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The European electricity and climate policy—complement or substitute?

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Abstract. The European electricity policy is intended to increase market competitiveness and liberalisation. The European climate policy is directed toward substantial reductions in greenhouse-gas emission and a significant increase in the use of renewable energy for electricity production. Both policies affect European utilities considerably. As a consequence, only those utilities that can produce electricity with cost-efficient and environment-friendly technologies will gain a comparative market advantage. The author investigates the impacts of the European energy and climate policy initiatives on the electricity market. It emerges that emissions trading leads to higher electricity prices and triggers a substitution process—from the use of coal to the use of gas and renewable technologies. Both policies have complementary effects, but only because the electricity market is not yet fully competitive.

Introduction

The energy policy initiative of liberalising electricity markets—that is, the introduction of competition, the reduction of external (particularly political) interferences and adjustments, and the opening of the market to new providers—is a worldwide phenomenon. Although the reasons for opening of markets vary from country to country, the main goal, apart from higher production efficiency, is to offer customers lower electricity prices.

Although only a few countries in the world have accomplished complete liberalisation, it can be observed that most countries aim for a completely open electricity market in the near future. In Europe all EU member states will have to liberalise their electricity markets according to the 1997 directive of the European Commission (Directive 96/92/EC). This directive provides that European electricity markets must have been opened up by an average of 25% in 1999.

However, this Directive has been translated into actual policy differently in different countries, and the progress of liberalisation of electricity markets in Europe varies between countries. In Germany the market was liberalised in 1999, by which time the markets in Norway, Sweden, and the United Kingdom were already completely open. Austria and Denmark have also liberalised their electricity markets almost completely (table 1), and Spain is aiming at an imminent opening of its market. France and Italy have not yet decided when they intend to open their markets to external competition; these two countries are characterised by having only a few electricity producers and, hence, a rather uncompetitive monopoly and/or duopoly (in France, EDF; in Italy, Elettrogen and Enel). This unequal distribution of market opening and liberalisation of the electricity markets in Europe has produced some competition distortions—some utilities already face competition, whereas others can continue to operate as a monopoly. Because utilities have to compete with each other after the opening of the market, in order to survive, providers need to alter their behaviour. In Germany, for example, utilities reacted very dynamically after the liberalisation of the electricity market in 1999 by firm mergers and strategic behaviour. A rise in the market shares of certain producers might lead to a somewhat uncompetitive market structure which will not

Table 1. Liberalisation of the electricity market in Europe in 2002 (source: Benchmark Report of the European Commission, see European Commission, 2003).

Country	Percentage liberalisation	Date of complete liberalisation	Main providers	Market share of the main providers (%)	Percentage of consumers who changed providers[a]
Austria	100	2003	EVN, Verbund, Wiener Stadtwerke	68	5–10
Belgium	35	2007	Electrabel	97	5–10
Denmark	90	2003	SK Power Company	75	na
Finland	100	1997	Fortrum, Ivo Group	54	30
France	30	discussion not ended	EDF	98	5–10
Germany	100	1999	E.On, EnBW, RWE, Vattenfall	63	10–20
Greece	30	not discussed	AEH (public company)	100	none
Ireland	97	2007	ESB	97	30
Italy	35	not discussed	Elettrogen, Enel	79	< 5
Luxemburg	50	2007	Cegetel	90	na
Netherlands	33	2003	Essent, Nea	64	10–20
Portugal	30	not discussed	EDP	85	< 5
Spain	45	2003	Endesa, Hidroelectrica del Cantabrico, Iberdrola Union Fenosa	79	< 5
Sweden	100	1998	Sydkraft, Vattenfall	77	na
United Kingdom	100	1998	British Energy, Innogy, Powergen, Scottish and Southern Energy, Scottish Power	44	80

[a] na—not available

reduce but, rather, increase electricity tariffs. Whether an electricity supplier is able to convert strategies in the electricity sector depends on the market situation, in particular on the dominant market conditions. Thus the market-entry conditions at the different levels of the current market—production, trade (and selling)—play a crucial role.

Furthermore, electricity-trading options can offer additional incentives for market power, unless there is a uniform price structure for tradable electricity. In Germany for example, a federation agreement regulates prices in the power market. However, it has been observed in the past that, because of strategic market behaviour, third-party provision of foreign electricity has been seriously delayed or refused. A regulation authority will soon observe these effects and regulate prices. In its second benchmark report, the European Commission recognised that distortions of competition and market power can arise through strategic behaviour of utilities: for example, through excessive net access fees, which obstruct the entrance of new providers. The different degrees of market opening diminish the advantages for the consumer. Therefore, future European electricity policy will try to decrease market distortions and harmonise market-opening processes in all European countries.

The European climate policy has one main intention: to reduce greenhouse-gas emissions. Two main policy directives are important in this context: the implementation of the European emissions-trading system (first planning phase from 2005 until

2007; the real phase starts in 2008 and lasts until 2012) and the directive to increase the share of renewable energy used in electricity production. For electricity providers this means that they have to produce electricity both cost-effectively and in an environmentally friendly manner. My main aim in this paper is to evaluate European energy and climate policy. I investigate whether the energy and climate policies have a harmonised effect on the European electricity market, and whether they provide incentives for contrary developments.

EMELIE (Electricity Market Liberalisation In Europe), a game-theoretic model, was applied to the European electricity market.(1) EMELIE was calibrated to the main European energy suppliers, which are linked by capital flows. The main aim was to assess whether the European energy policy of liberalisation of the electricity market, and the European climate policy of an emissions-trading system, can have complementary effects. More precisely, the effect of the European liberalisation process on European utilities was investigated. Those utilities also have to reach an emissions-reduction target set by European climate policy law in order to implement an emissions-trading system.

The paper is organised as follows: the current situation of the European climate policy and the European electricity policy and market are described in the second and third sections, respectively. The EMELIE applied game-theoretic modelling tool is then briefly described. In the fifth section the modelling results are reported and explained. A detailed mathematical description of the model is provided in the appendix.

The European climate policy

European climate policy is dominated by two main challenges: the European emissions-trading system and policies to increase renewable energy (European Commission, 2001). Europe has reacted to the challenges of climate change by establishing a European-wide emissions-trading system. In the first phase, from 2005 until 2007, all twenty-five European countries will be able to trade CO_2 emission allowances (European Commission, 2003). The idea of emissions trading is very attractive: to reach the overall emissions goal at minimal economic cost. However, the success of such a system depends critically on its design, organisation, and the monitoring process. The European Parliament and Council decided that each member state should be allocated initial allowances based on its National Allocation Plan (NAP). Up to now, only some European countries, including Germany, have notified their NAP to the European Commission. The German NAP may undermine the effectiveness of the European trading system for two reasons: first, only grant emitters are affected; and second, the past is counted as (past) early actions with no concrete proof as to whether these initiatives were made in order to reach concrete emissions-reduction targets being offered. The European Commission has recently criticised this and asked Germany to change this procedure.

The European Commission (1997) has issued a white paper supporting the increased use of renewable energy for electricity production. The share of renewable energy in electricity production should reach 12% by 2010, and the individual European countries have committed to concrete targets of renewable-energy contribution up to 2010 for electricity production. In order to reach their targets, different countries apply different policy tools. Belgium, Spain, France, and Portugal support a feed-in tariff (similar to Germany) to compensate the higher costs of electricity produced from renewable sources.

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(1) A first version of EMELIE was applied to a study of economic impacts of the German and European electricity market (Lise et al, forthcoming). The first application to the European market is given by Kemfert (2004).

Other countries, like Finland, the Netherlands, and Sweden, support tax relaxations to provide incentives for electricity production through renewable resources. A quota system regulates the share of renewable energy for electricity production; licences can be traded in a similar way to the emissions-trading system. Such a system is favoured by Austria, Italy, and Britain. Germany has implemented a renewable energy law (EEG),(2) which specifies the share of renewable energy and supports electricity production by renewable energy through concrete feed-in tariffs. The share of electricity produced from renewable energy should be increased by 20% by 2020, and by 50% by 2050.

The European electricity policy

The European electricity policy is characterised by the intention to open and liberalise the electricity market in all European countries. As the benchmark report of the European Commission of March 2003 testifies, the European electricity market can be characterised by increased market opening, improvements in the unbundling of net owners, and more transparent regulation methods (European Commission, 2003). Whereas Italy and the United Kingdom have seen electricity prices reduced for large consumers, Austria, Germany, and the Netherlands have seen increasing activities of customers. However, as not all countries have liberalised their electricity markets completely, some unsolved difficulties still remain, such as the degree of unbundling, increased market shares of dominant utilities in some European countries, and the lack of infrastructure in the intercountry electricity trade.

Because the market conditions for the current providers are still very different in the individual countries in Europe, there is as yet no clear trend to be seen in the development of the electricity market. In Germany the liberalisation of the electricity market first led to lowered electricity tariffs, particularly for the main customers, because of increased competition; the prices were reduced for private customers first. However so far, only a few private customers in Germany have changed providers (see table 1): therefore, for the private consumer in Germany the electricity tariffs rose once again. In contrast, in England private customers changed providers frequently because of large variations in electricity tariffs.

Because of various developments of the electricity market in individual European countries and the additional competitive pressure on particular providers, strong strategic behaviour on the part of individual providers is increasing. Mergers of large power suppliers in Germany reduced and obstructed competition, as this reduced access to a free decentralised market for small electricity providers. Although France has opened its electricity market, EDF, the largest French provider, still dominates the electricity supply in France and is increasingly important in Europe also. Because this nationally controlled giant pursued a strong policy of expansion overseas, it is very difficult for existing European providers to expand into the French market. Therefore, the European Commission has already demanded extra time to regulate the European market as uniformly as possible and to decrease market power by an independent adjustment authority.

Newberry (2002; 2002a; 2002b) studied potentials and opportunities for European utilities in a liberalised market. Day and Bunn (2001) investigated these aspects via a game-theoretic model of market power and strategic actions of firms in the United Kingdom. Bower and Bunn (2000) assessed trade opportunities within a pool versus a bilateral trade system in the UK electricity market. Amundsen and Bergman (2002) studied these issues for the Norwegian and Swedish power market, where transmission

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(2) Law to support renewable energy, German: Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare Energien-Gesetz-EEG) of March 2000.

and transport pricing plays a crucial role. Mansur (2004) studied the impacts of the US environmental regulation and electricity restructuring in an oligopolistic market: he found that in an oligopolistic market a tradable-permit system leads to less decline in welfare than does a pollution tax. Sartzetakis (1997) investigated an emissions-trading system in an imperfect competitive market; he found that, if emissions permits are correctly allocated and firms have positive abatement costs, emissions-permit trading leads to less welfare decline than if trading were not allowed. Nagurney and Dhanda (2000) elaborated an algorithm to allocate emissions permits in the presence of transaction costs in oligopolistic markets. Experiences in Scandinavia and the United Kingdom suggest that a uniform tariff is preferable to distance-related charges. Moreover, market opportunities and grid owners significantly influence trade. Dawson and Shuttleworth (1997) studied transmission pricing in Norway and Sweden, and Green (1997) examined this for the United Kingdom. Cardell et al (1997) investigated the negative effects of market power and transmission constraints on trading in an imperfect-competition model for North American electricity suppliers.

Diverse authors have examined different noncooperative games within various markets. Murphy et al (1982) demonstrated how mathematical programming approaches can be used to determine oligopolistic market equilibria. Salant and Shaffer (1999) illustrated the theoretical impacts on production and social welfare via two-stage Cournot – Nash equilibrium solutions, where learning by doing and investments in research and development (R&D) determine the marginal costs of identical agents differently. Jing-Yuan and Smeers (1999) have modelled an oligopolistic European electricity market with a sophisticated game-theoretic model calculating the Nash equilibria. More generally, Helman et al (1999) investigated different kinds of trade options and strategic price setting within the electricity market. Stern (1998) investigated the liberalisation of the European gas market. Hauch (2004) studied the impacts of electricity-market liberalisation and the emissions-reduction target for the Nordic countries.

Bower et al (2001) simulated the liberalised German electricity market via an agent-based model, and conclude that mergers increase market power, increasing the electricity prices. Their model is very sensitive to the phasing out of expensive oil-fired plants, nuclear energy, and to closing the borders to imports of (cheap) electricity: in all these instances, prices jump considerably. Bigano and Proost (2002) conducted a study of four countries (France, Germany, Belgium, the Netherlands) that are linked through electricity trade; a three-stage game was calculated in a partial equilibrium framework and the environmental impacts were quantified. They compared strategic action with perfect competition and concluded that phasing out nuclear energy leads to a substantial decrease in social welfare. In a liberalised electricity market, electricity suppliers can act strategically, which influences electricity prices, because of market shares changing in favour of large firms. Furthermore, mergers can become attractive as they increase the price of electricity and hence profits. While enhancing competition in the electricity market, strategic behaviour also determines the structure of the market and energy-supply network (see also Kemfert, 1999; 2004).

The applied modelling approach

I apply a similar approach to those of Newberry (2002a), Jing-Yuan and Smeers (1999), and Bigano and Proost (2002). I investigated market developments in seven European countries by use of the game-theoretic model EMELIE. EMELIE can be classified as a computational game-theoretic modelling tool that investigates strategic behaviour by firms within the fully liberalised European electricity market. In the first and last stages of the game, electricity suppliers play a Cournot – Nash game, optimising their profits under cost constraints and demand restrictions. Demand is represented by an inverse demand function, which is continuously differentiable twice. In the second stage of the game, firms maximise their profits in light of the strategic production behaviour of other actors. Electricity production is determined by variable production costs. Electricity can be traded—depending on capacity constraints, maximum net power, net access costs, and transport costs. Market shares (which may change with mergers or cooperatives) play an important role. In the oligopolistic market structure market shares and powers can influence prices, and prices are also influenced by the price elasticities of demand. An oligopolistic market structure is characterised by a mutual influence of market shares and power on prices. In the Nash equilibrium, to optimise their profits electricity firms react strategically by enlarging their market shares, thus influencing prices and demand. A Nash equilibrium is reached by the selection of each player's optimal strategic action considering the strategic behaviour of all other market actors. In a full-competition case, each agent reacts as a price taker—equalising prices and marginal costs to determine and optimise the firms' profits. We assume that there is no strategic behaviour in the emission-permit allocation. Various authors have studied the impacts of nonoptimal permit allocation on firm's decisions and output (for example, Carraro et al, 1996; van Engteren and Weber, 1996; Hahn, 1984; Sartzetakis, 2004). Although several authors find that permit allocation crucially affects marginal abatement costs, in this study an optimal permit allocation, such that no firm faces gains or additional losses, is assumed. It is assumed that the initial permit allocation is profit-neutral.(3) Firms face higher marginal abatement costs if high-emissions technologies dominate their technology portfolio. Emission targets determine permit prices at different levels. Although an emissions-trading system affects not only marginal costs but also the gains of each firms (as, for example, pointed out by Sartzetakis, 2004), this aspect is not included in this analysis.(4) A mathematical description of the model is given in the appendix.

The model was calibrated by providing the retail electricity price and the actual demand in a particular base year. For this paper, the year 2000 was taken as the base year. In the calibration of the model, production costs are minimised to see whether it is possible to meet the required demand. Below, the results from this calibration are referred to as the reference case (REF). In the first case the assumptions of the perfectly competitive market are used: that is, that firms are price takers and act as if they cannot influence the market price. This case is referred to as the perfect-competition case—COMP. The perfectly competitive outcome is equivalent to Bertrand oligopoly competition; that is, when firms set prices taking the actions of the other firms into account.

In contrast to the perfectly competitive situation, in the second case producers are assumed to act strategically. Each player decides on a production quantity taking the strategic choices of the other players into account. This is the Cournot–Nash oligopoly model, which is characterised by mutual strategic reactions by market players. This result leads to a Nash equilibrium, in which the strategies of all market actors are the best responses to the actions of all other market players. However, a so-called 'competitive fringe', consisting of the total sum of small, decentralised production units has been included, and this fringe is assumed always to behave as a price taker. Firms behaving strategically can influence prices by changing their production. I refer to this as the 'STRA' case.

(3) As the European Commission has decided to grandfather emissions permits, it is very likely that firms will gain high windfall profits. This aspect is not addressed in this analysis.

(4) The economic gains and losses of an European trading system are studied with a CGE model, see Kemfert et al (2005).

Table 2. Electricity production capacities in 2000 in TW per year.

Source	Denmark		Finland		France		Germany		Netherlands		Norway		Sweden	
	N	I	N	I	N	I	N	I	N	I	N	I	N	I
Nuclear	0	9.2	21.3	16.7	403.6	23.8	167.9	35.6	3.8	5.4		9.1	68.1	3.5
Coal	16.8	2.6	16.0		88.8	13.1	178.9	26.8	34.6			3.9		17.3
Lignite		1.5				2.4	99.3							0.4
Gas		2.7	6.3	0.4	13.2	18.5	157.7	10.2	61.2			0.5		1.5
Oil		2.8	8.7	1.8	85.6	10.3	64.1	3.5	8.5			2.5	22.8	1.4
CHP – G[a]	8.6	0.2	8.1	0.06		0.2	10.2	3.5	39.8			2.1	0.6	5.8
CHP – C	7.1	1.0	6.6	0.2		1.3	52.1	2.9				2.0	2.5	5.0
CHP – O		0.3	0.7	0.3		0.06	2.6	0.07				0.4	2.9	0.1
CHP – B		0.2	4.7	0.2				0.05	5.4			0.3	2.1	0.6
CHP – X		1.0	6.5	0.4	29.9	0.8	32.9	1.2			0.9	0.6	4.5	1.1
Hydro	0.03	15.7	12.5	6.8	72.6	38.9	37.4	33.9	0.3	22.1	142.3	8.2	64.4	23.1
Wind	4.4	0.06	0.08	0.05	0.2	0.02	0.7	1.8	1.9		0.03	1.1	0.5	2.4
Total	37.0	37.3	91.4	27.0	693.9	109.5	803.6	119.6	155.7	27.5	143.2	30.7	168.5	62.2

Notes: N—total domestic capacity, I—import capacity.
[a] CHP—combined heat and power.

The production of electricity depends on the production activities of other producers, the demand, and available production technologies and capacities. In addition to the main utilities of each country, the large numbers of small, decentralised production units are taken into account as a competitive fringe. As their sizes are small, these companies always acts as price takers in the model.

The demand for electricity varies with price changes. The model considers a one-stage game, and distinction is made between peak and load production activities. The model takes into account twelve different production methods: table 2 illustrates the different production capacities of each individual country. Conventional thermal power technologies—nuclear (N), coal (C), gas (G), lignite (L), and oil (O)—are applied. Furthermore, five different types of combined heat and power production (CHP) technologies are taken into account: gas (CHP – G), coal (CHP – C), oil (CHP – O), biomass (CHP – B), and other fuels (CHP – X). Finally, renewable energy technologies are included as hydro (H) and wind power (W). The EMELIE model was calibrated by considering data for the benchmark year 2000; production capacities of the largest producers; variable production costs for different technologies; transmission capacities between countries; and the wholesale market price and demand data. The following European countries were considered: Denmark, Finland, France, Germany, the Netherlands, Norway, and Sweden.

Impacts of the European electricity and climate policies

The European emissions-trading system was examined by simulating the impacts and reactions of European utilities if a permit price increases. The permit price changes the variable production cost of each production technology.(5) The higher the emission price, the greater the increase in variable production costs (see figure 1). Both scenarios lead to substantial electricity-price changes. In the reference scenario (no emissions trading), the real reference price is far higher than the simulation results assuming

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(5) Here, a solution for 2012, which allows time for the allowance prices to have their effect is considered.

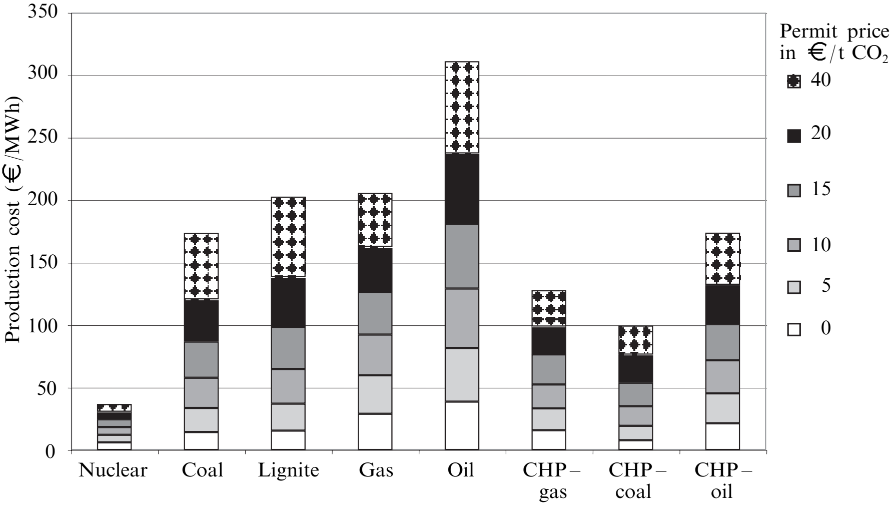

Figure 1. Variable production costs of different technologies with increasing permit price.

Table 3. Electricity prices in € per MWh with different emission prices in two different scenarios: full competition (COMP) and oligopoly (STRA).

Country	Real 2000	Emission price									
		0		5		10		20		40	
		COMP	STRA	COMP	STRA	COMP	STRA	COMP	STRA	COMP	STRA
Belgium	39.65	15.38	22.29	15.79	25.32	16.22	27.98	17.96	34.63	21.19	42.55
Denmark	17.41	15.26	17.17	15.79	18.77	15.73	20.14	17.37	23.13	20.60	23.57
Finland	14.88	15.23	16.70	15.72	18.32	15.64	19.69	17.28	22.36	20.51	23.12
France	20.81	15.38	20.54	15.79	23.55	16.22	25.66	17.96	29.96	21.19	34.2
Germany	15.19	15.38	19.38	15.79	22.81	16.22	25.79	17.96	30.02	21.19	35.49
Holland	39.65	15.38	22.88	15.79	26.75	16.22	29.68	17.96	35.05	21.19	43.09
Norway	12.25	15.38	17.62	15.79	20.26	16.22	21.29	17.96	24.59	21.19	26.95
Sweden	14.26	16.46	18.80	16.73	21.44	17.17	22.47	18.91	24.77	22.37	28.13

Table 4. Regional demand, in TWh per year, under different scenarios: full competition (COMP) and oligopoly (STRA).

Country	Emissions-permit price									
	0		5		10		20		40	
	COMP	STRA	COMP	STRA	COMP	STRA	COMP	STRA	COMP	STRA
Belgium	107.58	106.6	100.7	101.2	98.47	96.54	97.42	87.01	96.23	78.58
Denmark	15.05	32.61	11.66	31.83	12.28	31.01	17.81	29.13	12.28	28.75
Finland	55.26	70.95	50.4	68.36	50.91	66.01	49.23	61.61	48.25	60.19
France	451.81	412.64	433.42	389.67	424.85	373.68	412.98	344.69	411.25	323.04
Germany	449.29	421.57	431.38	393.09	423.85	371.04	411.9	342.75	401.84	317.24
Holland	121.96	123.56	116.13	117.56	114.56	113.66	116.64	106.72	114.56	99.16
Norway	79.62	92.54	74.02	86.96	73.28	84.8	75.5	79.11	73.28	75.71
Sweden	104.82	116.04	98.04	109.6	97.55	106.83	98.98	99.68	97.55	95.4
Average	173	172	164	162	162	155	160	144	157	135

Table 5. Firm payoffs in € millions in different scenarios: full competition—COMP, and oligopoly—STRA, and with different emissions-permit prices.

Firm	Emissions-permit price (€/t CO_2)									
	0		5		10		20		40	
	COMP	STRA	COMP	STRA	COMP	STRA	COMP	STRA	COMP	STRA
FrinBEL	−540.8	74.6	−177.1	82.2	−291	94.3	7.3	110.7	−213.1	136.8
ElectBEL	−403	706.4	−177.6	797.4	−216	875.7	−75.8	1 087.3	−30.9	1 370.9
FrinDEN	−448.6	171.2	−110.8	220.1	−149.9	257.3	−148.5	324.9	−260.7	396.8
Elsam	−487.7	176.7	−182.1	145.6	−262.3	117.8	−230.1	117.1	−525.9	111.1
E2Energi	−194.8	129.8	−104.9	107.9	−438.8	76.1	−340.4	69.2	−415	55.9
FrinFIN	−434.8	276	−336.5	320.3	−361.8	338.7	−495.3	423.7	−342.9	491.6
Fortrum	−399.9	319.8	−471.3	356.3	−275.6	379.4	−541	469.7	−2 571.1	552.1
PVO	−531.7	156	−581.5	178.8	−482.6	185.5	−555.5	228.3	−465	271.6
FrinFRA	−163.5	371.6	−410.5	407.9	−151.6	427.5	−253	570.6	35.4	703.8
EDF	4 674.2	5 309.7	3 732.2	6 269.2	4 002.7	7 166.1	4 146	8 693.4	5 210	10 265.6
EONGER	52.7	1 194.9	178.4	1 365.5	323.5	1 519.1	426.7	1 764.8	597.3	1 875
EnBW	−60.5	896.2	−97.3	830.4	−52.9	830.6	122.3	903.1	261.5	916.7
RWE	−271.8	502.3	−150.4	524.8	−95.1	567	−1.1	663.1	132.2	730
VattenGER	160.1	1 285.2	189	1 338.3	231.2	1 418.4	312.5	1 582.3	514.9	1 623.3
FrinHOL	−485	266.7	−291.5	331.6	−311.1	369	−358.2	471.1	−192	517.8
ElectHOL	−580.6	35.2	−358.9	27.8	−606.7	23.6	−219.9	32.2	−135.7	20.7
NUON	−562	80.9	−349.2	84.9	−287.9	86.1	−209.4	110.1	−110.6	105.8
EONHOL	−577.1	38.3	−358.2	25.5	−302.8	16.5	−222.3	17.9	−135.5	12.1
Essent	−560.2	120.7	−332.8	125.5	−275.5	123.5	−192.1	157.1	−93.5	166.9
FrinNOR	327.7	1 507.5	385.6	1 736.1	413	1 826.5	387.8	2 115.3	1 282.7	2 143.3
Statkraft	142	693.6	251.1	783.5	232.4	833.2	416.5	965.7	567.6	976.7
FrinSWE	−238.9	381.6	−119.5	454.3	−93	520.8	25.8	618.1	173.5	642.3
VattenSWE	688.3	1 217.6	318.1	1 454.6	557.2	1 653.8	379.5	1 967.8	769.8	2 061.1
Sydkraft	77.4	444.3	8	534.8	79	615.8	−13.5	739.2	61.2	775.5
Birka	7	345.4	−146	406.2	0.3	460.7	−93.7	539.6	−31.7	558.2

perfect competition both in Belgium and in Holland. The perfect-competition scenario means that all firms produce at a marginal cost. Full competition does not allow for any strategic behaviour that could influence the electricity price (table 3). Full competition leads to similar low prices within most countries. Only in Germany does the real electricity price reflect a fully competitive situation. The oligopolistic scenario allows for strategic actions of utilities that increase the electricity price. But even in this scenario (STRA), the electricity prices in Belgium and the Netherlands were less than the real electricity price in 2000. Along with increasing prices, demand is also decreasing (table 4). As most of the firms face higher marginal production costs than reflected by the simulated electricity price of the competition scenario (COMP), profits fall. Only EDF and Vattenfall Sweden/Germany can gain from the fully competitive situation, because of both the high share of nuclear power and the low production costs. The oligopolistic market situation leads to higher electricity prices, and hence all firms can increase their gains and profits (table 5).

With increasing emissions-permit prices, electricity prices increase as well. Again, the electricity prices are even higher if an oligopolistic market situation is assumed. The increasing emissions-certificate prices make technologies that produce more emissions more expensive (figure 1). Coal-powered plants produce the greatest emissions, followed by oil and gas. France is characterised by a high share of nuclear power, with low variable production costs. Germany still has a high share of coal power, but also nuclear and renewable power. Companies with a high share of coal power, like RWE, lose gains within a fully competitive situation as well as in an emissions-trading market. Belgium produces electricity by both coal-fired and nuclear power plants. In the overall European electricity-market simulation, emissions trading leads to a substitution of coal technology both by gas and by CHP (figure 2); Germany increases imports from France and Sweden with increasing emissions-permit prices, but also increases its electricity exports both to Holland and to Denmark (table 6).

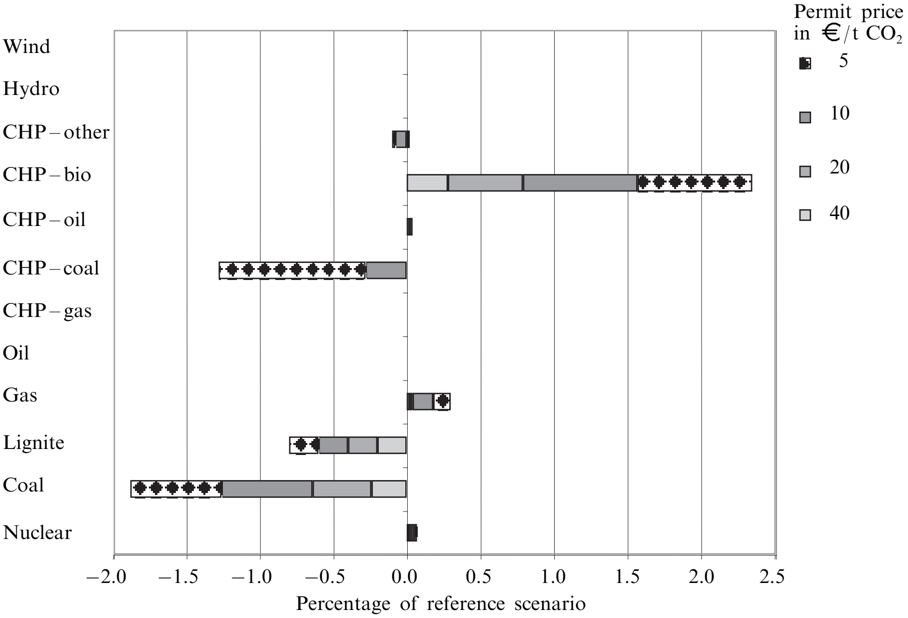

Figure 2. Technology-share changes compared with the reference scenario, with different permit prices.

Table 6. Trade impacts of different emissions-permit prices (in € per tonne of CO_2).

	Belgium	Denmark	Finland	France	Germany	Holland	Norway	Sweden	All
Emissions-permit price = 0									
Belgium	0	0	0	5.1608	0	−1.4091	0	0	3.752
Denmark	0	0	0	0	−3.5752	0	0.2972	0.7002	−2.578
Finland	0	0	0	0	0	0	−0.125	−0.798	−0.923
France	−5.1608	0	0	0	−5.2371	0	0	0	−10.398
Germany	0	3.5752	0	5.2371	0	−2.3887	0	10.284	16.708
Holland	1.4091	0	0	0	2.3877	0	0	0	3.797
Norway	0	−0.2972	0.125	0	0	0	0	−4.4124	−4.585
Sweden	0	−0.7002	0.798	0	−10.284	0	4.4124	0	−5.774
Emissions-permit price = 10 €/t CO_2									
Belgium	0	0	0	5.2811	0	−1.8169	0	0	3.464
Denmark	0	0	0	0	−1.2085	0	0.2601	0.3558	−0.593
Finland	0	0	0	0	0	0	−0.0144	−0.8189	−0.833
France	−5.2811	0	0	0	−6.4438	0	0	0	−11.725
Germany	0	1.2085	0	6.4438	0	−3.9028	0	11.0004	14.750
Holland	1.8169	0	0	0	3.9028	0	0	0	5.720
Norway	0	−0.2601	0.0144	0	0	0	0	−4.5093	−4.755
Sweden	0	−0.4943	0.8189	0	−11.0004	0	4.5093	0	−6.167
Emissions-permit price = 20 €/t CO_2									
Belgium	0	0	0	4.409	0	−1.5562	0	0	2.853
Denmark	0	0	0	0	−1.3469	0	0.2082	0.05027	−1.088
Finland	0	0	0	0	0	0	−0.3575	−0.5009	−0.858
France	−4.409	0	0	0	−5.863	0	0	0	−10.272
Germany	0	1.3469	0	5.863	0	−4.2317	0	11.2336	14.212
Holland	1.5562	0	0	0	4.2317	0	0	0	5.788
Norway	0	−0.2082	0.3575	0	0	0	0	−5.048	−4.899
Sweden	0	−0.5027	0.5009	0	−11.2336	0	5.048	0	−6.187
Emissions-permit price = 40 €/t CO_2									
Belgium	0	0	0	3.7717	0	−1.3848	0	0	2.387
Denmark	0	0	0	0	−0.5288	0	0.2986	0.451	0.221
Finland	0	0	0	0	0	0	−0.2677	−0.2493	−0.517
France	−3.7717	0	0	0	−8.9203	0	0	0	−12.692
Germany	0	0.5288	0	8.9203	0	−4.3827	0	11.827	16.893
Holland	1.3848	0	0	0	4.3827	0	0	0	5.768
Norway	0	−0.2986	0.2677	0	0	0	0	−5.2327	−5.264
Sweden	0	−0.451	0.2493	0	−11.872	0	5.2327	0	−6.841

Conclusions

The European electricity policy intends a liberalisation of the European electricity market. Model simulations confirm that the liberalisation process leads to a situation of increased competition. However, because of firm mergers the current market can be classified as an oligopolistic market which will lead to increased electricity prices. The climate policy is intended to reduce greenhouse-gas emissions and includes an emissions-trading system. Model simulations show that emissions trading increases electricity prices even further. In an oligopolistic market situation, firms benefit from emissions trading. Coal technologies are substituted by gas and renewable technologies. These effects are stronger in an oligopolistic market situation. We can conclude that the two policy initiatives are complementary, but only because the electricity market is not yet fully competitive. In a fully competitive market situation, climate policy targets will be more difficult to reach.

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Appendix: Mathematical description of the EMELIE model

The computational game-theoretic model EMELIE is characterised by the following indices, parameters, and variables:

indices

f	firms, $f \in F$,
i	technologies, $i \in I$;

parameters

c_i^{v}	variable production costs for technology i,
d^0	reference demand for electricity,
p^0	reference price for electricity,
σ	price elasticity of electricity demand,
$q_{i,f}^{\max}$	maximum production capacity with technology i in firm f,
λ	electricity net transport losses;

variables

p	demand price for electricity,
c_f^{m}	marginal and average costs of electricity production of firm f,
s_f	supply of electricity by firm f,
$q_{i,f}$	productionofelectricitybyfirm$f$withtechnology$i$.

EMELIE is a partial general equilibrium model of a liberalised electricity market with multiple actors. On the supply side, electricity-producing firms maximise their profits. On the electricity-demand side, consumers maximise utility. In equilibrium, prices p clear in national markets.

Note first that the market needs to be closed on the demand (consumer) side. This is achieved by the well-known inverse demand function:

$$\sum_{f \in F} s_f = d^0 \left(\frac{p}{p^0} \right)^{-\sigma} \perp 0 \leqslant p . \tag{A1}$$

The '$\perp$' sign is used to denote the dual variable to this equation.

Let us consider the case with strategic interaction among firms on the supply side. In this case, electricity-producing firms f maximise their net profits. They do this by choosing their strategies as represented by their supplies s_f and assume that other firms do the same. This is equivalent to maximising the profit that firm f can make by supplying the grid. This profit is the difference between incomes from supplied electricity minus the cost of production:

$$\text{maximise } \Pi_f(S) = [\mathrm{p}(S) - c_f^{\mathrm{m}}]s_f, \tag{A2}$$

where

$$S = \sum_{f \in F} s_f, \tag{A3}$$

where the dependence of the demand function $\mathrm{p}(.)$ on S constitutes 'strategic action', and the explicit functional form of $\mathrm{p}(.)$ can be derived from equations (A1) and (A3). The first-order conditions for optimisation of firms acting strategically follow directly from equation (A1), by taking the partial derivatives with respect to s_f:

$$\forall f \in F\colon \quad c_f^{\mathrm{m}} = \mathrm{p}\left(1 - \frac{\vartheta_f}{\sigma}\right) \perp 0 \leqslant s_f. \tag{A4}$$

The equation on the left-hand side holds when firm f has a positive supply, a result which is well known from the Karush Kuhn Tucker conditions and is a typical characteristic of a mixed complementarity problem (MCP).

Equation (A4) shows the equalisation between marginal costs and marginal income. The individual market shares in equation (A4) are conveniently determined by:

$$\forall f \in F\colon \quad \vartheta_f = \frac{s_f}{\displaystyle\sum_{g \in F} s_g} \perp 0 \leqslant \vartheta_f. \tag{A5}$$

The marginal income in the case of strategic action is reduced by the 'market-share' factor divided by price elasticity of demand. The market share represents a monopoly mark-up. Power supply by firm f to the grid can be generated with various technologies i, such as nuclear, coal, lignite, gas, oil, hydro, and so on. We assume here a λ% electricity transport loss, which is generally in the range of 0–5%.

$$\forall f \in F\colon \quad (1 - \lambda) \sum_{i \in I} q_{i,f} = s_f \perp 0 \leqslant c_f^{\mathrm{m}}. \tag{A6}$$

In order to define the model fully, we need to restrict firms' marginal costs. For this purpose we have used the variable cost data per technology, which does not differ between firms. Then, a logical lower bound of marginal costs are these variable costs.

$$\forall i, f \in (I, F)\colon \quad c_i^{\mathrm{v}} \leqslant c_f^{\mathrm{m}} \perp 0 \leqslant {}_{i,f} \leqslant q_{i,f}^{\max}, \tag{A7}$$

where the available technology is also restricted by an upper bound.

The model—equations (A1, and A4–A7)—was used to calculate the Nash equilibrium in the strategic-action scenario, where market information is typically incomplete and we are dealing with the case of imperfect markets. This quantity competition is referred to as STRA. A model with perfect markets is established by replacing equation (A4) by

$$\forall f \in F\colon \quad c_f^{\mathrm{m}} = p \perp 0 \leqslant s_f. \tag{A8}$$

Furthermore, in the case of equation (A8), equation (A5) should also be eliminated from the model, as market share ϑ_f is no longer a variable. Of course, the market shares now follow exogenously from the model. The model—equations (A1), (A6), (A7), and (A8)—was used to calculate the competitive equilibrium in the case without strategic action. This case is derived by reducing the demand function to an identity: $\mathrm{p}(.) = p$. Here, firms take market prices as given and we are dealing with the case of perfect markets. This case of price competition is referred to as COMP. These model relations are written in the programming language GAMS, which decomposes the nonlinear program as a mixed complementary problem (MCP). This is solved by the nonlinear MCP-solving algorithm MILES, which is a mixed inequality and nonlinear equation solver. Partially, MILES approximates linear subproblems by Lemke's algorithm and solves a nonlinear program by the generalised Newton algorithm iteratively with a backtracking line search. An optimal solution is found by maximising regional profit conditions reciprocally under all considered constraints.

It is also useful to verify whether the initial prices and demands are viable. This is done in the REF case, where the production cost is minimised. This is expressed in the following equation:

$$\text{minimise cost } (q_{i,f}) = \sum_{i \in I} \sum_{f \in F} q_{i,f} c_i^{\mathrm{v}} . \tag{A9}$$

The model—equations (A1) and (A6–A9)—is run as a nonlinear programming problem to establish the REF case. The main outcomes of the model are regional prices, interregional trade flows, and the optimal market shares of each electricity producer from which the regional concentration of the industry can be calculated in terms of the Hirschmann–Herfindahl index (HHI). HHI is a measure of (regional) competitiveness (see also Tirole, 1988, pages 221–223). For the industry as a whole, the Hirschmann–Herfindahl index is calculated as follows:

$$\mathrm{HHI} = 10\,000 \sum_{f \in F} \left(\frac{\displaystyle\sum_{r \in R} s_{f,r}}{\displaystyle\sum_{r \in R} \sum_{f \in F} s_{f,r}} \right)^2 , \tag{A10}$$

where r is the region or country.

A fourth possible market situation is where one firm is a leader and moves first, and the others are followers and move later—in reaction to the supply chosen by the leader. The followers behave just like the STRA case (whereas the fringe behaves as COMP). The leader chooses its output knowing that the outcome will ultimately depend on the followers' reaction function (A4). The followers' reaction is a constraint for the leader. The leader chooses its output to maximise profit given this constraint.

The first-order condition of the leader can then be written as:

$$c_f^{\mathrm{m}} = p\left(1 - \frac{\vartheta_f}{\sigma} \bigg/ \frac{\mathrm{d}S}{\mathrm{d}s_f}\right) , \tag{A11}$$

where $\mathrm{d}S/\mathrm{d}s_f = 1$ for the follower who behaves as in the STRA case, whereas $\mathrm{d}s/\mathrm{d}S_f > 1$ for the leader—which reduces the monopoly markup to the advantage of the leader. Hence, the outcome of the Stackelberg behaviour will lie between COMP and STRA.

Derivative $\mathrm{d}S/\mathrm{d}s_f$ no longer cancels out in the case of the Stackelberg equilibrium, as the term in the aggregate demand $S = \Sigma s_f$ is built up from the supply of all firms, which can be expressed implicitly via equation (A4) in the supply of the leading firm.

Let us now simplify the model of f to two firms, where i is the leader and j is the follower.[6] Then the reaction function $s_j(s_i)$ can be derived by rewriting equation (A4):

$$s_j = s_i \left[\frac{\sigma(p - c_j^{\mathrm{m}})}{p - \sigma(p - c_j^{\mathrm{m}})} \right] , \tag{A12}$$

$$S = s_i + s_j = s_i \left[1 + \frac{\sigma(p - c_j^{\mathrm{m}})}{p - \sigma(p - c_j^{\mathrm{m}})} \right] = s_i \frac{p}{\Omega_j} , \tag{A13}$$

where

$$\Omega_j = p - \sigma(p - c_j^{\mathrm{m}}) , \tag{A14}$$

$$\frac{\mathrm{d}S}{\mathrm{d}s_i} = \frac{p}{\Omega_j} + s_i \sigma c_j^{\mathrm{m}} \frac{\mathrm{d}p}{\mathrm{d}S} \frac{\mathrm{d}S}{\mathrm{d}s_i} \frac{1}{\Omega_j^2} , \tag{A15}$$

$$\frac{\mathrm{d}S}{\mathrm{d}s_i} = \frac{p}{\Omega_j} \bigg/ \left(1 - \frac{s_i c_j^{\mathrm{m}} \sigma}{\Omega_j^2} \frac{\mathrm{d}p}{\mathrm{d}S} \right) = p\Omega_j \bigg/ \left(\Omega_j^2 - s_i c_j^{\mathrm{m}} \sigma \frac{\mathrm{d}p}{\mathrm{d}S} \right) . \tag{A16}$$

We know from the definition of inverse demand equation (A1) that:

$$\frac{dp}{\mathrm{d}S} = \frac{-1}{\sigma} \frac{p}{S} , \tag{A17}$$

substituting this in equation (A16) this leads to:

$$\frac{\mathrm{d}S}{\mathrm{d}s_i} = \frac{p\Omega_j}{\Omega_j^2 + p c_j^{\mathrm{m}} \vartheta_i} . \tag{A18}$$

Finally, substituting (A18) in (A11) and rewriting, the expression leads to:

$$c_f^{\mathrm{m}} = p \left[1 - \frac{\vartheta_f}{\sigma} \frac{(1 - \sigma\gamma_f)^2 + (1 - \gamma_f)\vartheta_f}{(1 - \sigma\gamma_f)} \right] ,$$

where

$$\gamma_f = \frac{p - c_f^{\mathrm{m}}}{p} , \tag{A19}$$

γ_f is the Lerner index. Equation (A14) is used as the FOC for the Stackelberg leader, while the followers are competing in quantities (A4), whereas the competitive fringe is a price taker (A8).

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(6) To derive, mathematically, the FOC for the leader with n followers is not an easy task, as expressing the reaction functions of each follower leads to n equations, with n variables. This can be aggregated to total demand, but the derivative with respect to p is very complex. Nevertheless, the present approach already shows the advantage of being a leader (moving first).