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Financial risks for green electricity investors and producers in a tradable green certificate market

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Abstract

This paper analyzes financial risks in a market for tradable green certificates (TGC) from two perspectives; existing renewable producers and potential investors in new renewable electricity generation capacity. The equilibrium pricing mechanism for a consumer-based TGC market is described and a market with wind turbines as the sole renewable technology is analyzed. In this framework, TGC prices and fluctuations in production from wind turbines will be negatively correlated and, as a result, TGC price fluctuations can actually help decrease the total financial risk. Based on this recognition, analytical expressions for revenue-variance-minimizing trading strategies are derived and an analysis of the demand and supply for financial hedging is used to show that forward contracts will be traded at a risk premium.

JEL: D80; G18; O20; Q28

Keywords: Tradable green certificates; Financial risk; Forward contracts

1. Introduction

Following the global trend towards market-based systems for electricity trading, a number of countries are considering tradable green certificate (TGC) markets as a way of introducing market-based support schemes for renewable energy technologies. TGC markets in various forms are under consideration or actual implementation in a number of European countries, e.g. the Netherlands, Denmark, Sweden, Italy, the UK, etc. However, the specific design varies significantly across countries. An important distinction is whether the obligation to purchase green certificates rests on the consumer or producer. In this paper, we primarily consider the suggested Danish system, which is a consumer based one. The primary element of the Danish TGC market is an obligation on consumers to buy an amount of certificates corresponding to a percentage or quota of their total electricity consumption during a specified time period, e.g. one calendar year. Each supplier of renewable (green) electricity will receive a certificate for each unit of electricity produced and, given the fixed quota, it is then left to competition on the supply side to find the appropriate certificate price.

In spite of the market label, the TGC system is a specific form of quantity regulation. A demand for green electricity is created, but it is based on a quota defined by the Government rather than directly on the individual consumer's desire for electricity from renewable sources. A tendering system is another example of quantity regulation. But here, the price paid to renewable producers is typically fixed for a number of years ahead. The new and innovative part of the TGC concept is the dynamic price setting mechanism that results from creating a market for a tradable good (in this case a financial product called a green certificate). A detailed description of consumer-based TGC systems can be found in Amundsen and Mortensen (2001), Morthorst (2000), Schaeffer et al. (1999), Jensen and Skytte (2002a), Jensen and Skytte (2002b), Morthorst (2000) and Fristrup (2002).

This paper contributes to the ongoing discussion about TGC market design by analyzing the effects that a consumer-based TGC system will have on the financial risks for wind-turbine owners. Wind turbines are assumed to make up the entire supply side of the market, i.e. other renewable sources are supported either

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through separate technology specific TGC markets or other political instruments. In the proposed Danish system[1] it is likely that the supply side will attempt to form cartels, however, we assume that legal action will prevent such action and we have based the market analysis on perfect competition. With perfect competition, the pricing mechanism is based on the assumption that long-run marginal costs (LRMC) of the marginal renewable investor minus the expected price of electricity will equal the expected TGC price in equilibrium.

Two main factors will affect equilibrium in the framework described above. The short-term (annual) effects of these factors are analyzed by looking at trading strategies for existing producers, whereas the long-term effects are analyzed by looking at the risk premium required by investors. The first factor concerns the amount of information about the shape of supply and demand curves available to investors and producers. In a TGC system, potential investors need this information in order to evaluate future prices and expected return on the investment. Similarly, existing producers need the information to construct an optimal bidding strategy in the market. The second factor concerns the volume risk that arises because the average wind conditions fluctuate between the annual periods. Fluctuations in the wind regime imply that the amount of electricity, and thus also the number of certificates produced, are both stochastic variables. Because of this volume risk, the effect of signing fixed-price forward contracts, both in the TGC market and in the physical electricity market, is more ambiguous for a wind-turbine owner than for a power producer who can control production volume.

A liquid forward market plays an essential role in attracting new investors to a commodity market. Since the main goal of a TGC market is to obtain cost-efficient deployment of renewable capacity, it is important to analyze the role of such contracts for hedging purposes. Assuming that revenue is the essential parameter for investors, and that utility can be expressed in a mean variance framework, we derive analytical expressions for variance-minimizing portfolios of forward contracts. To illustrate the implications of stochastic production volume, the strategies are subsequently compared to those of producers with a deterministic production volume. Finally, we analyze the demand for hedging on both the supply and demand side of the TGC market and conclude that forward contracts will have an inherent tendency to trade at a risk premium, i.e. at a price above the expected spot price.

[1] Our point of departure is the proposed Danish system but most conclusions will be valid in other similar systems.

2. The price-setting mechanism in a TGC market

In this section, the pricing mechanism for a perfectly competitive consumer-based TGC market is described. The pricing mechanism constitutes a necessary basis for an analysis of the financial risks implied by the introduction of such a market. As described in detail below, it is crucial that at equilibrium a new entrant in the TGC market produces the marginal unit, and we therefore distinguish between existing and new capacity. Assuming perfect competition, new entrants will supply at the LRMC. LRMC is defined here as the price required by an investor in order to supply an additional unit of renewable capacity. It is therefore an average cost that encompasses short-run marginal costs (SRMC), average per unit repayment of fixed costs, and an average per unit risk premium. SRMC is defined as the variable costs of production, and in the case of a wind turbine this is simply the operation and maintenance (O&M) cost.

In addition to trading financial certificates, the wind-turbine owner will also sell the produced power on the physical market for electricity. This represents an additional income and the price, thus obtained, in this market must therefore be subtracted from the LRMC in order to derive a supply curve in the TGC market. It is important to note that by using the LRMC curve as part of the supply curve to form an equilibrium price in a single annual period (see Fig. 1), we are implicitly assuming that this equilibrium price equals the expected average equilibrium price during the lifetime of the investment. We shall make this assumption in the following, because it eases the illustration of market equilibrium considerably without affecting the results presented.

Fig. 1 illustrates market equilibrium in the proposed Danish TGC system. In this system, the obligation to buy certificates is an annual one, where each consumer must purchase certificates corresponding to a fraction of his/her annual power consumption (we use the term "quota" in this paper), or pay a predefined penalty[2] for the deficit.

With perfect competition price will equal SRMC if existing renewable generators can cover the demand for certificates. In practice, the SRMC of running a wind turbine is always lower than the electricity price received on the physical market implying that in this case the certificate price should be zero. For the TGC system to function properly, the quota must therefore be set at a level, which ensures that the marginal unit is a new

[2] This penalty is effectively a price cap in the market. The proposed Danish system also includes a minimum price cap. This minimum cap has been suggested to ensure that, as a minimum, all turbine owners receive the CO_2-reduction credit that was given to all renewable power producers in the previous system.

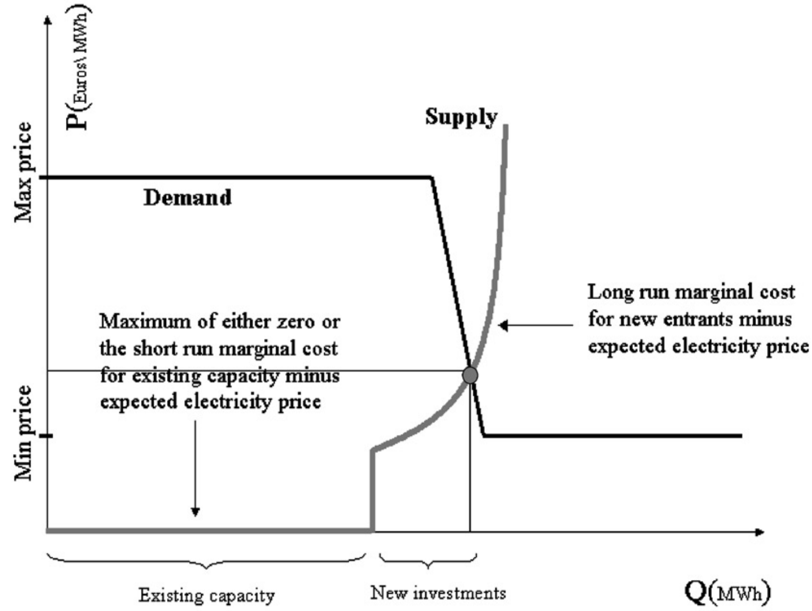

Fig. 1. Equilibrium in a perfectly competitive consumer based TGC market.

entrant at equilibrium. The opposite effect occurs if the quota is set at a level too high, i.e. an insufficient number of investors will react. In this case, the TGC price will equal the penalty price unless a decrease in the demand for electricity is able to establish a theoretical equilibrium. The elasticity of demand in the TGC market will be a function of the elasticity of demand for electricity, and since the quota will be a relatively small percentage of total demand, e.g. 20%, the elasticity of demand for certificates will be significantly lower than the already inelastic demand for electricity. We should therefore not expect the demand side to provide a significant response to price and as a result of this TGC prices will be highly sensitive to the quota even if some form of storage or banking of certificates is allowed (as planned in the proposed Danish system). This provides the regulator with the daunting task of predicting exactly how new investors will behave. If this prediction is slightly inaccurate, the result will be equilibrium prices at one of the price caps, and in this case the TGC system becomes a poorly set fixed feed-in tariff.

Looking at the dynamic price formation between annual periods, there are two main factors that will affect the equilibrium price in a TGC market. The first factor concerns the amount of information available to investors in this type of system and the second factor concerns variations in the total annual supply of certificates due to the stochastic nature of the wind. The problem of imperfect information is a general one for TGC systems, whereas the second factor related to volume risk is specific to the case discussed here where wind turbines make up the supply side.

Consider first the amount of information available to new investors about supply and demand in the TGC market. Equilibrium such as the one shown in Fig. 1 will only be realized if all potential investors act upon the same set of information about the shape of the long-run marginal cost curve. This type of information is, however, generally not available to the investor in perfect form. Instead each investor will guess or construct an estimate of the shape of future supply and demand in order to calculate future TGC prices and expected return on the investment.

Fig. 2 illustrates the case where insufficient information about the shape of the supply curve leads investors to wrongfully expect equilibrium at point A and thus a market price of P_E. This erroneous information leads all investors with LRMC below P_E to invest, and the marginal unit is therefore found at point B in Fig. 2. The difference between Q_E and Q_T describes the amount of excess capacity that results from the lack of information. In this case, the relatively low level of expected supply will result in a low TGC price (at minimum cap in the figure). The opposite case, where the expected supply curve lies to the right of the true curve, is equally likely and has the opposite effect, i.e. a high level of expected supply implies fewer investments and higher prices.

The insufficient information about supply and demand curves in the TGC market introduces a price risk that investors are not exposed to in a fixed feed-in tariff system.[3] In the fixed feed-in tariff system, the regulator

[3] In Denmark various fixed feed-in tariff systems have previously been used as a primary instrument in an attempt to promote wind power and other renewable power sources.

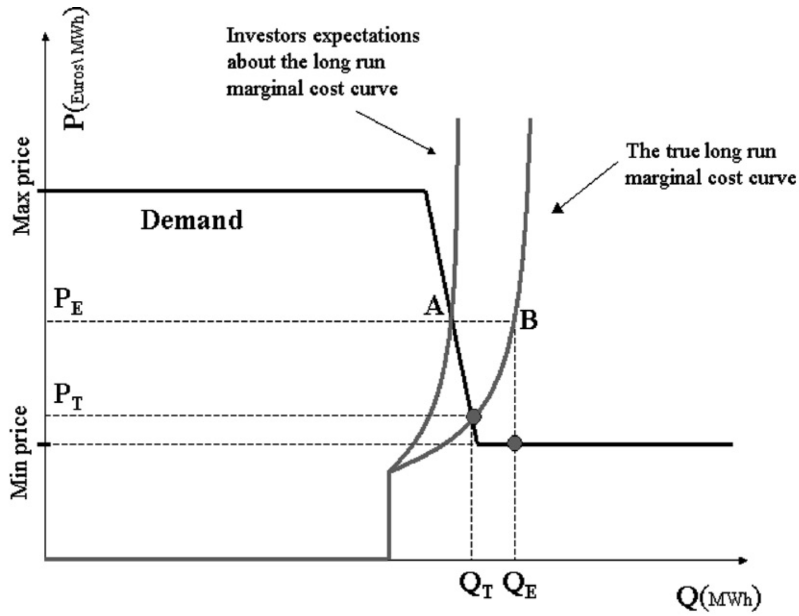

Fig. 2. The effect of investor's lack of information about the supply curve.

takes on the exposure to all risks related to imperfect information. Investors are exposed to political risk in the sense that there is always the possibility that politically induced system changes will occur. However, this kind of political risk is inherent in all systems and is therefore less interesting when comparing two different systems of regulation (of course, minimizing uncertainty about the structure and possible changes to the system is always desirable in the sense that it decreases the risk premium required by investors).

Switching from one form of regulation to another does not create new financial risks; rather it transforms risk from one form to another and redistributes risk between the different participants. In a price regulation regime, imperfect information about supply and demand leads to uncertainty about the quantity of new renewable investments, i.e. uncertainty about the ability to achieve a political objective. When switching to a TGC system, the risk exposure due to imperfect information about supply and demand is transferred from the regulator to the private investors. The question is then whether society is better off by paying an increased risk premium to investors, or by paying a higher price to all wind-turbine owners because the marginal investment exceed the stated policy goals. Additionally, one must recall that the regulator faces the problem of determining a set of future quotas that will ensure that equilibrium prices occur within the price span defined by the price caps. To achieve this end, the regulator must have information about the demand curve and the supply curve. If the future set of quotas is set 'incorrectly' in the sense that prices tend to form at one of the price caps, the result of the TGC system is simply a very poor form of price regulation. This is bad news since one of the main arguments for introducing a TGC system is to shift the risk exposure associated with poor information about the shape of the supply curve from the regulator to the market. It is therefore clear that an essential criterion for the success of a TGC market is that the market is designed to ensure that TGC prices are not highly sensitive to small mistakes in the setting of the quota.

The second factor that affects equilibrium is fluctuations in the total volume produced. In a market where wind turbines make up the supply side, the annual volume supplied to the market will fluctuate due the stochastic nature of wind energy. In the Danish system, annualized wind conditions have varied by up to approximately $\pm 18\%$ from the mean during the past 20 years.[4] Fig. 3 shows the effect of windy year on the equilibrium price in the TGC market. The increased production of power in a windy year translates directly into a larger amount of certificates for all producers than expected. As illustrated in Fig. 3, the SRMC part of the supply is extended to the right because each existing producer now has more than the expected amount of certificates to sell.[5] The LRMC part of the supply curve remains relatively unaffected by changes in production volume in a single year, because an investment decision is based on the average revenue

[4] Data can be found at http://www.naturlig-energi.dk/Pages/N_6_frame.htm.

[5] The short-run marginal costs are defined as constant variable costs and the level of the curve is therefore unaffected by the total quantity of certificates that producers receive.

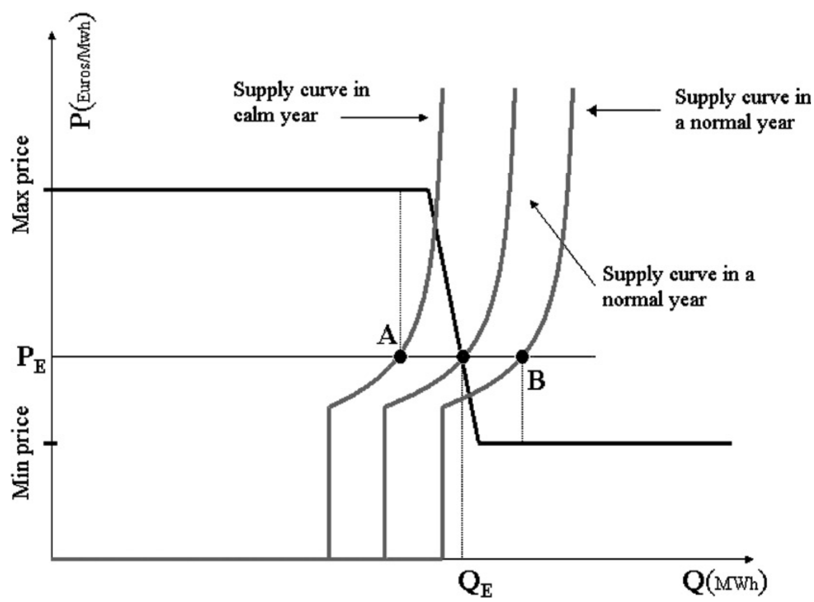

Fig. 3. The effect of variations in the wind on the TGC price.

obtained during the entire lifetime of the wind turbine, e.g. a 20-year horizon. The same amount of investments is therefore realized irrespectively of what wind conditions is realized in the annual period. This is illustrated as point A for a windy year and point B for a calm year in Fig. 3. The effect is an equilibrium price at, respectively, the lower or upper price cap.

The effect of a windy year is similar to the effect of imperfect information in the sense that the supply curve is shifted either to the left or to the right. There are, however, some crucial differences in the nature of the two effects. First of all, the lack of information is based on expectations and affects the amount of investments made, i.e. the realized part of the LRMC curve. The wind-fluctuation effect is based on actual realizations and affects only the SRMC part of the supply curve. Secondly, it is crucial to notice that the wind effect changes the short-term production volume of each producer, which means that every supplier has more electricity and more certificates to sell when the TGC price is low, and vice versa. This negative correlation between volume and price is important because it is revenue stability, and not price stability, that is essential to investors.

To summarize, we have discussed a pricing mechanism for the TGC market and described two different factors that can affect the equilibrium price. We have explained how the lack of information about supply and demand will lead investors to demand a risk premium. In general, the benefit of a TGC system's potential ability to achieve a politically desired level of new investments must therefore be weighted against the price that investors will demand for the increased risk exposure. We have further explained how fluctuations in the number of certificates due to wind conditions create both a volume and a price risk. However, unlike the lack of information factor, this factor will not lead investors to demand a higher risk premium than what would have been the case in a fixed feed-in tariff system.

Private investors are exposed to volume risk in both systems so no redistribution of volume risk occurs when switching from one system of regulation to the other. The negative correlation between production volume and the TGC price will actually decrease revenue fluctuations and as such this factor should actually lead investors to charge a lower risk premium. To illustrate this effect more clearly short-term trading strategies of risk-averse producers and the use of forward markets for risk management is analyzed in the following two sections.

3. Short-term financial risks

In the preceding section, we have discussed long-term financial risks in a TGC market from an investor's point of view. In this section, we discuss short-term financial risks for owners of existing capacity in the market.

With perfect competition, investment costs are considered sunk for existing capacity. Since the input fuel (the wind) is free of charge for wind turbines the only variable costs are those related to operation and maintenance. With the current technology these O&M costs are for all practical purposes always covered by the price of electricity. If existing capacity is able to cover total demand, then the TGC price should in theory equal zero in a perfectly competitive market. However, if, as assumed, the quota is set so that a new entrant becomes the marginal producer, then equilibrium will be determined by the LRMC of this investor, as described in the previous section. An existing producer has an SRMC of zero, but knows that the price will be determined by the LRMC of a new marginal investor. The producer will therefore act in the TGC market based on expectations (not unlike in a stock market) and will bid to sell at the price he expects will be the equilibrium price.

Unlike investors in a stock market, the owner of a wind turbine will have information about the stability of future revenue because volume and prices to some extent will be negatively correlated as indicated in the previous section. With a feed-in tariff the effect of fluctuations in the produced volume of electricity translates directly into revenue risk because the price is constant.

The effect that volume risk has on revenue is more complicated in a TGC system because short-term variations in wind conditions affect both volume and price in the TGC market. Based on economic reasoning a wind-turbine owner should never choose to switch off the turbine, because the price obtained for electricity exceeds the SRMC at all times. This means that the level of production is directly linked to wind conditions and, as shown in Fig. 3, prices will tend to fall in a windy year and tend to rise in a calm year. The revenue for a single wind-turbine owner is therefore a product of two negatively correlated stochastic variables. This is important, because it indicates that TGC price fluctuation can actually have a positive effect on the financial risk exposure of a turbine owner. The argument rests on the assumption that a single turbine owner's production is highly correlated with the total production supplied to the market. In a small geographical region such as Denmark this is a reasonable assumption, since wind conditions are homogenous, i.e. when it is windy in one part of the country it tends to be windy in all parts of country. Thus, when one turbine owner has more than average certificates all turbine owners have more than average certificates and TGC prices will fall.

In a fixed feed-in tariff system the amount of information available to an investor about supply and demand is irrelevant, because he receives a fixed price for all units of electricity produced, regardless of the shape of supply and demand. In the TGC system, the price that can be obtained for a certificate will be uncertain. This implies that any lack of information about supply and demand will make the expectations-based bidding strategy a risky one. In contrast to the volume risk arising from wind variations, the price risk that results from insufficient information translates into revenue risk in a simple manner. Although lack of information increases risk for existing producers, they are paid for this increased exposure by a general uplift in TGC prices. This uplift arises because TGC prices are determined by the LRMC of the marginal new investor, who will account for the added risk exposure by increasing the required risk premium.

With regard to the long-term development of TGC prices, it seems reasonable to assume that TGC prices will fall over time as wind-turbine technology matures and eventually becomes fully competitive on the electricity market. TGC forward prices will therefore be in normal backwardation, i.e. forward prices are lower than the current spot price. The falling tendency in TGC prices will clearly reduce the overall desire to bank certificates and create a need for a well functioning forward-contract market.

4. Forward contracts

Forward contracts are commonly used in commodity markets to ensure a fixed price for a product at some specific date in the future. Thermal electricity producers can sell forward contracts to stabilize income and as such they constitute a valuable risk management tool. The situation is somewhat different for a wind-turbine owner because production is a stochastic variable. The fact that the TGC price needed to cover SRMC for existing turbines is zero implies that the owner will have no motivation to turn off the wind turbine, simply because it will never be profitable to do so. To analyze the effect that this has on the optimal trading strategy of a wind-turbine owner seeking stable revenue, we consider four basic strategies based on the use of forward contracts in either of the two markets (see Fig. 4).

As a working assumption, turbine owners are assumed to be risk averse with respect to revenue. For simplicity, it is further assumed that the utility function of any potential investor can be described in a mean variance framework, i.e. the individual preferences can be described as a trade-off between expected revenue and the variance of revenue.

	Spot trading in the TGC market	Forward trading in the TGC market
Spot trading in the physical market	1	2
Forward trading in the physical market	3	4

Fig. 4. Four simple trading strategies in the financial TGC market and the physical electricity market.

4.1. Comparing strategy 1 and strategy 2

Purchasing forward contracts on the TGC market and trading spot on the physical market (strategy 2) is intuitively linked to the form of price regulation where renewable capacity receives a subsidy per unit of electricity in addition to the market price. An annually cleared TGC market leaves a wind-turbine owner who follows strategy 2 exposed to three elements of risk:

- the amount of electricity produced;
- the price received for the electricity produced;
- the mismatch between the contracted number of certificates and the actual production.

By comparing expected revenue (R) in strategies 1 and 2 at a future time t_1 [6] the following expression for the expected revenue can be derived (see the appendix for the derivation):

$$E[R_{s2}] = E[R_{s1}] \Rightarrow F_{P,\mathrm{TGC}} = E[P_{\mathrm{TGC}}], \tag{1}$$

where R_{s1} and R_{s2} represent revenues in strategies 1 and 2, respectively, $E[]$ represents the expectation operator, P_{TGC} denotes the green certificate price at a future time t_1 and F_{TGC} is the forward price of green certificates at the time of decision t_0. An identical result would be obtained for producers with deterministic production. The effect of stochastic production becomes more interesting when we consider the variance of revenue (a detailed derivation of all expressions is provided in the appendix). The difference in the variance of revenue between the two strategies ($\Delta\mathrm{VAR}[R_{s2} - R_{s1}]$) can be written as

$$\Delta\mathrm{VAR}[R_{s2} - R_{s1}] = F^2_{\mathrm{V,TGC}}\,\mathrm{VAR}[P_{\mathrm{TGC}}] - 2F_{\mathrm{V,TGC}}\,\mathrm{COV}(R_{s1}, P_{\mathrm{TGC}}), \tag{2}$$

where VAR[] is the variance operator, COV() is the covariance operator and $F_{\mathrm{V,TGC}}$ represents the volume of TGC forward contracts signed at the time of decision t_0.

Using the first-order conditions for local optimum (differentiate with respect to $F_{\mathrm{V,TGC}}$ and set equal to zero) we can derive the portfolio of forward contracts that minimizes the variance of revenue as

$$\frac{\partial(\mathrm{VAR}[R_{s2}])}{\partial F_{\mathrm{V,TGC}}} = 0 \Rightarrow F_{\mathrm{V,TGC}} = \frac{\mathrm{COV}(R_{s1}, P_{\mathrm{TGC}})}{\mathrm{VAR}[P_{\mathrm{TGC}}]}. \tag{3}$$

The expression shows that the revenue-variance-minimizing strategy consists of buying or selling (depending on the sign of the numerator) an amount of forward contracts corresponding to the covariance between revenue in strategy 1 and the green certificate price divided by the variance of the certificate price. In the previous section we illustrated that the TGC price and the total number of certificates produced were negatively correlated. When the wind regime is roughly identical for all producers[7] we find the same negative correlation for the volume produced by a single producer and the TGC price. This negative correlation reduces the effect that TGC price fluctuations have on the variance of revenues[8] and in a system with significant TGC price fluctuations (high variance of the TGC price) the numerator in (3) will be small compared to the denominator. The amount of contracts that minimizes revenue variance will thus be small even in absolute terms and it will generally not be optimal to sign forward contracts for a significant amount of the expected level of production. This result is in strong contrast to the result that we obtain for a producer with a deterministic volume:

$$\frac{\partial(\mathrm{VAR}[R_{s2(\mathrm{det})}])}{\partial F_{\mathrm{V,TGC}}} = 0 \Rightarrow F_{\mathrm{V,TGC}} = V\left(\frac{\mathrm{COV}(P_e, P_{\mathrm{TGC}})}{\mathrm{VAR}[P_{\mathrm{TGC}}]} + 1\right), \tag{4}$$

where $R_{s2(\mathrm{det})}$ is the revenue for a producer with a deterministic production volume. Note that unlike expression (3) the optimal amount of contracts is here proportional to the volume produced.

4.2. Comparing strategies 1 and 3

Turning to strategy 3 we follow the same line of analysis by comparing the variance of revenue in strategy 3 with strategy 1. This gives us the following variance-minimizing strategy for a producer with a stochastic volume:

$$\frac{\partial(\mathrm{VAR}[R_{s3}])}{\partial F_{\mathrm{V,e}}} = 0 \Rightarrow F_{\mathrm{V,e}} = \frac{\mathrm{COV}(R_{s1}, P_e)}{\mathrm{VAR}[P_e]}. \tag{5}$$

Here, we cannot conclude that the numerator will be small compared to the denominator without making a set of assumptions about the short-term relationship between the TGC price and electricity price. It is clear from expression (5), however, that stochastic production has a significant effect on the trading strategy in electricity forward contracts. In comparison, the variance-minimizing strategy for a non-renewable producer with a deterministic production is $F_{\mathrm{V,e}}=\mathrm{V}$, i.e. to sign forward contracts for the entire volume that will be produced.

[6] Theoretically a wind turbine cannot produce power at an instant of time and t_1 should therefore be interpreted as an interval in time.

[7] This assumption is not unrealistic in a small geographical region like Denmark.

[8] To analyze extensively the covariance term in (3), we would need to make assumptions about both the relationship between the TGC and electricity price in the short-term and the relationship between volume and electricity price. However, none of these relationships will tend to decrease the negative correlation between revenue and TGC price and the results therefore remain valid.

4.3. Comparing strategies 1 and 4

Finally, we can derive the variance-minimizing-combined strategy in the two markets:

$$F_{\mathrm{V,e}} = \frac{BC - AD}{AD - B^2} \quad \text{and} \quad F_{\mathrm{V,TGC}} = \frac{C}{A} - B\frac{BC - AD}{D - B^2/A},$$

where

$$\begin{aligned} &A = \mathrm{VAR}[P_{\mathrm{TGC}}], \quad B = \mathrm{COV}[P_{\mathrm{TGC}}, P_{\mathrm{e}}], \\ &C = \mathrm{COV}[(P_{\mathrm{TGC}} + P_{\mathrm{e}})V, P_{\mathrm{TGC}}], \\ &D = \mathrm{COV}[(P_{\mathrm{TGC}} + P_{\mathrm{e}})V, P_{\mathrm{e}}]. \end{aligned} \tag{6}$$

This expression is relatively complex and gives little intuitive feeling for the elements of an optimal strategy. If we look at the difference in variance between strategies 1 and 4 (see (A.12) in the appendix) we can, however, note that variance is a two dimensional polynomial function of the amounts of forward contracts signed, i.e. variance increases as a polynomial function when we increase or decrease the number of contracts signed, compared with the level stated in (6). This implies that simply signing contracts for the entire expected level of production will significantly increase the variance of revenue and have a profound negative effect on the financial risk of the total portfolio.

5. Risk premium

So far, we have only considered variance-minimizing strategies. However, in a mean–variance framework the individual turbine owner's level of risk aversion will give rise to an efficient frontier[9] of optimal portfolios describing the preferred trade-off between the mean and variance of revenues. Each point on this efficient frontier describes a portfolio of forward contracts that provides the minimum possible variance at a given level of expected return.

From expression (3) we can obtain the portfolio of TGC forward contracts that minimizes revenue variance. The level of variance can subsequently be found by substituting (3) into (A.6) (see the appendix) and reducing terms. The expected revenue obtained with this portfolio of forward contracts will depend upon whether the market price of forward contracts equals the expected future TGC price or not, i.e. $F_{P,TGC}=E[P_{TGC}]$. If this equation holds, the expected revenue will be unaffected by the value/number of contracts signed. The portfolio of forward contracts given by (3) is then not only the variance-minimizing strategy, but also the only optimal strategy in a mean-variance framework.

Demand for hedging on the supply side > Demand for hedging on the demand side	$E[P_{TGC}] > F_{P,TGC}$
Demand for hedging on the supply side = Demand for hedging on the demand side	$E[P_{TGC}] = F_{P,TGC}$
Demand for hedging on the supply side < Demand for hedging on the demand side	$E[P_{TGC}] < F_{P,TGC}$

Fig. 5. Relationship between the expected future spot price and the forward price.

Financial theory states that forward prices will equal expected future prices if the demand for hedging on the demand side equals demand for hedging on the supply side (Hull, 2000). This result arises because speculators will require an additional expected return in order to undertake a risky investment, e.g. buying a TGC forward contract. At the other end, a forward contract has value for a hedger if it can provide stable revenue. The hedger is then willing to pay for this in terms of a lower level of expected return (see Fig. 5).

In order to analyze whether or not TGC forward contracts will trade at a risk premium, we compare our results from the variance-minimizing hedging strategy for suppliers with an analysis of the need for hedging on the demand side.[10] The important question is:

- Is the stochastic nature of consumption related to the TGC price and if so then how?

As described in Section 2, the demand for certificates is directly linked to the demand for electricity through the TGC quota. When demand for electricity is high, electricity prices will tend to rise. This induces a high demand for certificates through the quota (recall that the quota is defined as a percentage of electricity consumption), which in turn will increase TGC price. From this line of reasoning we see that electricity demand is positively correlated with TGC prices. So, unlike the green producers who will have more certificates when the price is low, i.e. negative correlation and a positive effect on revenue stability, consumers will face higher prices when they need to buy more

[9] Here, as previously stated, we assume that the investor's utility function can be described fully in a mean-variance framework. (This corresponds to a special case of the family of concave quadratic utility functions.) One could easily analyze optimal strategies assuming other utility functions, however this is beyond the scope and aim of this paper.

[10] We assume that well-diversified speculators are equally likely to enter as buyers or sellers of TGC forward contracts.

certificates (i.e. positive correlation and a negative effect on revenue stability). This is interesting, because it implies that demand for hedging will be higher on the demand side of the TGC market than on the supply side. This will cause speculators to enter primarily as suppliers and charge a risk premium for the sale of forward contracts to consumers. These consumers will be willing to pay a higher price to avoid revenue fluctuations implying that $E[P_{TGC}] < F_{P,TGC}$ (see Fig. 5). The mean–variance optimal strategy for an individual turbine owner is therefore not the variance-minimizing strategy in expression (6). The optimal portfolio is found as follows:

- Start out with the portfolio given by (6) and then sell forward contracts at an expected profit until the increase in both mean and variance of revenues matches your level of risk aversion.

In conclusion, we expect forward contracts to trade at a risk premium in the TGC market, i.e. forward prices will be higher than the expected TGC spot prices. This does not mean that forward prices will be higher than current spot prices. On the contrary, we should expect that TGC prices will fall over time as the renewable technology (in this case wind turbines) matures. This will reduce the desire to bank certificates, and increase the need for a well-functioning TGC forward market.

6. Conclusions

In this paper, we have described how the financial risks for potential investors and existing owners of capacity will be affected by the introduction of a consumer-based TGC system for wind turbines. With respect to policy analysis the paper has focused on the switch from a fixed feed-in tariff system to a TGC system with perfect competition and equilibrium prices based on long-run marginal costs.

The main conclusions can be summarized as follows.

First of all there are two critical risk factors that affect the financial risk for investors in the TGC system:

- fluctuations in production, i.e. volume risk;
- imperfect information about supply and demand.

The lack of information about supply and demand will cause investors to demand a higher risk premium than in the fixed feed-in tariff system. To minimize this negative effect the regulator should attempt to make the market as transparent as possible, e.g. announcing future quotas, publishing information, etc. Conversely, wind fluctuations will tend to decrease the short-term financial risks, because of the negative correlation between production volume and TGC price. This positive effect on the financial risk compared to a fixed feed-in system is generally not recognized. It is, however, important, because it shows that fluctuations in the TGC price can be a desirable phenomenon.

Secondly, we have presented analytical expressions for the variance of revenue with different trading strategies based on forward contracts. These expressions illustrate that selling forward contracts will tend to increase the financial risk for generators with a stochastic production volume. Again this somewhat counterintuitive result rests on the negative correlation between volume and TGC price. It illustrates how the certificates will act as a natural hedging instrument for producers and that fixed price contracts will tend to reintroduce some of the volume risk that the certificates remove.

Finally, the demand for hedging with TGC forward contracts will be lower on the supply side than on the demand side of the market. This implies that forward contracts will trade at a risk premium, i.e. forward prices will be higher than the expected TGC spot prices.

If a TGC system is to function as desired, both the regulator and potential investors must properly understand the implied financial risks. The uncertainty that exists today in many countries about the structure and financial effects of TGC systems discourages potential investors from directing capital towards renewable capacity. To counter this tendency a clear political signal must be given and financial effects, such as the ones described in this paper, must be communicated to potential investors.

Appendix

In this appendix we provide detailed derivations for all expressions (5)–(11). The following notation is used throughout:

R	revenue obtained by the supplier of green electricity
P_e	average price of electricity in a given time period t_1
P_{TGC}	average price of green certificates in a given time period t_1
V	total volume of certificates produced in the period t_1
$F_{V,TGC}$	volume of forward contracts on tradable green certificates
$F_{V,e}$	volume of forward contracts on electricity
$F_{P,TGC}$	forward price of tradable green certificates at the time of decision t_0
$F_{P,e}$	forward price of electricity at the time of decision t_0
$E[]$	expected value operator based on information available at time t_0
VAR[]	variance operator based on information available at time t_0

Expression (1) is found by comparing the expected revenue in strategies 1 and 2:

$$\begin{aligned} E[R_{s1}] &= E[(P_e + P_{TGC})V] \\ &= E[P_e V] + E[P_{TGC} V], \end{aligned} \tag{A.1}$$

where P_e and P_{TGC} denote, respectively, the electricity and green certificate price at a future time t_1 and V denotes the volume produced at t_1

$$\begin{aligned} E[R_{s2}] &= E[(P_e V + (V - F_{V,TGC})P_{TGC}) \\ &\quad + F_{V,TGC}F_{P,TGC}] \\ &= E[P_e V] + E[(V - F_{V,TGC})P_{TGC}] \\ &\quad + E[F_{V,TGC}F_{P,TGC}], \end{aligned} \tag{A.2}$$

where $F_{P,TGC}$ is the observed forward price of a TGC contract at the current time t_0 and $F_{V,TGC}$ is the volume contracted.

When the decision to sign forward contracts is made at time t_0 the forward price is known. Since the volume contracted must also be chosen at this point in time t_0 both values are known, i.e. they are deterministic and can be moved outside the expectation operator. This gives us:

$$\begin{aligned} E[R_{s2}] &= E[P_e V] + E[VP_{TGC}] - F_{V,TGC}E[P_{TGC}] \\ &\quad + F_{V,TGC}F_{P,TGC}. \end{aligned} \tag{A.3}$$

For expected revenue to be identical in both strategies the following relation must hold:

$$\begin{aligned} E[R_{s2}] = E[R_{s1}] &\Rightarrow E[P_e V] + E[P_{TGC} V] \\ &\quad - F_{V,TGC}E[P_{TGC}] \\ &\quad + F_{P,TGC}F_{V,TGC} - E[P_e V] \\ &\quad + E[VP_{TGC}] = 0 \\ &\Leftrightarrow \mathbf{F_{P,TGC} = E[P_{TGC}]}. \end{aligned} \tag{A.4}$$

Eq. (2) can be found in a similar way by comparing the variance of revenue in the two strategies 1 and 2:

$$\begin{aligned} \mathrm{VAR}[R_{s1}] &= \mathrm{VAR}[(P_e + P_{TGC})V] \\ &= \mathrm{VAR}[P_{TGC} V] + \mathrm{VAR}[P_e V] \\ &\quad + 2\mathrm{COV}[P_e V, P_{TGC} V]. \end{aligned} \tag{A.5}$$

For strategy 2, revenue is a sum of the income from electricity, the income from forwards on certificates and the income from the amount of certificates not sold on a forward contract. The variance can be written as

$$\begin{aligned} \mathrm{VAR}[R_{s2}] &= \mathrm{VAR}[P_e V + P_{TGC}(V - F_{V,TGC}) \\ &\quad + F_{V,TGC}F_{P,TGC}] \\ &= \mathrm{VAR}[P_e V] + \mathrm{VAR}[P_{TGC} V] \\ &\quad + \mathrm{VAR}[P_{TGC}F_{V,TGC}] \\ &\quad + 2\mathrm{COV}[P_e V, P_{TGC} V] \\ &\quad - 2\mathrm{COV}[P_e V, P_{TGC}F_{V,TGC}] \\ &\quad - 2\mathrm{COV}[P_{TGC} V, P_{TGC}F_{V,TGC}] \\ &= \mathrm{VAR}[P_e V] + \mathrm{VAR}[P_{TGC} V] \\ &\quad + 2\mathrm{COV}[P_e V, P_{TGC} V] \\ &\quad + F_{V,TGC}^2\mathrm{VAR}[P_{TGC}] \\ &\quad - 2F_{V,TGC}(\mathrm{COV}[P_e V, P_{TGC}] \\ &\quad + \mathrm{COV}[P_{TGC} V, P_{TGC}]) \\ &\quad = \mathrm{VAR}[R_{s1}] + F_{V,TGC}^2\mathrm{VAR}[P_{TGC}] \\ &\quad - 2F_{V,TGC}(\mathrm{COV}[P_e V, P_{TGC}] \\ &\quad + \mathrm{COV}[P_{TGC} V, P_{TGC}]), \end{aligned} \tag{A.6}$$

where the second equation is due the fact that both the forward price and volume are known variables at the time of decision and therefore deterministic variables with zero variance and covariance terms. The third equation also utilizes this result to move the deterministic variables outside the expectation operator. The difference in variance between the two strategies can be written as

$$\begin{aligned} \Delta\mathrm{VAR}[R_{s2} - R_{s1}] &= F_{V,TGC}^2\mathrm{VAR}[P_{TGC}] \\ &\quad - 2F_{V,TGC}(\mathrm{COV}[P_e V, P_{TGC}] \\ &\quad + \mathrm{COV}[P_{TGC} V, P_{TGC}]) \\ &= F_{V,TGC}^2\mathrm{VAR}[P_{TGC}] \\ &\quad - 2F_{V,TGC}\mathrm{COV}(R_{s1}, P_{TGC}), \end{aligned} \tag{A.7}$$

where the second equation is based on the relation $\mathrm{COV}(A, C) + \mathrm{COV}(B, C) = \mathrm{COV}(A + B, C)$.

The variance-minimizing strategy can be found by deriving the first-order conditions for optimum, i.e. differentiating (A.2) with respect to the decision variable (the amount or volume contracted $F_{V,TGC}$) and setting equal to zero. This leads directly to the expression:

$$\begin{aligned} \frac{\partial(\mathrm{VAR}[R_{s2}])}{\partial F_{V,TGC}} = 0 &\Rightarrow 2F_{V,TGC}\mathrm{VAR}[P_{TGC}] \\ &\quad - 2\mathrm{COV}(R_{s1}, P_{TGC}) = 0 \\ &\Leftrightarrow \boldsymbol{F}_{V,TGC} = \frac{\mathrm{COV}(R_{s1}, P_{TGC})}{\mathrm{VAR}[P_{TGC}]}. \end{aligned} \tag{A.8}$$

For producers with a deterministic production volume, strategy 2 yields the following expression:

$$\begin{aligned}\mathrm{VAR}[R_{s2(\mathrm{det})}] &= \mathrm{VAR}[P_e V + P_{TGC}(V - F_{V,TGC}) \\ &\quad + F_{V,TGC}F_{P,TGC}] \\ &= V^2\mathrm{VAR}[P_e] + V^2\mathrm{VAR}[P_{TGC}] \\ &\quad + F^2_{V,TGC}\mathrm{VAR}[P_{TGC}] \\ &\quad + 2V^2\mathrm{COV}[P_e, P_{TGC}] \\ &\quad - 2F_{V,TGC}V\mathrm{COV}[P_e, P_{TGC}] \\ &\quad - 2F_{V,TGC}V\mathrm{COV}[P_{TGC}, P_{TGC}] \\ &= F^2_{V,TGC}\mathrm{VAR}[P_{TGC}] \\ &\quad - 2VF_{V,TGC}(\mathrm{COV}[P_e, P_{TGC}] \\ &\quad + \mathrm{VAR}[P_{TGC}]) \\ &\quad + V^2(\mathrm{VAR}[P_e] + \mathrm{VAR}[P_{TGC}] \\ &\quad + \mathrm{COV}[P_e, P_{TGC}]). \end{aligned} \tag{A.9}$$

Differentiating with respect to $F_{V,TGC}$ and setting equal to zero yields

$$\begin{aligned}&\frac{\partial(\mathrm{VAR}[R_{s2(\mathrm{det})}])}{\partial F_{V,TGC}} = 0 \\ &\Rightarrow 2F_{V,TGC}\mathrm{VAR}[P_{TGC}] - 2V(\mathrm{COV}(P_e, P_{TGC}) \\ &\quad + \mathrm{VAR}[P_{TGC}]) = 0 \\ &\Leftrightarrow F_{V,TGC} = V\left(\frac{\mathrm{COV}(P_e, P_{TGC})}{\mathrm{VAR}[P_{TGC}]} + 1\right).\end{aligned} \tag{A.10}$$

A similar set of derivations can be made for strategy 3:

$$\begin{aligned}\mathrm{VAR}[R_{s3}] &= \mathrm{VAR}[VP_{TGC} + P_e(V - F_{V,e}) + F_{V,e}F_{P,e}] \\ &= \mathrm{VAR}[VP_{TGC} + P_eV - F_{V,e}P_e] \\ &= \mathrm{VAR}[P_eV] + \mathrm{VAR}[P_{TGC}V] \\ &\quad + \mathrm{VAR}[P_eF_{V,e}] + 2\mathrm{COV}[P_eV, P_{TGC}V] \\ &\quad - 2\mathrm{COV}[P_eV, P_eF_{V,e}] \\ &\quad - 2\mathrm{COV}[P_{TGC}V, P_eF_{V,e}] \\ &= \mathrm{VAR}[R_1] + F^2_{V,e}\mathrm{VAR}[P_e] \\ &\quad - 2F_{V,e}(\mathrm{COV}[(P_e + P_{TGC})V, P_e]).\end{aligned} \tag{A.11}$$

Differentiating with respect to $F_{V,e}$ and setting equal to zero we obtain (5) directly. Finally, we can derive the expression for variance in strategy 4 as

$$\begin{aligned}\mathrm{VAR}[R_{s4}] &= \mathrm{VAR}[(V - F_{V,e})P_e + (V - F_{V,TGC})P_{TGC} \\ &\quad + F_{V,TGC}F_{P,TGC} + F_{V,e}F_{P,e}] \\ &= \mathrm{VAR}[P_eV - F_{V,e}P_e + P_{TGC}V \\ &\quad - F_{V,TGC}P_{TGC}] \\ &= \mathrm{VAR}[P_eV] + \mathrm{VAR}[P_{TGC}V] \\ &\quad + \mathrm{VAR}[P_{TGC}F_{V,TGC}] + \mathrm{VAR}[P_eF_{V,e}] \\ &\quad + 2\mathrm{COV}[P_eV, P_{TGC}V] \\ &\quad - 2\mathrm{COV}[P_eV, P_{TGC}F_{V,TGC}] \\ &\quad - 2\mathrm{COV}[P_eV, P_eF_{V,e}] \\ &\quad - 2\mathrm{COV}[P_{TGC}V, P_{TGC}F_{V,TGC}] \\ &\quad - 2\mathrm{COV}[P_{TGC}V, P_eF_{V,e}] \\ &\quad + 2\mathrm{COV}[P_{TGC}F_{V,TGC}, P_eF_{V,e}] \\ &= \mathrm{VAR}[R_{s1}] + \mathrm{VAR}[P_{TGC}F_{V,TGC}] \\ &\quad + \mathrm{VAR}[P_eF_{V,e}] \\ &\quad - 2\mathrm{COV}[P_eV, P_{TGC}F_{V,TGC}] \\ &\quad - 2\mathrm{COV}[P_eV, P_eF_{V,e}] \\ &\quad - 2\mathrm{COV}[P_{TGC}V, P_{TGC}F_{V,TGC}] \\ &\quad - 2\mathrm{COV}[P_{TGC}V, P_eF_{V,e}] \\ &\quad + 2\mathrm{COV}[P_{TGC}F_{V,TGC}, P_eF_{V,e}] \\ &= \mathrm{VAR}[R_{s1}] + F^2_{V,TGC}\mathrm{VAR}[P_{TGC}] \\ &\quad + F^2_{V,e}\mathrm{VAR}[P_e] \\ &\quad + 2F_{V,TGC}F_{V,e}\mathrm{COV}[(P_{TGC}, P_e] \\ &\quad - 2F_{V,TGC}(\mathrm{COV}[(P_e + P_{TGC})V, P_{TGC}]) \\ &\quad - 2F_{V,e}(\mathrm{COV}[(P_e + P_{TGC})V, P_e]).\end{aligned} \tag{A.12}$$

Taking the first-order conditions by differentiating in two dimensions with respect to, respectively, $F_{V,TGC}$ and $F_{V,e}$

$$\nabla(\mathrm{VAR}[R_{s4}]) = \left(\begin{pmatrix} 2F_{V,TGC}\mathrm{VAR}[P_{TGC}] + 2F_{V,e}\mathrm{COV}[P_{TGC}, P_e] \\ -2(\mathrm{COV}[P_eV, P_{TGC}] + \mathrm{COV}[P_{TGC}V, P_{TGC}] \end{pmatrix}, \begin{pmatrix} 2F_{V,e}\mathrm{VAR}[P_e] + 2F_{V,TGC}\mathrm{COV}[P_{TGC}, P_e] \\ -2\mathrm{COV}[(P_e + P_{TGC})V, P_e] \end{pmatrix}\right). \tag{A.13}$$

Setting equal to a vector of zeros we can obtain (11) directly from solving the equation:

$$\left(\begin{pmatrix} 2F_{V,TGC}\mathrm{VAR}[P_{TGC}] + 2F_{V,e}\mathrm{COV}[P_{TGC}, P_e] \\ -2(\mathrm{COV}[P_eV, P_{TGC}] + \mathrm{COV}[P_{TGC}V, P_{TGC}] \end{pmatrix}, \begin{pmatrix} 2F_{V,e}\mathrm{VAR}[P_e] + 2F_{V,TGC}\mathrm{COV}[P_{TGC}, P_e] \\ -2\mathrm{COV}[(P_e + P_{TGC})V, P_e] \end{pmatrix}\right) = (0, 0). \tag{A.14}$$

References

Amundsen, E.S., Mortensen, J.B., 2001. The Danish green certificate system: Some simple analytical results. Energy Economics 23 (5), 489–509.

Fristrup, P. 2002. Some challenges related to introducing tradable green certificates. Energy Policy, this issue

Hull, C.J., 2000. Options, Futures & Other Derivatives. Prentice-Hall, NJ.

Jensen, S.G., Skytte, K., 2002a. Interaction between the power and green certificate markets. Energy Policy 30 (5), 425–435.

Jensen, S.G., Skytte, K., 2002b. Simultaneous attainment of energy goals by means of green certificates and emission permits. Energy Policy, this issue.

Morthorst, P.E., 2000. The development of a green certificate market. Energy Policy 28 (15), 1085–1094.

Schaeffer, G.J., Boots, M.G., Anderson, T., Mitchell, C., Timpe, C., Cames, M., 1999. The implications of tradable green certificates for the deployment of renewable electricity. ECN Report, ECN-C–99-072 ECN, 1-10-1999.