}{Q^r}+\frac{P^r\left(Q^r\right)}{\in^r}\right). \qquad (4)$$

3 Data and Calibration

The model uses extensive data on the ownership and cost structure of the generation equipment of 25 countries connected to the European electricity grid. The relevant transmission capacities are estimated from ETSO's indicative net transfer capacities, while the reference demand and prices are taken from Eurostat. The permit demand of the non electricity sectors are derived from calculation with GTAP-E, Truong (2007). All quantities in the model refer to annual values, e.g. electric work per annum. The calibration is achieved by the choice of the residual demand elasticity as to replicate the reference values. In the following, the supply, demand and transmission side of the model are described in greater detail. The supply side of the model is represented by a bottom-up approach where generation capacities are characterized by the used energy carrier – dammed water, uranium, hard coal, lignite, natural gas and heavy oil – and, in case of the thermal power plants, the technology that is applied. Altogether the production capacity is represented by ten technology classes as shown in Table 1.

Table 1:
Technologies of the conventional power plants in the model

fuel type	plant type	efficiency	emissions factor [kg/kWhel]	variable cost [€-cent/kWhel]
uranium	small	0,32	0,00	0,66
	large	0,34	0,00	0,62
lignite	old	0,34	1,00	1,32
	new	0,43	0,89	1,05
hard coal	old	0,34	0,74	1,59
	new	0,43	0,68	1,26
natural gas	conventional	~0,38	~0,52	~2,76
	combined cycle	0,55	0,33	1,91
heavy oil	gas turbine	0,33	0,84	2,55
	steam turbine	0,38	0,73	2,21

Source: Own calculations based on expert communication.

Power plants that burn solid fossil fuels and nuclear power plants use steam turbines for electricity generation. These plants are classified into efficiency clusters ranging from 32 percent in the case of small nuclear power plants to 43 percent for comparatively new hard coal and lignite firing units. Natural gas and heavy oil are used in power plants equipped with gas turbines as well as steam turbines. The combination of both technologies – the so called combined cycle gas turbines (CC) – reach the highest efficiencies ranging from 52 to 59 percent with an average of about 55 percent. In accordance with these efficiency parameters the variable costs of the technologies range between 0,21 and 1,05 Eurocent/kWh and the specific emissions between 0 and 1 kg CO_2 per kWh as depicted in Table 1.

The simulation of strategic behavior demands a detailed assessment of the plant ownership structure of the dominant players. Therefore, a database has been constructed mainly on the basis of Glückauf (2006) and the research of annual reports. Table 2 summarizes the capacities that are available for the fifteen largest players and their major foreign subsidiaries based on a multiplicative calculation of effective shares in cases where several ownership layers are present. Subsequently, we calculated from these figures estimated continuous marginal costs and emissions functions for annual electricity supply of the dominant firms and the competitive fringe in each country. The marginal cost function of firm i is

$$C^i\left(y^i\right) = a^i \exp\left(b^i \frac{y^i}{\overline{y}^i}\right), \qquad (5)$$

Table 2:
Net capacities [GW] of the fifteen largest firms in Europe

[GWel]	Hydro	Nuclear	Coal	Gas & Oil	Total
EdF (Fr)	6,51	62,96	6,38	6,89	82,75
Enel (It)	2,43	0,00	8,48	22,18	33,09
E.ON (Ger)	1,51	7,64	11,25	5,35	25,75
RWE (Ger)	0,64	3,54	13,07	3,00	20,25
Endesa (Es)	1,95	2,63	6,76	5,97	17,32
International Power (GB)	0,00	0,00	12,16	4,96	17,11
E.ON (GB)	0,00	0,00	8,66	6,53	15,19
Vattenfall (Ger)	0,00	1,42	8,97	2,75	13,14
Vattenfall (S)	6,74	5,12	0,13	0,93	12,91
Iberdrola (ES)	3,78	1,73	0,67	5,84	12,02
British Energy (GB)	0,00	9,28	1,72	0,00	11,00
D.E.I. (Gr)	2,95	0,00	4,72	1,60	9,27
Suez (Be)	0,00	4,68	1,32	3,15	9,14
EnBW/EdF (Ger)	0,43	4,02	3,08	1,48	9,01
Statkraft (Nor)	7,69	0,00	0,00	0,00	7,69
EDP (Pt)	3,03	0,00	1,81	2,04	6,88
FNM (Cz)	0,47	2,34	3,89	0,05	6,75
BOT (Pl)	0,00	0,00	6,30	0,37	6,67

Source: Own calculations based on information from Glückauf (2006) and annual reports.

where $\overline{y}^i$ denotes the maximum annual generation of firm i in country r. The emission functions are closely linked to the production. Each production level of firm i yields in each period a unique level of marginal emissions. The marginal emissions function of firm i for production in country r is:

$$E^i\left(y^i\right) = f^i \exp\left(g^i \frac{y^i}{\overline{y}^i}\right). \tag{6}$$

The values for the parameters of the marginal cost and emission functions of the fifteen largest firms represented in the model are listed in Table 3. The transmission capacities between countries are calculated from ETSO (2006) net transfer capacities where summer and winter indicative values are equally weighted with half a year in order to receive maximum annual transfer capacities and are summarized in Table 4.

Table 3:
Parameters of the marginal cost and emission functions of the fifteen largest firms in Europe

	$\bar{y}$	a	b	f	g
EdF (Fr)	613,8	0,6	0,4	0,0	2,1
Enel (It)	242,3	1,8	0,0	0,6	0,1
E.ON (Ger)	188,7	1,3	0,2	0,5	0,2
RWE (Ger)	149,6	1,5	0,1	0,7	0,1
Endesa (Es)	126,3	1,5	0,1	0,5	0,2
International Power (GB)	124,3	1,8	0,0	0,8	0,1
E.ON (GB)	110,9	1,8	0,0	0,8	0,1
Vattenfall (Ger)	97,6	1,5	0,1	0,8	0,1
Vattenfall (S)	90,7	0,7	0,9	0,2	0,5
Iberdrola (ES)	86,4	1,1	0,3	0,2	0,6
British Energy (GB)	82,2	0,8	0,3	0,1	2,0
D.E.I. (Gr)	68,4	1,2	0,3	0,2	0,5
Suez (Be)	66,4	1,1	0,2	0,6	0,3
EnBW/EdF (Ger)	66,4	1,1	0,2	0,3	0,4
EDP (Pt)	50,0	0,9	0,0	0,4	0,4
FNM (Cz)	49,9	1,1	0,1	0,6	0,3
BOT (Pl)	49,3	1,5	0,0	1,0	0,0

Source: Own calculations.

The parameters of the demand side, reference demand and prices, are average electricity exchange[3] prices of the year 2006 or are taken from Eurostat (2006) where a fifty percent discount for transmission and distribution services inside the countries is applied to the Eurostat final consumer prices. For the calibration of the model the residual demand elasticity $\in^r$ of the inverse iso-elastic demand function $P^r\left(Q^r\right)=\left(Q^r\right)^{-\frac{1}{\in^r}}\frac{P_0^r}{Q_0^r}$ is chosen to replicate the benchmark values for prices and quantities in Germany under price taking behavior of minor actors and strategic behavior of dominant firms à la Cournot. The value for the residual demand elasticity found for a good replication of the benchmark under a assumed permit price of 20 Euro per ton of CO_2 has been 0.5.

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[3] Amsterdam Power Exchange (apx), Amsterdam; Powernext, Paris; European Energy Exchange (EEX), Leipzig; Mercado de Electricidad (OMEL), Madrid; NordPool, Oslo.

Table 4:
Transmission capacities [TWh/a] between countries

from\to	Ger	FR	AT	BE	Ch	Cz	DK	SE	Pl	NL	ES	FI	GB
Ger	inf	42,0	12,3		30,7	7,0	11,8	3,7	11,8	34,2			
FR	20,4	inf		17,7	28,8						11,4		17,5
AT	12,3		inf		10,5	4,8							
BE		23,0		inf						19,1			
Ch	35,0	20,1	11,8		inf								
Cz	16,9		8,8			inf			6,6				
DK	15,3						inf	19,2					
SE	4,9						16,4	inf	5,0			16,6	
Pl	9,6					15,6		1,3	inf				
NL	25,8			18,8						inf			
ES		6,6									inf		
FI								13,1				inf	
GB		0,4											inf
GR													
HU			5,9										
IT		22,1	1,8		25,9								
NO							8,8	29,3				0,6	
PT											6,1		
SK						7,0			5,8				
Si			5,1										
EE												2,8	
Lt													
Lv													
BG													
RO													

from\to	GR	HU	IT	NO	PT	SK	Si	EE	Lt	Lv	BG	RO
Ger												
FR			22,1									
AT		3,1	1,8				5,1					
BE												
Ch			25,9									
Cz						14,9						
DK				8,3								
SE				26,5								
Pl						5,9						
NL												
ES					8,0							
FI				0,9				2,8				
GB												
GR	inf		3,5								4,8	
HU		inf				3,5						4,4
IT	4,4		inf				3,4					
NO				inf								
PT					inf							
SK		9,1				inf						
Si			3,0				inf					
EE								inf		6,8		
Lt									inf	17,5		
Lv								8,8	17,5	inf		
BG	2,6										inf	7,0
RO		3,3									8,1	inf

Source: Own calculation on the basis of ETSO (2006).

Finally, on the market for emission permits, the total supply is fixed by the amount of permits that are allocated by the national authorities. As the model is calibrated on values of the year 2006, the allocation of the first trading period is broken down into annual allocation applies. We assume a total allocation for one year to be 2234 million tons of carbon dioxide.[4] The demand side of the emission market can be broken down into two parts, i.e. the demand of the electricity sector which is calculated directly by the EMELIE model, and the demand of the non-electricity emission trading sectors. The determination of the non-electricity permit demand simulations based on the GTAP-E model yielded the following permit demand of the non-electricity emission trading sector in dependence of the permit price σ:

$$E^{nely}(\sigma) = 1032 - 40.35\ln(\sigma), \qquad (7)$$

where the first term on the right hand side is the baseline emissions and the second term represents the permit supply curve of the non electricity sector.

4 Results

In the following paragraphs, three scenarios under oligopolistic behavior of dominant firms are presented. The baseline for 2006, Scenario A, includes a feed-in tariff of the current values for the year 2006, i.e. 10.3 Eurocent/kWh as in VDN (2006) and an amount of supported renewable electricity of 53 TWh as stated by BMU (2007).

Table 5:
Effects of the feed-in tariff on prices, supply and emissions

	electricity prices cent/kWh		permit price €/ton of CO_2	total supply TWh	electricity emissions Mt CO_2	
scenario	producer	consumer			Germany	Europe
A	4,3	4,8	20	582	302	1230
B	4,5	4,5	20	601	350	1280
C	4,7	4,7	23,1	585	335	1235

In scenario B, we fix the emission price at the level of scenario A and exclude the feed-in in order to decompose the isolated electricity market effect with no feed-back of permit prices. Finally, we calculated scenario C where no feed-in applies and, due to increased production in polluting plants, the permit price is significantly higher compared to scenario A. Table 5 pro-

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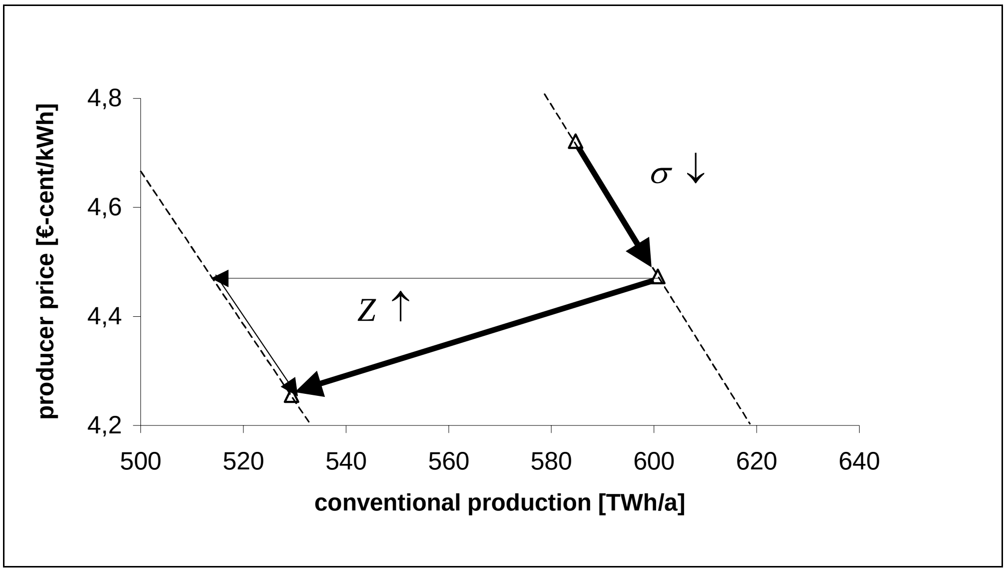
[4] The figure is in line with DEHST (2005) and the information on the internet page of the European Commission while taking the the opt-in reserve into account.

vides an overview of results. Apparently, the consumer price of electricity increases by only 0.1 Eurocent/kWh and consequently the total supply in Germany is reduced by only about 3 TWh. However, the price for emission permits is significantly reduced by the feed-in by about 3.1 Euro per ton and the producer price for electricity in Germany is also considerably lowered. Figure 1 demonstrates the results for the German producers price for electricity in greater detail.

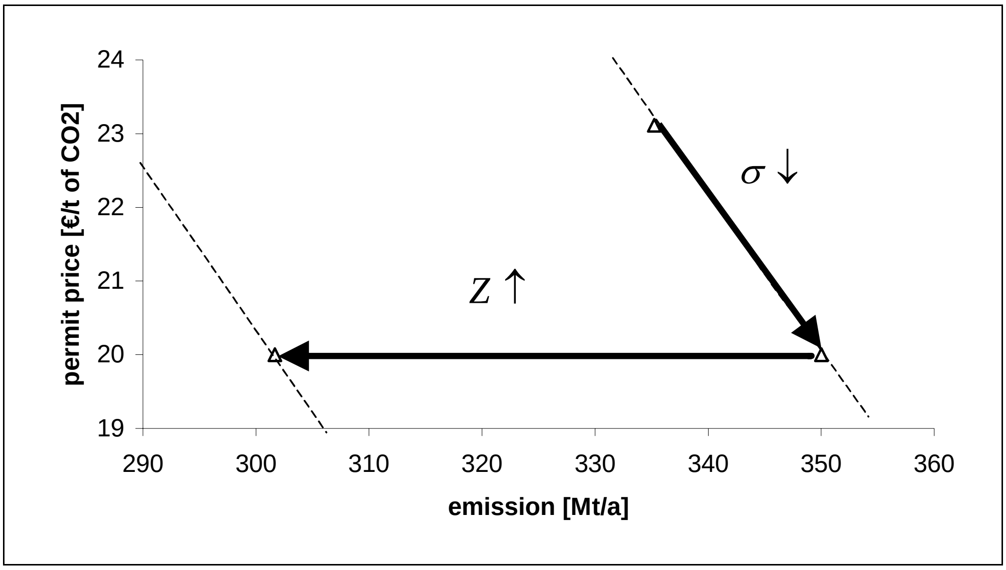
Figure 1:
Effect of the feed-in on the German producer price



When we move from point C, the situation with out the feed-in tariff, to point A which represents the current situation, we find a reduction of about 0.4 Eurocent/kWh induced by the feed-in tariff. As mentioned, the scenario choice facilitates the decomposition of the total effect into two separate effects. A first effect, triggered by the substitution of less expensive conventional sources by more expensive renewable energy, termed substitution effect in the following. And a second effect, the permit price effect, induced by the drop in permit prices σ. The substitution effect itself consists of two components:

- Substitution of conventional supply by renewable energy Z leading to a shift of the dotted demand for conventional electricity,
- Introduction of a gap between consumer and producer prices which corresponds with a downward move on the demand function for conventional electricity.

Figure 2:
Effect of the feed-in on German electricity sector emissions



In total, we find that both effects are negative and of the same size, i.e. -0.2 Eurocent/kWh each. This is a remarkable result since previous work mostly neglects this effect (Bode 2006).

In the remainder of the article, we analyze the impact of the feed-in tariff on emissions and profits of the electricity sector. In regard to emissions, the picture depends on the scope of the analysis. If we focus on Germany, the results are significantly larger than those we get for Europe. The overall effect essentially depends on the slope of the permit demand indicated with dotted lines in Figure 2 which shows both effects for Germany. In accordance with the substitution effect triggered by the introduction of renewable energy, the emission effect of the feed-in tariff under constant permit prices is clearly negative – the renewable energy is assumed to produce no emission – and of a size of about 48 Megatons of CO_2. This effect is partially compensated by the reduction of permit prices and the subsequent increase by about 15 Megatons of CO_2 such that the emission reduction in the German electricity sector is only about 33 Megatons of CO_2 in total. On the contrary, the total sectoral emission in Europe decreases by a mere 4 Megatons of CO_2. Here, the effect induced by the drop in permit prices of 27 Megatons of CO_2 almost compensates the effect that is due to substitution of dirty sources by renewable sources which sums up to 31 Megatons of CO_2.

Finally, we present the impact of the feed-in on the profit of producers listed in Table 6 below. In the profit column, the profit from the operation of the power plants are given in millions of Euro annually. It appears that in a liberalized market Eléctricité de France (EdF) clearly has the most profitable generation assets with an annual profit of almost 12 billion Euro followed by comparably large companies with low carbon assets like E.ON Germany and British Energy with about 3 and 2 billion Euro profit from plant operation respectively. These companies are followed by Dimosia Epicheirisi Ilektrismou (D.E.I) of Greece, the partly EdF controlled Energie Baden-Württemberg (EnBW) of Germany, Spain's Iberdrola and Germany's Rheinisch-Westfälisches Elektrizitätswerk AG (RWE) with roughly 1.8, 1.4, 1.4, and 1.2 billion Euro respectively. These leading companies are followed by companies that are either smaller or have a more costly production ranging from Italy's Ente Nazionale per l’Energia Elettrica (Enel) with one billion Euro profit to Polish Belchatow, Opole and Turow power plants (BOT) with a profit of only about 26 million Euro from plant operation.

The total effect on the profits of the largest firms that is caused by the German feed-in tariff can be detected from the last column in Table 6 and has again been separated into the two basic effects caused by substitution of sources and by the change in permit prices. We find that the firms are affected differently. On the one hand, firms incur negative or at best zero impacts on their profits due to the substitution effect. Here, the German firms are affected the most with losses of 126 million Euro for EnBW, 379 million Euro for Vattenfall Germany, 467 million Euro for RWE and 650 million Euro for E.ON Germany. At the same time, firms that are remote to the German market and loosely connected by the electricity grid are not affected by a substitution effect like the firms in Great Britain, Spain and Portugal. Contrarily, the permit price effects on firms are ambiguous. Clearly, firms with high emission factors like RWE, Vattenfall Germany, and Enel benefit the most from a drop in permit prices while firms with comparatively low CO_2 emissions like EdF, British Energy and E.ON are negatively impacted by the permit price decrease: Firms with low emissions lose some of their comparative advantage over dirty firms if the permit price decreases. In regard to the total effect, most of the firms are impacted negatively by the feed-in tariff with the exception of firms that are comparatively dirty or remotely located to the German market like Enel, E.ON Great Britain, Endesa or BOT.

Table 6:
Effects of the German feed-in tariff on European electricity sector profits [million Euro]

	profit		feed-in effect on profit		
Mio €	feed-in	no feed-in	substitution	permit price	total
EdF (Fr)	11794	11981	-57	-130	-187
E.ON (Ger)	2918	3596	-650	-27	-677
British Energy (GB)	2100	2204	0	-103	-103
D.E.I. (Gr)	1805	1838	-10	-23	-33
EnBW/Edf (Ger)	1435	1636	-126	-75	-201
Iberdrola (ES)	1381	1377	0	4	4
RWE (Ger)	1171	1527	-467	111	-356
Enel (It)	1046	961	-11	97	86
Vattenfall (S)	984	1006	-11	-12	-23
EDP (Pt)	941	923	0	18	18
Vattenfall (Ger)	748	1024	-379	102	-276
FNM (Cz)	449	498	-37	-12	-49
Endesa (Es)	356	310	0	46	46
Suez (Be)	120	115	-2	7	5
E.ON (GB)	88	60	0	27	27
Interational Power (GB)	49	26	0	23	23
BOT (Pl)	26	14	-9	20	11

5 Conclusions

We investigated effects of the German feed-in tariff with a bottom-up model for the electricity market of Europe and analyzed impacts on producer as well as consumer prices, electricity sector emissions in Germany and Europe as a whole, and on the firm's profits from plant operation. We found that, while the burden of the feed-in tariff per total output amounts to 0.5 cent per kilowatt hour, the consumer price is impacted only to a minor extend, i.e. plus 0.1 Eurocent per kilowatt hour, compared to the significant decrease in producer price of about 0.4 Eurocent per kilowatt hour. The producer price effect introduced by the feed-in can be separated into a substitution and a permit price effect of roughly equal size, i.e. -0.2 Eurocent per kilowatt hour, which emphasizes the importance of feed backs from the emission market. These feed backs also lead to a reduced impact on emissions in the electricity sector. While under constant emission prices, the emissions from the German electricity sector are reduced by about 48 mega tonnes of CO_2 due to the substitution of conventional energy, the permit price effect increases the German electricity market emissions by roughly 15 mega tonnes of CO_2 such that the total sectoral reduction in Germany amounts only to 34 mega tonnes of CO_2. Moreover, if we consider the whole European electricity sector emission, we find an insignificant decrease in emissions. Of course, the total emissions of the whole ETS sectors are not affected, which renders the renewable support ineffective regarding emission reduction if the overall emission cap is not adjusted. Finally we investigated the effects of the feed-in on the profits of firms and found a ambiguous effect. Two characteristics of the firms are crucial: the physical connection with the German market and the emission intensity. While the unambiguously negative substitution effect does not apply to firms that are not directly connected with the German electricity grid, the permit price effect is determined by the firms emission intensity. We find that firms that are only loosely connected with the German grid and have high emissions are likely to benefit from the German feed-in tariff. At the same time, firms with low emissions on or close to the German market suffer losses.

In light of the discussion in the literature, we cannot confirm a theoretically possible decrease in consumer prices by renewable energy support, even though the increase of German consumer prices is only of minor size. Moreover, in regard to effects on emissions, our findings are in line with the treatment of Mordhorst (2003) insofar as renewable energy induced emission reductions in one country will, in part, be compensated by increases in other countries. A concerted policy might, therefore, be suggested. In order to assess the problem of a optimal concerted action of emission policy and renewable support, the cost structure of the renewable energy sources has to be considered in future research.

Appendix: Notation

I	Set of firms
R	Set of regions
$P^r(Q^r)$	Inverse demand for electricity in country r
P_0^r	Consumer price of electricity in country r in the base period
P_S^r	Producer price of electricity in country r
σ	Emission permit price
Q^r	Electricity consumption in country r
Q_0^r	Electricity consumption in country r in the base period
$E(\sigma)$	Total emissions of the electricity sector
$E^{nely}(\sigma)$	Total emissions of the non electricity sector
$Ex^{r,r*}$	Export from country r to $r*$
y^i	Electricity production of firm i
Q^r	Total electricity supply in country r
$s^{i,r}$	Electricity supply of firm i in country r
S^r	Total electricity supply of firms in country r
Z^r	Renewable electricity production in country r
ς^r	Feed-in tariff in country r
$C^i(y^i)$	Marginal costs of electricity production of firm i with costs $C^i(y^i)$
$E^i(y^i)$	Marginal emissions of electricity production of firm i
$\overline{y}^i$	Capacity restriction of power plants of firm i
$\overline{Ex}^{r,r*}$	Transmission restriction from country r to $r*$
κ^i	Shadow price of capacity restriction of installed power plants of firm i in country r
$\tau^{r,r*}$	Shadow price of transmission capacity from country r to $r*$
$\in^r$	Residual demand elasticity
$\vartheta^{i,r}$	Market share of firm i in country r
l^i	Binary variable representing different behavioral assumptions with regard to firm i
a^i, b^i	Axis intercept and slope parameter of the marginal cost function of firm i
f^i, g^i	Axis intercept and slope parameter of the marginal emission function of firm i

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