Green Certificates and Market Power on the Nordic Power Market

Eirik S. Amundsen* and Lars Bergman**

The purpose of this study is to elucidate under which circumstances, how, and to what extent market power on a Tradable Green Certificates (TGC) market can be used to affect an entire electricity market. There are basically two reasons for being concerned with this. 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. We formulate both an analytical model to investigate economic principles and a numerical model based on that to investigate the Swedish TGC market operating in a setting of a common Nordic electricity market. The analysis shows that Swedish producers may exercise market power using the TGC-market but that this problem will be eliminated by opening the TGC-market for other Nordic countries.

Keywords: Renewable energy, Electricity, Green certificates, Market power, Nordic power market

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1. INTRODUCTION

In Sweden a market for Tradable Green Certificates (TGCs) was introduced in 2003. The purpose was to stimulate investments in electricity generation based on renewable energy sources without using direct governmental subsidies.

* Corresponding author. Department of Economics, University of Bergen, Fosswinckelgate 6, N-5007, Bergen, Norway. E-mail: eirik.amundsen@econ.uib.no, Phone: + 47 55 58 97 18, Fax: + 47 55 58 92 10.

** Stockholm School of Economics, Box 6501, SE-113 83 Stockholm, Sweden. E-mail: Lars.Bergman@hhs.se.

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to renewable energy. More precisely the aim was 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. The sellers are the generators of “green” electricity. The generators obtain an amount of TGCs corresponding to the amount of green electricity they feed-into the network i.e. one MWh of green electricity generated gives rise to one TGC. The sellers thus get revenues both from selling the electricity on the electricity wholesale market and from immediately selling the TGCs received from the issuing body on the TGC-market. However, they may also decide to sell the certificates at a later date, or even not at all.

The buyers of TGCs are the consumers and 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.

An important aspect of a TGC system is that the percentage requirement creates a direct link between the electricity market and the TGC-market. What happens in the electricity market has a direct impact on the TGC-market and vice versa. Moreover, as the demand for electricity tends to be inelastic, the derived demand for TGCs is even more inelastic. Several studies have focused on various implications of the direct link between the two markets.

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, one
important source of green electricity, depends on the wind conditions at the site of the plant, and that different sites differ significantly in this respect. The situation is similar for environmentally friendly hydro power, and, to some extent, for other types of green electricity. In the short and medium term the location of suitable sites in relation to the existing power grid implies that investments in green electricity generation, to a varying extent, should include investments in transmission capacity connecting the power plant to the existing grid. In the case of biomass and peat other kinds of transportation infrastructure investments may be needed.

Thus, given the state of technology and the upward sloping cost curve, there is a limit on the 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. Currently the number of “green electricity” producers in Sweden is very large, but 96 percent of them produce less than 50 GWh per annum (18 percent of the total production of green electricity). On the other hand the three major power companies produce around 25 percent of all green electricity, and on the basis of current investment plans this share is likely to increase significantly in the near future.

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 (e.g. if the percentage requirement is 10 the withdrawal of one certificate will induce a reduction of 10 MWh of 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 a Norwegian-Swedish market for TGCs is used to quantify the impact of TGC-market power under various assumptions of trade and market power exertion.

2. AN ANALYTICAL MODEL

The following model is designed to capture the interplay between the electricity and TGC-markets. The following variables will be applied

\[ p: \text{ End-use price of electricity} \]
\[ s: \text{TGC price} \]
\[ q: \text{ Wholesale price of electricity} \]
\[ x: \text{Quantity of total electricity} \]
The inverse demand function for electricity 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, \( i(i=1,\ldots,n) \) is assumed given by

\[ c_i = c_i(y_i), \text{ with } c_i'(y_i) > 0 \]

and

\[ c_i''(y_i) \geq 0 \]

The cost function for green electricity is assumed given by

\[ h_i(z_i), \text{ with } h_i'(z_i) > 0 \]

and

\[ h_i''(z_i) > 0 \]

The cost functions are taken to represent long run relationships. Otherwise, observe that 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 where the producers of green electricity are the sellers and the retailing companies / end-users are the buyers.

To gain insight into the joint functioning of these two markets we consider two cases. In the first we assume that the electricity market is an oligopoly market where agents behave in accordance with the Cournot model, while there is perfect competition on the TGC-market. This case will serve as a reference case for the analytical model to follow. In the second case both markets are oligopolistic, and Cournot behavior is assumed. Both cases concern a single country. In order to prepare for our numerical analysis in a Nordic setting we thereafter expand the analytical model to include trade in electricity and TGCs.

In the first 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 maximization problem of the producer may be formulated as

$$\text{Max } \Pi_i(y_i + z_i) = qy_i + [q + s]z_i - c_i(y_i) - h_i(z_i)$$

The first order conditions 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, we use

$$\frac{\partial q}{\partial y_i} = \frac{\partial q}{\partial z_i} = \frac{\partial q}{\partial x} = \frac{\partial (p - \alpha s)}{\partial x} = \frac{\partial p}{\partial x},$$

Hence, we assume that the producer recognizes that the sale of electricity will affect the wholesale price of electricity through its effect on end-user demand. Also we assume for this case that the TGC-price, $s$ is perceived as given. The first of the two first order conditions states that the producer in generating black electricity will equate the marginal revenue of selling black electricity with the marginal cost of generating black electricity. Likewise, the second condition states that the producer in generating green electricity will equate the marginal revenue of selling green electricity and the corresponding TGC generated with the marginal cost of generating green electricity. Hence, the producer has focus on the electricity market and recognizes that he can influence the market price of electricity by choosing the level of output of black and green electricity.

Equilibrium conditions are

$$p^* = q^* + \alpha s^*$$

$$x^* = y^* + z^* = \frac{z^*}{\alpha}, \text{ where } x^* = \sum_i x_i^*, \quad y^* = \sum_i y_i^*, \quad z^* = \sum_i z_i^*$$

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

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

A more compact way of characterizing the solution in market equilibrium may be obtained by successive substitution of the above conditions i.e.
3. We use standard Cournot assumptions for multiple markets, i.e. we assume that the producer takes the prices in the other markets as given when operating in one of the markets. Hence, we do not assume what has been called “simultaneous gaming.” For a discussion of problems related to simultaneous gaming with a TGC-market of the Nordic type, see Amundsen and Nese (2004). Otherwise, market power of interconnected markets (e.g. emission permit markets and energy markets) is dealt with in Montero (2009). Furthermore, Traber and Kemfert (2009) analyze the impacts of the German Feed-in tariffs on both electricity prices, emissions and firms while taking account of market power and oligopolistic behaviour.

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

This condition states that the producer’s marginal revenue in equilibrium 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. Thus, under market equilibrium the optimality conditions for the producer simply boils down to the standard oligopoly condition except that the relevant marginal cost now is composed of two marginal cost elements. As the marginal cost of generating green electricity is larger than the marginal cost of generating black electricity in optimum it is also clear that this is not a least cost solution of generating electricity as this would necessitate equal marginal cost of generation for the two kinds of electricity.

Next we turn to the second case of this section and consider an electricity producer that behaves as a Cournot player in both markets. In so doing we assume that the producer recognizes that his sale of TGCs will influence the end-user price of electricity and hence behaves accordingly. In part the producer has to decide on how many TGCs to sell, \( w_i \). The producer is, however, constrained by the amount of TGCs generated, i.e. we have

\[ w_i \leq z_i \]

The electricity producer, thus, faces the following optimization problem

\[
\text{Max } \Pi_i(y_i,z_i,w_i) = q[y_i + z_i] + sw_i - c(y_i) - h(z_i),
\]

s.t. \( w_i \leq z_i \)

To solve this problem, formulate the Lagrangian function

\[
L_i(y_i,z_i,w_i) = q[y_i + z_i] + sw_i - c(y_i) - h(z_i) - \lambda[w_i - z_i]
\]

The first order conditions are

\[
\frac{\partial L_i}{\partial y_i} = \frac{\partial p(x)}{\partial x} x_i + q - c_i'(y_i) = 0
\]

\[3. \text{ We use standard Cournot assumptions for multiple markets, i.e. we assume that the producer takes the prices in the other markets as given when operating in one of the markets. Hence, we do not assume what has been called "simultaneous gaming." For a discussion of problems related to simultaneous gaming with a TGC-market of the Nordic type, see Amundsen and Nese (2004). Otherwise, market power of interconnected markets (e.g. emission permit markets and energy markets) is dealt with in Montero (2009). Furthermore, Traber and Kemfert (2009) analyze the impacts of the German Feed-in tariffs on both electricity prices, emissions and firms while taking account of market power and oligopolistic behaviour.}
In deriving these conditions we use

\[ \frac{\partial L_i}{\partial z_i} = \frac{\partial p(x)}{\partial x} x_i + q + \lambda_i - h_i'(z_i) = 0 \]

\[ \frac{\partial L_i}{\partial w_i} = \frac{1}{\alpha} \frac{\partial p(x)}{\partial x} w_i + s - \lambda_i = 0 \]

Hence, we assume that the producer recognizes that his sale of TGCs spills over on the electricity market and influences the end user price of electricity. Thus, if the producer sells one extra TGC he perceives that the effect on total electricity demand is equal to that results in a price drop of \((1/\alpha)(dp/dx)\) in the electricity market. Observe that if the producer does not find it optimal to sell all TGCs received (i.e. \(w_j < z_j\)), we must have \(\lambda_i = 0\).

Eliminating \(\lambda_i^*\) the equilibrium conditions may be expressed as

\[ p^* = q^* + \alpha s^* \]

\[ x^* = y^* + z^* = \frac{w^*}{\alpha} \]

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

\[ \frac{\partial p(x^*)}{\partial x} \left[ x_i^* + \frac{w_i^*}{\alpha} \right]^* + q^* + s^* = h_i'(z_i^*), \ \forall i \]

Comparing the last two of these conditions with the corresponding conditions of the previous case, we see that the optimality condition for black electricity generation is the same, while the optimality condition for green electricity generation has been changed. In particular, the negative element of the marginal revenue expression has become an extra element, implying that the producer now recognizes that his sale of TGC triggers an increase of demand equal to \((w_i^*/\alpha)\) that will affect the electricity price negatively. Hence, the producer recognizes that his sale of TGCs also affects the market price negatively in addition to the negative price effect of his electricity sale. Consequently, he cuts back on his electricity generation as compared with what he would have had without market power on the TGC-market.

Upon successive substitution of the above conditions, the following compact relationship appears
4. The consequence of this is that the relevant marginal revenue curve becomes steeper. With a linear demand curve, the marginal revenue curve pivots inwards around the point where the demand curve hits the price axis.

This condition states that the producer’s marginal revenue from the electricity and the TGC-market in market equilibrium 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. By comparing this condition with the previous condition where market power on the TGC-market was not exercised, we see that the marginal cost concept is the same, but as referred to above, that the marginal revenue expression has been altered. Thus, the negative element of the marginal revenue expression is enlarged when the producer possesses market power on the TGC-market in addition to market power on the electricity market. The effect of this in the market is to increase the end user price of electricity and to reduce the consumption of electricity. Hence, exertion of market power on the TGC-market spills over to the electricity market in terms of lower electricity generation and a higher end user price.

3. A TWO-COUNTRY MODEL

The objective of this part of analysis is to investigate the joint functioning of an electricity and a TGC-market in a Norwegian-Swedish setting. Hence, we next expand the analytical model to consider two countries, A and B, (such as Norway and Sweden) that trade electricity and/or green certificates with each other. In this setting policy measures taken in one country may effect the decisions made in the other country.

Under autarky each country will have to satisfy the same general set of equilibrium conditions as discussed above. 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).

Opening for trade in electricity while still keeping separate TGC-markets, the electricity wholesale price will become the same in both countries. Thus it holds that \( q_A^* = q_B^* = q^* \). In this setting black and green electricity flow freely between the two countries, whereas TGCs can only be sold in the country where they originate. Since both the TGC price and the percentage requirement may differ between the countries, end user prices may also differ. As always, with integration of markets, market power gets diluted due to the smaller relative size of each producer in the common market as compared with the relative size under autarky for each of the joining countries. For the case where market power is not exercised on the TGC-markets the effect of opening for trade in electricity while still keeping separate TGC-markets is simply to reduce market power on the
electricity market. The consequence of this is an increase of the joint generation of electricity in the two countries as compared with what it was prior to market integration.

In the above case where market power on the TGC-markets is not exercised and where the TGC-markets are separate without any trade a producer can not exercise market power on the electricity market specifically related to his own country. This is, however, still an option if market power is exercised on the separate TGC-markets. Considering the case of market power exertion in both markets but with national TGC markets the following conditions apply:

$$p_j^* = q^* + \alpha, s_j^*, \; j = A, B$$

$$x_A^* + x_B^* = y_A^* + z_A^* + y_B^* + z_B^*$$

$$x_j^* = y_j^* + z_j^*, \; j = A, B$$

$$\frac{\partial p_j(x_j^*)}{\partial x_j} x_j^* + q^* = c_j'(y_j^*), \; \forall i, j, \; j = A, B$$

$$\frac{\partial p_j(x_j^*)}{\partial x_j} \left[ x_j^* + \frac{w_{ij}^*}{\alpha_j} \right] + q^* + s_j^* = h_j'(z_{ij}^*), \; \forall i, j, \; j = A, B$$

In the above relationships we have $$\sum_i x_{ij}^* = x_j^*$$ i.e. $$x_j^*$$ is the aggregate electricity generation in country $$j = A, B$$. Likewise, we have $$\sum_i y_{ij}^* = y_j^*$$ for black electricity and $$\sum_i z_{ij}^* = z_j^*$$ for green electricity.

As is seen from the relationships above, the decisions of the single producer are equal to what they were prior to market integration. Hence, a producer of green electricity will sell his TGCs in order to influence the TGC-price and the end user price of electricity in his own country. Consequently, sizable market power may still persist in a country even after integration of the electricity market has taken place. Otherwise, it may be interesting to note that even for this case a compact version of the producer’s production decisions in market equilibrium may be derived from the above conditions i.e.

$$p_j(x_j^*) + \frac{\partial p_j(x_j^*)}{\partial x_j} [x_j^* + w_{ij}^*] = (1 - \alpha_j)c_j'(y_j^*) + \alpha_j h_j'(z_{ij}^*), \; \forall i, j$$

The interpretation of this condition is the same as the one given for the corresponding expression in the previous section. It should be observed that the composition of marginal cost in terms of weight (the percentage requirement) put on the two cost components is the same for every producer in a given country, but
different between countries if the percentage requirements differ. The reason for this is that TGCs will only be sold in the country where they originate. The next step is to open for trade also for TGCs in addition to the electricity trade. The effect of this is to equate TGC prices so that they become the same for both countries i.e. so that \( s_A^* = s_B^* = s^* \) where \( s^* \) is some intermediate level as compared with the initial TGC prices of the two countries.

In order to give an analytic illustration of this case 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 by \( j \). Net import of certificates for country \( j \) is then equal to \( v_j - w_j \). The set of equilibrium conditions now reads

\[
\begin{align*}
p_j^* &= q^* + \alpha_j s^*, \ j = A, B \\
x_A^* + x_B^* &= y_A^* + z_A^* + y_B^* + z_B^* \\
x_j^* &= y_j^* + v_j^*, \ j = A, B \\
v_A^* + v_B^* &= w_A^* + w_B^* \\
\frac{\partial p(x^*)}{\partial x} x_{ij}^* + q^* &= c_{ij}'(y_{ij}^*), \ \forall i, j, \ j = A, B \\
\frac{\partial p(x^*)}{\partial x} \left[ x_{ij}^* + \frac{w_{ij}^*}{\alpha_j} \right] + q^* + s^* &= h_{ij}'(z_{ij}^*), \ \forall i, j, \ j = A, B
\end{align*}
\]

The interpretation of these conditions is similar to the interpretation of the conditions of the previous case considered. There is, however, one important distinction: as the TGCs may be used in both countries the sale—or withdrawal—of an additional TGC does not only affect the end user price in the country where the sale is taking place but indeed in both countries. Therefore, market power gets diluted due to the smaller relative size of each producer of green electricity in the common TGC-market. Hence, market integration of the TGC-markets will result in smaller market power exertion showing up as an increase of the joint generation of electricity in the two countries as compared with what it was for the case where only electricity was traded. Otherwise, it should be observed that end user prices may still differ between the two countries if the percentage requirements are different. It should also be observed that the relative weight on the marginal cost of black and green electricity generation now is the same in market equilibrium for all producers irrespective of where production is taking place. The combination weight will be intermediate to the level of each country’s percentage requirement and depends on the size of the markets.
A special case of the analytical model applies if only one of the two countries has a TGC system and generators in the other country are allowed to participate in that system. For instance, Norwegian generators of green electricity could receive Swedish TGCs and be allowed to participate in the Swedish market for TGCs. This is the case we set out to investigate in the following.

4. A NUMERICAL MODEL

In order to shed some light on the real world situation a numerical model with the same basic structure as the analytical model has been used. The model is an updated version (see Amundsen and Nese, 2009) of the static model of the Nordic electricity market, i.e. the integrated electricity market of Denmark, Finland, Norway and Sweden, initially used in Bergman and Radetzki (2003).

The basic features and assumptions of the numerical model are as follow:

- In each country there are 2–5 major electricity generation firms, acting as Cournot players, and a number of small generation firms forming a competitive fringe. There is no entry of new firms, but the incumbent firms may invest in new capacity.
- Marginal cost curves are step-wise increasing and linear, reflecting unit costs and capacity limits for various technologies.\(^5\)
- Green electricity encompasses electricity generated by wind, water and biomass. However, only electricity generation in new small hydropower plants are considered green, whereas electricity generation in existing hydropower plants are considered black\(^6\) just as electricity generated in nuclear-, gas-, coal- and oil power plants.
- Free-trade in electricity between the four Nordic countries, but interconnector capacity limits may lead to different wholesale prices in the various countries.
- Two alternative trade regimes for the TGC-market: Autarky or free trade between the four Nordic countries.
- Two alternative assumptions about the behavior of the major firms in the TGC-market: Price taking (perfect competition) or Cournot behavior. The fringe firms always behave as price takers both in the electricity and the TGC-market.
- Constant elastic demand curves in each country (price elasticity: \(-0.3\))

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5. The cost of production in an electricity generation unit is equal to the variable cost in existing units and the sum of the variable cost and the annualized capital cost in a new unit.

6. 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.
Using 2001 as its base year the model projects annual equilibrium prices and quantities in, and cross border tariffs between, the electricity markets in Denmark, Finland, Norway and Sweden. It also projects equilibrium prices and trade in the markets for TGCs in Norway and Sweden.

In the Swedish system the producers of certificate-entitled electricity can be essentially classified into two groups: one consisting of a few large companies, which produce most of the electricity, and the other consisting of a large number of producers who individually have relatively small production quantities (Swedish Energy Agency, 2009). In accordance with this we split the producers in two groups and assume that the rights to exploit the most favorable sites for wind power production have been acquired by the major power producers. Thus a “fringe” power producer who wants to enter the market for green electricity only has access to more costly wind power sites, i.e. sites where wind conditions and/or the cost of connecting to the grid is higher than for the sites available for the major generators. Unfortunately lack of available data on ownership prevents us from using exact information and the above assumptions may turn out to be too strong and thus exaggerate the extent of market power of the national Swedish TGC market. Nevertheless, there are clear indications that the major producers do have a significant share of the new wind power sites eligible for TGCs in Sweden. For instance, Vattenfall owns the large Lillgrund Wind Farm, while one of the largest land-based wind farms in Europe currently under construction, Blaiken Vind AB, is owned by Fortum and Skellefteå Kraft, the second and fourth largest power producers in Sweden. This project alone accounts for some 15 percent of the total installed wind capacity in 2010. Furthermore, Vattenfall is about to assess the project Kriegers Flak 2 with a capacity of 2.5 times that of Blaiken.

In the following we will use the numerical model to analyze to what extent a requirement to have a certain percentage of green electricity in Sweden affects the Nordic electricity market. We consider both autarky and free trade of TGCs. Moreover we analyze to what extent that market power in the TGC-market affects the electricity market. The case of no TGC-market is considered as a benchmark. The focus is on the year 2010. As the effects of the Swedish TGC system are similar in the three other Nordic countries we only present the results for Norway (being a significantly larger national electricity market than Denmark and Finland together).

5. SIMULATION RESULTS

Using the numerical model we have considered three alternative cases, or projections and compared the outcome for prices and quantities with the corresponding data for the benchmark case (denoted Base 2010). Note that the Base case is also a projection, and that “electricity consumption” includes transmission and distribution losses. The different cases are defined in the following way:
Table 1: Results of the Numerical Model

<table>
<thead>
<tr>
<th></th>
<th>Base 2010</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity consumption in Norway, TWh</td>
<td>128.2</td>
<td>131.4</td>
<td>132.5</td>
<td>132.8</td>
</tr>
<tr>
<td>Electricity consumption in Sweden, TWh</td>
<td>165.9</td>
<td>163.0</td>
<td>140.7</td>
<td>162.6</td>
</tr>
<tr>
<td>Producer price of electricity in Sweden, €/MWh</td>
<td>26.5</td>
<td>24.4</td>
<td>23.8</td>
<td>23.6</td>
</tr>
<tr>
<td>Producer price of electricity in Norway, €/MWh</td>
<td>26.6</td>
<td>24.4</td>
<td>23.8</td>
<td>23.6</td>
</tr>
<tr>
<td>Price of TGCs, €/MWh</td>
<td>—</td>
<td>29.0</td>
<td>174.7</td>
<td>37.8</td>
</tr>
<tr>
<td>Consumer price in Sweden, €/MWh</td>
<td>26.6</td>
<td>28.1</td>
<td>46.0</td>
<td>28.4</td>
</tr>
</tbody>
</table>

Base 2010

In this case there is free trade in electricity between the Nordic countries, i.e. Denmark, Finland, Norway and Sweden. There is no TGC system in Sweden or in any other Nordic country.

Case 1

Again free trade in electricity between the Nordic countries is assumed, but now a TGC system with the percentage requirement equal to 12.7% is introduced in Sweden. Perfect competition in the Swedish TGC-market is assumed, but there is no cross-border trade in TGCs.

Case 2

This case is like Case 1, except that the major generators act as Cournot players in the market for TGCs.

Case 3

This case is like Case 2, except that generators in Denmark, Finland and Norway are allowed to participate in the Swedish TGC system, and to trade TGCs across the Nordic borders.

We present the simulation results by pair-wise comparisons of the four alternatives. The key results are summarized in Table 1 above.

Base 2010 vs Case 1

In order to analyze the impact of a TGC system on the electricity market we compare Base 2010 and Case 1. Note that in Case 1 the Swedish TGC-market

7. The official percentage requirement for 2010 is 17.9 percent. However, as electricity intensive industries are exempt from the requirement to use a certain fraction of “green” electricity the average percentage requirement on all electricity consumption is 12.7.
is assumed to be perfectly competitive, i.e. no generator can, or decides to, exercise market power on the TGC-market. Also note that producer prices in Sweden are equal to producer prices in Norway. As can be seen in the table the introduction of a TGC system leads to a reduction of the producer prices of electricity, i.e. the system and area prices determined at the common Nordic power exchange Nord Pool. This is well in line with theory as one would expect producer prices to fall as a consequence of introducing what amounts to a tax on black electricity generation. The consumer price of electricity in Sweden, however, increases as a result of the percentage requirement and the positive price of TGCs. Thus electricity consumption increases in Norway (where producer and consumer prices are the same in the model) and decreases in Sweden.8

The price of TGCs in Case 1 is somewhat lower than the actual Swedish TGC prices observed 2008–2009, which varied within the range 30–35 €/MWh. For the period 2004–2006, when the percentage requirement was lower, the prices projected by the model were very close to the observed prices. The somewhat higher prices in 2008 and 2009 could be a result of market power being exercised, but it could also reflect relevant costs not fully taken into account by the model.9

Case 1 vs Case 2

Next we analyze the potential impact of market power on the Swedish market for TGCs, i.e. we compare Case 1 and Case 2. As can be seen in Table 1 there is considerable potential market power on the TGC-market. If this market power is fully exercised the equilibrium prices of TGCs would be several times higher than the prices hitherto observed.

Moreover, the impact on the electricity market would be significant, reducing electricity consumption in Sweden by around 15 percent. The numbers may seem unrealistic, but they clearly indicate that the percentage requirement, which is the core feature of a TGC system, opens up a new possibility to exercise market power in the electricity market.

One reason for the significant potential market power created by the TGC system is that the TGC-market is a quite small national market with a small

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8. The effect on producer prices of introducing a TGC system is extensively dealt with in the literature. Hence, Amundsen and Mortensen (2001) as well as Bye (2003) show that an increase of the percentage requirement always results in a reduced producer price in a joint competitive electricity and TGC-market. However, the effect on end-user price and total electricity consumption is indeterminate.

9. Only a few empirical analyses exist for the Swedish TGC system e.g. Kåberger et al. (2004), Knutsson et al. (2006) and Bergek and Jacobsson (2010). Two of these are rather critical to the functioning of the system. Hence, Kåberger et al. find that the Swedish TGC system is not really efficient while Bergek and Jacobsson find that the Swedish TGC market functions as a rent-generating machine that only to a small extent stimulates technical change. None of the studies address the question of market power. Otherwise information on the functioning of the Swedish market is reported annually by the Swedish Energy Agency.
number of relatively large players. Consequently it is an oligopolistic market in which each player has significant market power. As discussed in the analytical model one way of dealing with that problem is to enlarge the market and open up for international trade in TGCs. Case 3, where generators in the other Nordic countries are allowed to participate in the Swedish TGC-market, represents one possibility along these lines.

**Case 3 vs Case 2 and Case 1**

Case 3 implies that, from a Swedish policy perspective, green electricity generated in Denmark, Finland and Norway is seen as a perfect substitute for green electricity generated in Sweden. Consequently TGCs are allocated to generators in the other Nordic countries on the basis of the same principles as TGCs are allocated to Swedish generators. Moreover, all generators in the Nordic countries can sell their TGCs in the Swedish TGC-market. Needless to say a full version of the Case 3 “model” has not been seriously considered by policy makers in the Nordic countries. However, it illustrates a serious drawback of the current Swedish TGC-market.

As can be seen in the table the addition of new participants on the Swedish TGC-market increases competition and significantly reduces the possibilities to exercise market power. In fact, opening up for cross-border trade with TGCs (Case 3) essentially has the same effect on the electricity market as perfect competition in a national Swedish market for TGCs (Case 1).

**6. CONCLUDING REMARKS**

In connection with the restructuring of the electricity markets in the Nordic countries market power was seen as a major potential problem. The reason was that each one of the national markets (in Denmark two disconnected regional markets) was dominated by one major power company. However, by integrating the national markets this problem was significantly mitigated. Our results indicate that market power is a potential problem in the Swedish market for TGCs, but again the solution seems to be market integration. That is, to open up the Swedish market for green power producers in the other Nordic countries. The argument for doing this becomes even stronger if a TGC system is introduced in the other Nordic countries. In fact, this has recently happened as a joint Swedish-Norwegian TGC market was established on January 1, 2012.

An alternative to applying a TGC-market for stimulating the generation of renewable electricity is to use a system of so called feed-in tariffs which simply amounts to a subsidy per unit of green electricity produced. This is a system that is in use in many countries (e.g. Germany and Denmark). There are similarities as to how a TGC market and a system of feed-in tariffs function but there are also differences. One similarity is that both systems provide the producer with a subsidy for each unit of green energy produced. However, as the feed-in tariff
system involves governmental bodies in determining the size of the subsidy this is left to the market (as determined by the percentage requirement) for the TGC-system.

Another important difference is that the feed-in tariff system avoids the problem of market power exertion as the size of the feed-in tariffs can not be directly influenced by the producers. On the other hand, a feed-in tariff system is not well suited to stimulate cooperation among countries in installing new capacity of renewable energy. Hence, if two countries have a common target of achieving a certain share of renewable energy for both countries viewed as one, a common TGC-system may realize mutual gains of cost reductions by letting the country with the lowest cost take a larger share than the other while implicitly being paid by the other country in terms of TGCs received from that country. This is not easily done with a feed-in tariff system as this would imply a system of direct cross border subsidies.

In concluding this paper it should further be noted that the success of introducing TGC-markets not only depends on the ability to mitigate market power but also on other factors. One potential problem is the volatility, both short term and on an annual basis, of TGC prices resulting from natural variations in wind conditions (see Amundsen, Baldursson and Mortensen (2006)). In Denmark, for instance, the supply of wind power may vary by 25 percent (compared with the annual average) between windy and calm years.

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 other Nordic TGC-markets would be a solution, or at least a remedy, to this problem. This is because wind variations in various parts of the Nordic area probably are not closely correlated. Hence, an extension of the TGC-market would stabilize TGC prices.

REFERENCES


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