

Green Certificates and Market Power on the Nordic Power Market

By

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Abstract:

Many countries have started to design and introduce systems of Tradable Green Certificates (TGCs) in order to foster and stimulate electricity generation from renewable energy sources. The purpose of this study is to elucidate under which circumstances, how, and to what extent market power in the TGC market can be used to affect the entire electricity market. There are basically two reasons for being concerned with market power in TGC markets. One is that a small number of companies may have exclusive access to first rate sites for wind power generation. The other is that withdrawal of a small number of TGCs implies a multiple reduction of electricity consumption, with corresponding increases of end user prices. For the purpose of investigating the principles by which market power may be exercised in this setting an analytical model is designed and analytical results are derived. To investigate matters further a numerical model, based on the analytical model, is constructed and applied on the emerging TGC and electricity markets in Norway and Sweden. The analysis shows that companies possessing capacity for green electricity generation, indeed, have the ability to exercise market power by withholding TGCs. This is particularly true for the case where Norway and Sweden have separate domestic markets for TGCs. However, the analysis reveals that an opening of TGC trade between the two countries to a large extent achieves the objective of eliminating the use of market power that would otherwise be established.

JEL classifications: C7; Q28; Q42; Q48

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1. Introduction³

In recent years many countries have started to design and introduce systems of Tradable Green Certificates (TGCs) in order to foster and stimulate electricity generation from renewable energy sources. Thus, a TGC market was introduced in England & Wales in 2002 (now the UK Renewables Obligation Certificates Market). In Sweden a TGC market was established in 2003, and will be extended to include Norway in 2006. Common to these systems is that they seek to replace systems of direct governmental subsidies to renewable energy by market mechanisms⁴. More precisely the aim is to create a market where different types of renewable electricity can compete on equal terms, thus relieving governments and public agencies from being directly involved in power industry investment decisions.

Like any other market a TGC-market consists of sellers and buyers. Sellers are the generators of “green” electricity (i.e. generators using renewable sources for electricity generation). The generators obtain an amount of TGCs corresponding to the amount of green electricity they load into the network. The sellers thus get revenues both from selling the electricity on the electricity wholesale market, and from selling the TGCs received from the issuing body on the TGC market. Buyers of TGCs are consumers/retailing companies that are required to acquire certificates corresponding to a certain percentage of the total consumption of electricity (“the percentage requirement”). In other words the demand for TGCs is directly derived from the demand for electricity. A market clearing price of TGCs is determined by the interplay of supply and demand.

Although the practical experiences are limited various aspects of the functioning of TGC markets have been analysed within the frame of both theoretical and numerical models. Both the analytical and the numerical models of TGC markets show that these markets have some special features that make them different from other markets. In particular, this is related to the effects of applying the inherent policy

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⁴ One basic difference between the UK system and the Nordic system is that the UK system allows recycling of revenues from the buy-out payments that electricity companies that do not obtain sufficient ROCs have to pay. These buy-out payments are recycled to suppliers that have presented ROCs. Contrary to this, there is no recycling of the corresponding penalty payments in the Nordic system.

measures of the system i.e. the percentage requirement, the TGC price bounds as determined by the policy makers as well as policies related to CO₂ emission.

Thus, as shown in Amundsen and Mortensen (2001) and Amundsen and Nese (2002) an increase of the percentage requirement does not necessarily lead to an increase of the generation of green electricity. The same authors also showed that harsher CO₂ constraints (increased CO₂ taxes or reduced number of emission permits) will necessarily lead to an increase of green electricity generated. [Amundsen, Baldursson and Mortensen, 2004] analysed the volatility of TGC price stemming from the annual variations of wind power. Several specific features of multi-country TGC markets have been studied by Bye et al. (2002), Finon and Menanteau (2003), Bergman and Radetzki (2003), Nese (2003) and Unger and Ahlgren (2003), Butler and Neuhoff (2004).

It seems to us that many of the problems discussed in these studies were not well understood when TGC markets were designed and introduced. Another issue that also seems to have been overlooked is the risk for and impact of market power in the TGC market. The purpose of this study is to elucidate under which circumstances, how, and to what extent market power in the TGC market can be used to affect the entire electricity market. There are basically two reasons for being concerned with market power in TGC markets.

The first is the fact that the industry average cost curve for “green” electricity tends to be upward sloping. This is because the cost of wind power, the main source of green electricity, depends on the location of the power plants, and that the availability of first rate sites that do not involve sizable new transmission and network infrastructure, is limited. The situation is similar for environmentally friendly hydro power, and, to some extent, for other types of “green” electricity. Thus, given the state of technology and an upper cost limit, there is a maximum amount of “green” electricity that can be produced within a country. This means that some generators, by getting access to the suitable sites, will become dominating producers of “green” electricity and thus may be able to exercise market power in the TGC market.

The second reason for being concerned with market power in a TGC market is that, as a result of the percentage requirement, the withdrawal of a given number of TGCs from the market forces a much larger reduction of electricity consumption. Thus relatively modest exercise of market power in the TGC market may have a significant impact on the price of electricity and the allocation of resources in the power industry. Moreover, by having access to a large share of the best sites for generation of “green” electricity a “small” power producer may be able to exercise market power in the electricity market by exercising market power in the TGC market.

In order to elucidate the interplay between the electricity and TGC markets a simple analytical model is presented. Then a numerical version of the model, depicting the Nordic electricity market and the Norwegian-Swedish market for TGCs is used to quantify the impact of TGC market power under various assumptions about the distribution of the essential resources for “green” electricity production.

2. Model

The following model is designed to capture a long-run situation for simultaneous functioning electricity and TGC markets. The following variables will be applied

- p : End-use price of electricity (net of distribution costs and tax)
- s : TGC price
- \bar{s} : Upper TGC price bound
- \underline{s} : Lower TGC price bound
- q : Wholesale price of electricity
- x : Quantity of total electricity
- y : Quantity of “black” electricity
- z : Quantity of “green” electricity
- w : Number of TGCs sold
- v : Number of TGCs used
- α : Percentage requirement

The inverse demand function is assumed given by

$$p(x), \text{ with } \frac{\partial p}{\partial x} = p'(x) < 0$$

The cost function for black electricity for a given producer, i ($i = 1, \dots, n$) is assumed given by

$$c_i = c_i(y_i), \text{ with } c_i'(y) > 0 \text{ and } c_i''(y) \geq 0$$

The cost function for green electricity is assumed given by

$$h_i(z_i), \text{ with } h_i'(z_i) > 0 \text{ and } h_i''(y_i) \geq 0$$

Both black and green electricity are delivered to a common wholesale market, from where profit maximizing retailing companies purchase electricity for end-use deliveries. In addition to the wholesale market there is also a market for TGCs.

Perfect competition

For the case of perfect competition in both markets, the profit maximizing market participants are price takers. We assume each single electricity producer, i ($i = 1, \dots, n$) seeks to maximize

$$\Pi_i(y_i + z_i) = qy_i + (q + s)z_i - c_i(y_i) - h_i(z_i)$$

The first order conditions are (assuming interior solutions)

$$\frac{\partial \Pi_i}{\partial y_i} = q - c_i'(y_i) = 0$$

$$\frac{\partial \Pi_i}{\partial z_i} = q + s - h_i'(z_i) = 0$$

These conditions reflect that each producer of green electricity sells all TGCs generated. As the producer obtains one TGC per unit of green electricity generated, the marginal gain from generating one unit of green electricity is equal to the sum of the wholesale price and the TGC price.

For each unit of electricity bought on the wholesale market and sold to end-users the retailing companies will have to pay the wholesale price plus a proportion α of the TGC price in accordance with the percentage requirement. In market equilibrium this implies that the end user price must be equal to the sum of the wholesale price and the mentioned proportion of the TGC price, i.e.

$$p = q + \alpha s$$

The consumption of electricity, and its composition of green and black electricity, in equilibrium, vary according to whether the price of TGCs in equilibrium, s^* is within the specified price interval, i.e. $\underline{s} < s^* < \bar{s}$, or at either the upper or lower price bound. If the price of TGCs is within the price bounds, the percentage requirement is fulfilled and total consumption of electricity is given by $x^* = \frac{z^*}{\alpha}$ (the "allowed" consumption), where z^* denotes total TGCs sold for all producers (and total green electricity generated). If the TGC price is at the lower price bound, i.e. $s^* = \underline{s}$, the demand for TGCs is less than z^* , and the excess supply of TGCs is bought by the State. In this case the percentage requirement is more than fulfilled. If the TGC price is at the upper price bound, i.e. $s^* = \bar{s}$ the demand for TGCs exceeds the maximum possible supply. In this case, the consumers are allowed to buy more electricity if they (the retailing companies) pay a fine of $\alpha\bar{s}$ per unit of electricity in addition to the wholesale price. In this case the percentage requirement is not fulfilled.

Denoting aggregate quantities by (corresponding) symbols without subscripts and equilibrium values by $*$, the equilibrium conditions for the electricity market under perfect competition read as follow⁵

$$1) \quad p^* = q^* + \alpha s^*$$

$$2) \quad x^* = y^* + z^* \begin{cases} \geq \\ \leq \end{cases} \frac{z^*}{\alpha}$$

⁵ In equation 2), $<$, $=$ and $>$ refer to the cases $s^* = \underline{s}$, $\underline{s} < s^* < \bar{s}$ and $s^* = \bar{s}$

$$3) q^* = c_i'(y_i^*), \forall i$$

$$4) q^* + s^* = h_i'(z_i^*), \forall i$$

As explained the demand for TGCs is a derived demand determined simply as a percentage of the electricity demand. Denoting the demand for electricity by $x(p) = x(q + \alpha s)$ the demand for TGCs is thus given by $\alpha x(q + \alpha s)$. The supply is equal to the number of TGCs generated which is identical to the amount of green electricity generated. Hence in equilibrium of the TGC market (interior solution) we have

$$z^* = \alpha x^*(q^* + \alpha s^*)$$

A more compact way of characterizing the competitive solution for the electricity market may be obtained by successive substitution of the above conditions i.e.

$$5) p(x) = (1 - \alpha)c_i'(y_i^*) + \alpha h_i'(z_i^*), \forall i$$

This condition states that the end-user price is equal to a linear combination of the individual producer's marginal cost of providing black and green electricity, with the percentage requirement as the combination weight.

The competitive solution is illustrated in Fig. 1 for the case of an interior value of the TGC price and constant marginal generation costs for each technology, identical for all producers. The constant marginal generation cost of black and green electricity are denoted c and h , respectively; with $h > c$. In particular, Fig. 1 illustrates how the TGC-system functions so as to constrain total electricity consumption, to raise the end-user price and to drive a wedge between the end user price and the wholesale price of power. Thereby, the revenue paid by the consumers become equal to $\alpha s x^*$. This revenue is transferred to the producers of green electricity that will receive $s z^*$ (recall $z^* = \alpha x^*$).

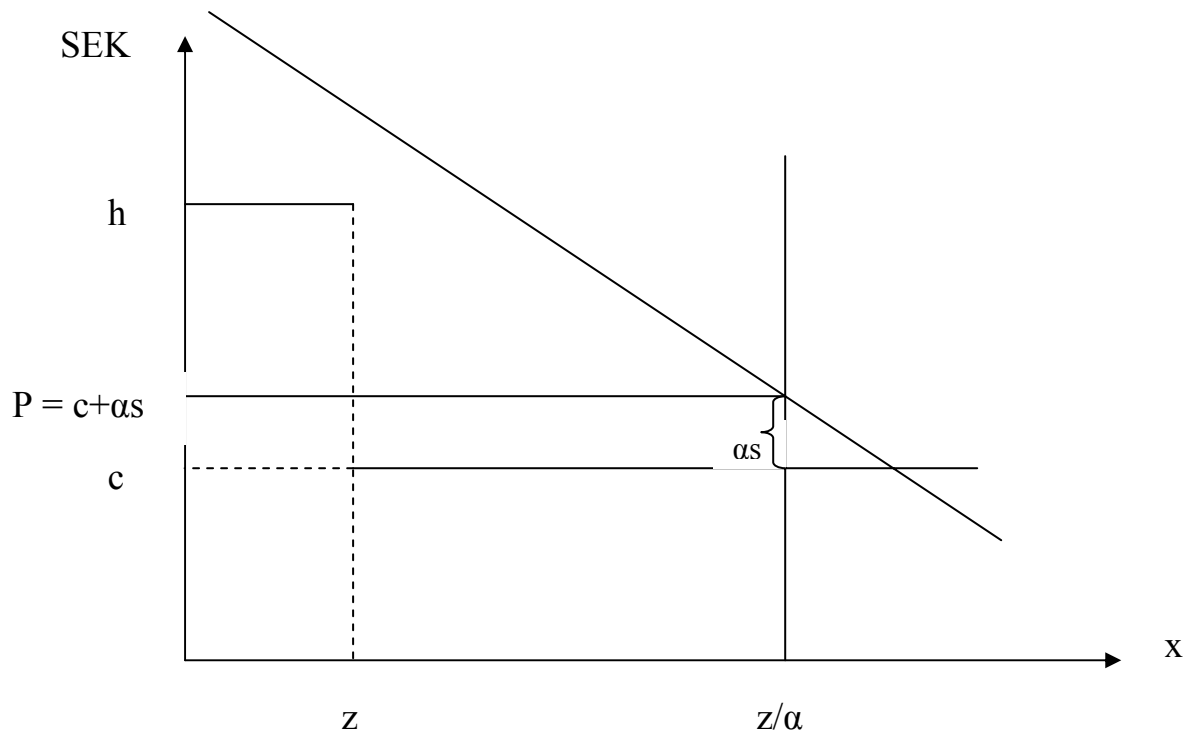


Fig.1. Illustration of the electricity market equilibrium assuming constant generation costs for green electricity, h and for black electricity, c .

Cournot solution and market power

Assuming standard Cournot behavior we consider two cases in the following. First we consider the case where there is Cournot behavior only on the electricity market. Thereafter we consider Cournot behavior on both the electricity and the TGC market.

Market power on the electricity market

In this case we assume that the producers take the TGC price as given and maximize profits as a Cournot player on the electricity market. Clearly, the implication of this is that the producers will sell all TGCs generated. Hence, the objective function may be formulated as in the competitive case

$$\Pi_i(y_i + z_i) = qy_i + (q + s)z_i - c_i(y_i) - h_i(z_i)$$

The first order conditions now read

$$\frac{\partial \Pi_i}{\partial y_i} = \frac{\partial p(x)}{\partial x} x_i + q - c_i'(y_i) = 0$$

$$\frac{\partial \Pi_i}{\partial z_i} = \frac{\partial p(x)}{\partial x} x_i + q + s - h_i'(z_i) = 0$$

In deriving these conditions, observe that

$$\frac{\partial q}{\partial y_i} = \frac{\partial q}{\partial z_i} = \frac{\partial q}{\partial x} = \frac{\partial(p - \alpha s)}{\partial x} = \frac{\partial p}{\partial x}, \text{ as } s \text{ is considered as given by the agents}$$

Equilibrium conditions are

$$6) \quad p^* = q^* + \alpha s^*$$

$$7) \quad x^* = y^* + z^* \begin{cases} \geq \\ \leq \end{cases} \frac{z^*}{\alpha}$$

$$8) \quad \frac{\partial p(x)}{\partial x} x_i^* + q^* = c_i'(y_i^*), \forall i$$

$$9) \quad \frac{\partial p(x)}{\partial x} x_i^* + q^* + s^* = h_i'(z_i^*), \forall i$$

A more compact way of characterizing the competitive solution may be obtained by successive substitution of the above conditions i.e.

$$10) \quad p(x^*) + \frac{\partial p}{\partial x} x_i^* = (1 - \alpha)c_i'(y_i^*) + \alpha h_i'(z_i^*), \quad \forall i$$

This condition states that the producer's marginal revenue is equal to a linear combination of the individual producer's marginal cost of providing black and green electricity, with the percentage requirement as the combination weight.

Market power on both the electricity market and the TGC market

In this section we consider an electricity producer that behaves as a Cournot player in both markets. In the formulation to follow, however, we assume that the electricity producer does not game on the simultaneous functioning of the two markets⁶. Rather we assume that the producer in determining the generation of green and black electricity only considers the electricity market and thus takes the TGC price as given. Likewise, we assume that the producer in determining the amount of TGCs to sell, w_i only takes the TGC market into account and thus takes the wholesale price as given. This formulation may be considered as a standard Cournot formulation with multiple markets. It is however, necessary to take into account that the producer is constrained by the amount of TGCs generated, i.e. we must have

$$w_i \leq z_i$$

The electricity producer, thus, faces the following optimization problem

$$\text{Max } \Pi_i(y_i, z_i, w_i) = q(y_i + z_i) + sw_i - c(y_i) - h(z_i), \quad \text{s.t. } w_i \leq z_i$$

To solve this problem, formulate the Lagrangian function

$$\mathfrak{R}_i(y_i, z_i, w_i) = q(y_i + z_i) + sw_i - c(y_i) - h(z_i) - \lambda_i(w_i - z_i)$$

⁶ For a discussion of this problem, see Amundsen and Nese (2004).

The first order conditions are

$$11) \frac{\partial \mathfrak{R}_i}{\partial y_i} = \frac{\partial p(x)}{\partial x} x_i + q - c_i'(y_i) = 0$$

$$12) \frac{\partial \mathfrak{R}_i}{\partial z_i} = \frac{\partial p(x)}{\partial x} x_i + q + \lambda_i - h_i'(z_i) = 0$$

$$13) \frac{\partial \mathfrak{R}_i}{\partial w_i} = \frac{1}{\alpha} \frac{\partial p(x)}{\partial x} w_i + s - \lambda_i = 0$$

In deriving condition 13) observe that

$$\frac{\partial s}{\partial w_i} = \frac{\partial(\frac{p-q}{\alpha})}{\partial w_i} = \frac{1}{\alpha} \frac{\partial p(x)}{\partial x}, \text{ as } q, \text{ by assumption, is considered as given by}$$

the agents as they sell TGCs.

A producer with $w_i^* < z_i^*$, must have $\lambda_i^* = 0$. For this case condition 13) says that the marginal revenue of selling TGCs should be equal to zero. In this case there is an excess of TGCs and the TGC system does not induce this particular producer to generate more TGCs (more green electricity) than what he otherwise would have done (i.e. the marginal generation cost is equal to marginal revenue for both technologies).

A producer with $w_i^* = z_i^*$, must have $\lambda_i^* > 0$. For this case condition 13) says that the marginal revenue of selling TGCs should be equal to λ_i^* and thus larger than zero. In this case the TGC system does induce the producer to generate more TGCs (green electricity) than what he otherwise would have done.

Eliminating λ_i^* from conditions 12) and 13), equilibrium conditions may be expressed as⁷

$$14) \quad p^* = q^* + \alpha s^*$$

$$15) \quad x^* = y^* + z^* = \frac{z^*}{\alpha}$$

$$16) \quad \frac{\partial p(x^*)}{\partial x} x_i^* + q^* = c_i'(y_i^*), \forall i$$

$$17) \quad \frac{\partial p(x^*)}{\partial x} x_i^* + q^* + \frac{1}{\alpha} \frac{\partial p(x^*)}{\partial x} w_i^* + s^* = h_i'(z_i^*), \forall i$$

Upon successive substitution of the above conditions, the following compact relationship appears

$$18) \quad p(x^*) + \frac{\partial p(x^*)}{\partial x} (x_i^* + w_i^*) = (1 - \alpha)c_i'(y_i^*) + \alpha h_i'(z_i^*), \forall i$$

This condition states that the producer's marginal revenue from the electricity and the TGC markets is equal to a linear combination of the individual producer's marginal cost of providing black and green electricity, with the percentage requirement as the combination weight⁸.

3. Trade between two countries

In this part we consider two countries, *A* and *B*, (such as Norway and Sweden) that trade both electricity and green certificates with each other. In this setting policy measures taken in one country may effect the decisions made in the other country.

⁷ Observe that condition 15) assumes an interior solution for the TGC price. The reason for this is that the change of the TGC price following from a change in the sale of TGCs is equal to zero if the TGC price is at the price bounds. In such a case there would be no difference between optimality conditions of the present market setting and the market setting considered above (i.e. market power in the electricity market only).

⁸ The additional market power that a producer of green electricity may exercise is reflected in the marginal revenue function that- in addition to the amount of electricity sold, x_i - also contains the number of TGCs sold by the producer, w_i . Hence, if the producer finds it optimal to sell *all* TGCs generated, i.e. $w_i^* = z_i^*$, green electricity “counts twice” in the marginal revenue function of equation 18), i.e. $p(x^*) + \frac{\partial p(x^*)}{\partial x} (y_i^* + 2z_i^*)$.

Trade in electricity only

Under autarky each country will have to satisfy the same general set of equilibrium conditions (e.g. conditions 1) – 4) for perfect competition or conditions 14) - 17) for Cournot behavior in both markets). Prices and quantities will, however, be specific to each country as determined by the demand function, the cost functions and the policy measure applied (percentage requirement and TGC price bounds). Opening for trade in electricity while still keeping separate TGC markets, the electricity wholesale price will become the same in both countries (i.e. $q_A^* = q_B^* = q^*$). Considering the most general case of Cournot behavior in both markets we have (other market settings may easily be derived from these conditions by putting relevant price derivatives equal to zero)

$$19) \quad p_j^* = q^* + \alpha_j s_j^*$$

$$20) \quad x_A^* + x_B^* = y_A^* + z_A^* + y_B^* + z_B^*$$

$$21) \quad x_j^* = y_j^* + z_j^* = \frac{z_j^*}{\alpha_j}$$

$$22) \quad \frac{\partial p(x^*)}{\partial x} x_{ij}^* + q^* = c_{ij}'(y_{ij}^*), \forall i, j, j = A, B$$

$$23) \quad \frac{\partial p(x^*)}{\partial x} \left(x_{ij}^* + \frac{w_{ij}^*}{\alpha_j} \right) + q^* + s_j^* = h_{ij}'(z_{ij}^*), \forall i, j, j = A, B$$

Observe that the common wholesale market implies that the derivatives of end-user prices will be the same for both countries even though end user prices may be different. This follows from the fact that $q^* = p_A(x_A^*) - \alpha_A s_A^* = p_B(x_B^*) - \alpha_B s_B^*$ and the assumption that the TGC price is considered as given when operating in the electricity market.

Trade in both electricity and TGCs

Opening for trade in certificates, the TGC prices will be equated and become the same for both countries (i.e. $s_A^* = s_B^* = s^*$) at a level intermediate to the initial TGC prices of the two countries. In this setting there is a need for an additional variable and

an additional equation (stating that total certificates applied must be equal to total certificates sold) to describe the equilibrium solution. Hence, we describe the number of certificates used in country j by v_j . Net import of certificates for country j is then equal to $v_j - w_j$. The set of equilibrium conditions now reads

$$24) \quad p_j^* = q^* + \alpha_j s^*$$

$$25) \quad x_A^* + x_B^* = y_A^* + z_A^* + y_B^* + z_B^*$$

$$26) \quad x_j^* = y_j^* + v_j^* = \frac{v_j^*}{\alpha_j}$$

$$27) \quad v_A^* + v_B^* = w_A^* + w_B^*$$

$$28) \quad \frac{\partial p(x^*)}{\partial x} x_{ij}^* + q^* = c_{ij}'(y_{ij}^*), \quad \forall i, j, \quad j = A, B$$

$$29) \quad \frac{\partial p(x^*)}{\partial x} \left(x_{ij}^* + \frac{w_{ij}^*}{\alpha_j} \right) + q^* + s^* = h_{ij}'(z_{ij}^*), \quad \forall i, j, \quad j = A, B$$

4. Numerical model

It has been pointed out that there is an indeterminacy of the effects on green capacity of an increase of the percentage requirement and that the precise results depend on the parameters of the problem. This goes for both TGC markets under autarky as well as for integrated TGC markets. In order to evaluate the effects of introducing a joint TGC market in the Nordic countries and in particular a joint Norwegian-Swedish market, it may thus seem like a good idea to apply numerical models with realistic parameter values.

In a study by Bergman and Radetzki (2003) a numerical model has been applied to investigate the effects of a Swedish TGC market on green electricity generation and electricity trade within the Nordic power market. Only Sweden is assumed to have a TGC market. Among other results the study shows that the net export of electricity to the other Nordic countries will increase a lot (i.e. by 5.2 TWh). This somewhat surprising result is explained by a high equilibrium price of TGCs and the resulting low net cost of generating green electricity in Sweden. Hence, the introduction of a TGC system in Sweden significantly affects the investment decisions in the electricity

industry. However, as Sweden is the only country applying a TGC system, the effect on the common Nordic electricity wholesale price is rather small⁹.

To further investigate these relationships a numerical model based on the principles of the analytical model developed above is designed to take care of trade in both electricity and TGCs between Sweden and Norway. Just as the analytical model the numerical model may take account of market power in both the electricity market and the TGC market. The basic assumptions of the model are as follow:

- Electricity generation takes place in major firms (3-5) with Cournot behaviour plus a fringe with competitive behaviour for each country
- Step-wise increasing linear marginal cost curves, reflecting unit costs and capacity limits for various technologies
- Green electricity encompasses electricity generated by wind, water and biomass. However, only electricity generation in new small water power plants are considered green, whereas electricity generation in existing water power plants are considered black¹⁰ just as electricity generated in nuclear-, gas-, coal-, and oil power plants.
- Free-trade in electricity but inter-connector capacity limits may lead to different wholesale prices in the various countries
- Autarky or free trade in the TGC market
- Perfect competition or Cournot behaviour for the major firms and perfect competition for the fringe in the TGC market
- Constant elastic demand curves in each country (price elasticity: -0,3)

The model determines equilibrium prices and quantities on, and cross border tariffs between, the electricity markets in Denmark, Finland, Norway and Sweden. Also, it determines equilibrium prices and trade on the markets for TGCs in Norway and Sweden.

⁹ In broad, these conclusions seem to be in line with other model simulation studies of the effects of TGC systems in the Nordic countries (see Hindsberger et al., 2003 and Unger and Ahlgren, 2003).

¹⁰ For Norway black electricity generation is almost exclusively taking place in water power plants whereas black electricity generation in Sweden also includes electricity from nuclear-, gas- and coal power plants.

In the following we address the question as to how a requirement of having a certain percentage of green electricity affects the electricity market under autarky and under trade of TGCs as market power is exercised. The case of no TGC markets at all is considered as a benchmark. The focus is on the year 2006.

Domestic TGC markets with market power and trade in electricity only

Specific assumptions made for this case are

- A TGC market for Sweden with a percentage requirement of 8,4%
- A TGC market for Norway with a percentage requirement of 4,5%
- The fringe is constrained by a generation capacity of green electricity totalling 5 TWh in both countries
- Cournot behaviour of major firms and competitive behaviour of the fringe on both TGC markets
- No trade of TGCs
- No TGC markets for the other Nordic countries

Comparing with the case of no TGC markets in any of the Nordic countries (the base case) the model shows that the introduction of TGC markets give rise to the following changes (see Table 1)

- The Norwegian end-user price is reduced and the Norwegian electricity consumption is increased
- The Swedish end-user price is increased and the Swedish electricity consumption is reduced
- The aggregate electricity consumption in the two countries decreases
- The (common) wholesale price of electricity is reduced
- The TGC price in Sweden becomes larger than the Norwegian TGC price
- In Norway, all TGCs generated are sold
- In Sweden, TGCs are held back from the market (corresponding to 1,4 TWh)

Hence, the introduction of TGC markets with Cournot behaviour does stimulate green electricity generation and – as expected- influences prices and quantities in the electricity markets, notably for Sweden.

Table 1. Model simulations of quantity (TWh) and prices (SEK/MWh) on the electricity and TGC markets. Assumptions stated in the main text.

	No TGC markets		Separate TGC markets Market power		Trade in TGCs Market power		Trade in TGCs Perf. competition	
	Norway	Sweden	Norway	Sweden	Norway	Sweden	Norway	Sweden
Total electricity consumption	121,3	156,9	121,4	155,0	121,3	155,3	121,3	155,4
Green electricity consumption	0	2,8	5,5	13,0	5,5	13,0	5,5	13,0
Green electricity production	0	2,8	5,5	14,4	5,0	14,2	3,7	14,8
Wholesale price of electricity	24,0	24,0	22,9	22,9	23,0	23,0	23,1	23,1
Price of TGCs	-	-	24,0	26,6	22,8	22,8	20,9	20,9
End-user price of electricity	24,0	24,0	23,9	25,1	24,0	24,9	24,0	24,9

Trade and market power for both markets

In the next case considered a common TGC market is introduced for Norway and Sweden. It is assumed that the major firms still exercise market power in the TGC market.

- Compared with the previous case the effects of TGC trade on end-user prices and consumption are to some extent counteracted. Indeed, for Norway the end-user price and consumption is back to what it was in the base case. For Sweden, end-user price and consumption of electricity get somewhat closer to those of the base case
- The (common) wholesale price increases somewhat as compared with the previous case and thus gets closer to what it is in the base case

- The price of TGCs is the same in both countries and is lower than either of the TGC prices for the previous case
- The generation of green electricity falls both in Norway and Sweden
- Norway generates less green electricity than it consumes and imports TGCs from Sweden
- Less TGCs are held back from the market as compared with the previous case (i.e. corresponding to 0,7 TWh)
- The consumption of green electricity (i.e. use of TGCs) is approximately the same as in the previous case for each of the countries

Trade and perfect competition for both markets

The assumptions are the same as for the previous case, except that all producers act competitively on the TGC market. Compared with the previous case we get the following results

- For Norway, end-user price and consumption remain the same. For Sweden there is a further slight increase of consumption and a further slight reduction of end-user price.
- There is a further increase of the (common) wholesale price of electricity for both countries
- There is a further reduction of the TGC price
- Norway reduces its generation of green electricity while Sweden increases its green electricity generation, but total generation of green electricity is reduced
- Norway imports TGCs from Sweden
- No TGCs are held back from the market.
- The consumption of green electricity (i.e. use of TGCs) is approximately the same as in the previous case for each of the countries
- There is an increase of the combined electricity consumption in Norway and Sweden

The cases considered above show that market opening of the TGC markets comes a long way in eliminating the negative effects of market power in the TGC markets. With trade in TGCs end-user prices and consumption are practically speaking the

same with and without market power. Also, the wholesale prices are close to being the same, while some differences in the TGC prices remain.

5. Concluding remarks

With the parameter values applied, it looks as if the joint TGC market functions as expected for Norway and Sweden. In particular, it seems like the TGC market mechanism does have the positive effect on green electricity generation as intended and that this takes place without distorting total electricity consumption significantly. Depending on market form and trading options for TGCs total generation of green electricity will increase by 16 - 17 TWh for the two countries combined, while total electricity consumption is reduced by approximately 1 -1,5 TWh. The adjustments, thus, imply a “crowding out” effect for black electricity and a redistribution of producer surplus from black electricity generation to green electricity generation. With respect to price effects from introducing markets for TGCs, the wholesale price will fall whereas the end user price in Norway remains more or less unaffected. The end user price in Sweden increases somewhat.

With respect to the question of market power it turns out that companies possessing capacity for green electricity generation may exercise market power by withholding TGCs. This is particularly true for the case where Norway and Sweden have separate domestic markets for TGCs. However, the analysis reveals that an opening of TGC trade between the two countries to a large extent achieves the objective of eliminating the use of market power that would otherwise be established on the separate domestic markets for TGCs. The usual reason for this applies i.e. that the market enlargement makes each single producer relatively less dominating and less potent when it comes to influencing price.

It should be noted, however, that market power on the common TGC market gives rise to rather high TGC prices as the percentage requirement gets harsher. Indeed the price may be so high that the penalty price is reached. This may lead to large changes in the functioning of the markets, as the percentage requirement will no longer be effective because the retailing companies may pay the penalty instead of purchasing

TGCs.¹¹ For Sweden the problem of paying the penalty rather than purchasing TGCs has been observed among retailing companies¹². However, Sweden is about to leave the system of a fixed penalty price in favour of a system of variable penalty price (i.e. set at 150% of last years average TGC price). For Norway nothing has yet been decided with respect to the penalty system. Presumably this will be coordinated with the Swedish system.

In concluding this paper it should be noted that the success of introducing TGC markets not only depends on the ability to mitigate market power but also on other factors. The question of compatibility of the TGC system with other environmental instruments, notably the CO₂ emission permit system (the ETS-system) has already been mentioned. Otherwise, the possible large volatility of TGC prices may also be of significance in this respect. In Denmark, for instance, wind power may vary between windy years and calm years with an annual variation of 25% as compared with the annual average. As the marginal cost of wind power generation is close to zero for existing capacities competitive wind power generators will at all times produce what is feasible and thus generate erratic and price inelastic supply. Hence, the number of TGCs issued and available for sale will also be highly volatile and this will lead to a considerable uncertainty with respect to the remuneration (i.e. the sum of the TGC price and the wholesale price) of investment in green technologies. This in its turn may also influence the required rate of return for investors in renewable electricity i.e. the required rate of return would be higher as compared with what would be necessary if subsidies were stable and certain. However, an integration of the Swedish TGC market with a Norwegian TGC market would be a remedy to this problem as wind variations in various parts of Sweden and Norway are probably not very correlated. Hence, an extension of the TGC market to include both countries would work so as to stabilize TGC prices. Otherwise, banking of TGCs is an efficient way of dampening price oscillations.

¹¹ In the Nordic power market penalty payments are not recycled to producers of green electricity, as is the case in the UK system (see Butler and Neuhoff, 2004). The recycling rule of the UK system probably leads to even larger market power potential of green electricity producers than what is the case for the Nordic counterpart.

¹² See <http://www.stem.se/>.

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