ELSEVIER

Energy Policy 31 (2003) 73–83

ENERGY POLICY

www.elsevier.com/locate/enpol

National environmental targets and international emission reduction instruments

P.E. Morthorst*

Risø National Laboratory, Senior Research Specialist, Systems Analysis Department, P.O. Box 49, 4000 Roskilde, Denmark

Abstract

According to the agreed burden sharing within the European Union the overall EU emission reduction target as agreed by in the Kyoto protocol is converted into national greenhouse gas reduction-targets for each of the member states. In parallel with national emission reduction initiatives common EU policies for emission reductions are considered. Currently discussed is the introduction of a market for tradable permits for CO_2-emissions to achieve emission reductions within the power industry and other energy intensive industries. In parallel with this markets for green certificates to deploy renewable energy technologies seem to be appearing in a number of countries, among these Denmark, Italy, Sweden, Belgium (Flanders), England and Australia. Although these national initiatives for a green certificate market are fairly different, they could be a starting point for establishing a common EU certificate market. But interactions between national targets for greenhouse gas emissions and these international instruments for emission reduction are not a trivial matter, especially not seen in relation to the possible contributions of these instruments in achieving national GHG-reduction targets.

The paper is split into three parts all taking a liberalised power market as starting point: The first part discusses the consequences of a general deployment of renewable energy technologies, using planning initiatives or national promotion schemes (feed-in tariffs). In the second part an international green certificate market is introduced into the liberalised power market context, substituting other national promotion schemes. Finally, in the third part a combination of an international green certificate market (TGC) and an international emission-trading scheme for CO_2 is analysed within the liberalised international power market set-up.

The main conclusion is that neither the use of national renewable support schemes nor the introduction of a TGC-market into a liberalised power market can be recommended, if these initiatives efficiently are expected to contribute in achieving the national CO_2-reduction targets. Countries most ambitious in implementing renewable energy technologies will only partly be gaining the CO_2-reduction benefits themselves. The ambitious countries will support the less ambitious ones in achieving their GHG-reduction targets. Finally, in a TGC-market context the most ambitious countries to fulfil their TGC-quotas will have to buy certificates from the less ambitious ones, although this only contributes to fulfilling a national target for renewable development, not in reaching their national CO_2-reduction targets.

However, a combination of an international tradable permits market and a green certificate market is seen to be efficient in contributing in achieving the national CO_2-reduction targets if a close co-ordination of the two instruments is undertaken at least at the national level: When the green power production is increased, the tradable permits quota should be decreased correspondingly. Otherwise the expected CO_2-reductions will not contribute by the full value in achieving the national targets for greenhouse gas reductions. Thus, if it is a prerequisite that renewable power contributes to achieving national GHG-reduction targets, then the combination of these two markets might be the right solution.

Keywords: Green certificates; Tradable permits; Energy policies; Electricity market; National targets for CO_2 reductions

1. Introduction

As well known the European Union in the Kyoto protocol has agreed on a common greenhouse gas (GHG) reduction of 8% by the years 2008–12 compared with 1990. According to the agreed burden sharing within the EU this overall EU-target is converted into national GHG-targets for each of the member states. Thus, some of the member states will have to reduce their GHG-emissions significantly in the above-mentioned time-period, while others are allowed to increase their emissions, mostly on account of a required economic development. In this way

*Tel.: +45-4677-5106, fax: +45-4677-5199.
E-mail address: p.e.morthorst@risoe.dk (P.E. Morthorst).

0301-4215/03/$ - see front matter
PII: S0301-4215(02)00119-2

the EU-bubble is translated into a set of national commitments.

Thus, what is mostly called for are strategies for country specific actions to comply with their Kyoto commitments. Of course, this does not rule out the possibilities and relevance of the use of EU-co-ordinated policies. An example of such a policy is the EU-directive on the promotion of renewable energy technologies (European Commission, 2000), including a proposal on the share of renewable in the individual member states in 2010, based on the percentage of each country's consumption of electricity. Although not binding it seems that these targets by now are accepted by the EU member states. Thus the directive signals the need to include renewable energy technologies as one of the serious options in achieving the targets for GHG-reductions.

The above-mentioned EU-directive fails to indicate which instruments should be used to reach these targets for renewable development, but among the highly relevant ones is the establishment of an EU-market for tradable green certificates (TGCs). Within the past few years green certificate markets have gained an extensive interest in Europe and elsewhere, and markets seem to be appearing in a number of countries, among these Denmark, Sweden, Italy, Belgium (Flanders), England and Australia. In Denmark targets for deploying renewable energy resources have existed for quite a long time and the establishment of a green certificate market to be functioning by 2004–5 is agreed by the Danish Parliament. Although these national initiatives for a green certificate market are fairly different, they could be a starting point for the establishment of a common EU-market.

A final example of a common EU-policy initiative is the recently launched directive proposal for a common EU emission trading scheme (European Commission, 2001)[1]. The main idea of such a scheme is to ensure that CO_2 reductions in the power industry and other selected industries are undertaken in the most cost-efficient manner, that is in those countries with the highest reduction potentials and the lowest costs. In this way the tradable permits (TEPs) will help ensuring that the EU member countries achieve the Kyoto greenhouse gas reduction targets as cheap as possible. The Commission within short notice withdrew the first version of this proposal, but although the new version still contains some controversial issues, it is believed that it might gain more support from the member countries.

How such international instruments as markets for emission trading and green certificates interact with each other and with the national targets for reducing greenhouse gas emissions is not a trivial matter. This paper tries to analyse these interactions within a liberalised power market context, especially in relation to the possible contributions of the instruments in achieving national GHG-reduction targets. Thus, the main purpose of the paper is to give the reader a clear understanding of how the markets act together and what this implies for national reduction policies.

The paper gives very short descriptions of the two instruments, only—an extensive number of papers and articles already do exist on these subjects, for more detailed information see Morthorst, (2000, 2001a). The next section will shortly describe the tradable permits market and the green certificate market. Following that a first case study exemplifies how a general deployment of renewable sources (using planning procedures, feed-in tariff schemes or similar) goes together with a liberalised power market. In the second case study the renewable deployment is undertaken by establishing a green certificate market and how this interacts with the liberalised power market is analysed. Finally, the introduction of a TEP-market as well as a TGC-market into the framework of a liberalised electricity market is treated.

2. An introduction to a green certificate market and a tradable permits market

2.1. A tradable permits scheme

The idea in a tradable emission permit scheme is to achieve reductions in CO_2-emissions from the power industry and other energy intensive industries by establishing a set of national quotas (permits) that can be traded both nationally and internationally. The main idea with TEPs is that CO_2-reductions are carried out where it is least costly. National and if possible international trade in permits will secure a cost-effective utilisation of CO_2-reducing options within the industries covered by the scheme. CO_2-reductions will be implemented in those companies and countries with the highest potentials and lowest costs. This ensures that the national targets for CO_2-reduction within those industries are reached in the most cost-efficient way. For TEP the emission credit will be attached directly to the emission permits: As a net importer of emission permits a country is allowed to increase its total GHG-emissions beyond its national target, the opposite being the case for net exporters of permits. If the industrial companies exceed the specified quotas, adjusted for any traded permits, they have to pay a penalty for that part of emissions exceeding the quotas.

2.2. A green certificate system

At present almost no renewable energy technologies on their own can economically compete with

[1] Observe that in the EU directive the term "permit" is used in a different way. In this paper the term "permit "is equivalent to the term "allowance" in the EU-directive.

conventional energy producing ones. The idea of a TGC-approach is to use market forces to determine the necessary additional payment to investors in renewable plants. This is done by establishing an obligation for the electricity consumers to buy a certain share of their power consumption as renewable produced energy[2]. All renewable energy technologies will be certified for producing green electricity. The owners will get a green certificate per unit of electricity produced (per MWh). This certificate can be sold to distribution companies or other electricity consumers, who are obliged to cover the specified share of their electricity consumption. Thus, the payments to owners of renewable production facilities will consist of two parts: one from the sale of the electricity produced to the spot market and the other from the sale of green certificates. The two parts will be traded at two separate markets and thus the financial certificate market in principle will be totally separated from the physical electricity market. As usually, in this analysis it is assumed that no CO_2-credits are attached to the green certificates.

3. A case study on the deployment of renewable technologies in a liberalised power market

In this section the consequences of a national deployment of renewable technologies in a liberalised power market context will be analysed, especially seen in relation to the possibilities for renewable technologies to contribute significantly in reaching the national Kyoto-targets for emission reductions. To perform this analysis a small three-country model is developed. The main assumptions behind the model are the following:

- The three countries are all part of the same physical electricity market and there are no barriers for export/import of electricity between the countries.
- All countries are assumed to have committed themselves to national GHG-reduction targets. No emission-adjustments are allowed with regard to export/import of electricity.
- All power production from renewables is assumed to be sold at the physical electricity market, no matter what the spot market price turns out to be. That is, the short-run marginal cost of renewable electricity production is sufficiently low that this production can always be sold at the market. This is the case for some renewables, e.g. wind power and photovoltaics.
- Domestic electricity consumption is assumed to be constant over time and to have a price-elasticity of zero. In reality a small price-elasticity is to be expected.

The last two assumptions are only introduced to simplify the analysis.

In the following a small numerical example will be described to illustrate how a national deployment of renewable technologies will perform in a liberalised power market, especially in relation to achieving the national GHG reduction targets. Observe that all data in the model are constructed, but especially what concerns the specification of cost curves caution is taken to make these as close as possible to the observed reality[3].

The starting point is that all the three countries previously have engaged in developing renewable power production and all three presently are trading electricity at the common power market. The initial situation is given in Table 1.

As shown in Table 1 all three countries have a renewable power production, which together with conventional fossil fuel based power production covers the total demand for power in the region. Country B has the highest power demand and imports 6.6 TWh from the two other countries determined by the marginal conditions at the spot market. Correspondingly, both country A and country B have a significant export of electricity. CO_2-emissions are related to the conventional power production using the emission-coefficients as stated in Table 1.

Now caused by government policies all three countries are increasing their renewable power production, but at quite a different pace. As shown in Table 2 country C is most ambitious increasing renewable production by 2.2 TWh, to a total of 8.2 TWh. The other two countries are more modest, only increasing renewable production by 0.2 and 0.3 TWh, respectively. How these increases in renewable deployment are undertaken is not vital for the analysis. Only that the development of renewables is undertaken as part of national deployment schemes including some kind of governmental subsidisation, e.g. using support mechanisms as feed-in tariffs or bidding procedures.

The consequences of this increase in renewable power production are shown in Table 2. When total demand in the region is fixed, the increase in renewable power will substitute conventional power production. Thus, conventional power production decreases with a total of 2.7 TWh and trade of power between the three countries is changed as well, increasing the export from country C due to its higher renewable power production. As expected the spot price goes down because of the lower demand for conventional power. But country C does not

[2] Other possibilities do exist, e.g. to put the obligation on power producers.

[3] The applied model is described in further details in Morthorst (2002a).

Table 1
The initial situation in the three countries. Exchange rate: 1€ = 7.45 DKK

	Renewable power production (TWh)	Conventional power production (TWh)	Power demand (TWh)	Export of power (TWh)	Spot price of power (c€/kWh)	CO_2-emissions (MT/year)	Initial CO_2-emission coefficients (kg/kWh)
Country A	4.0	39.8	40	3.8	3.0	35.8	0.9
Country B	5.0	34.4	46	−6.6	3.0	29.2	0.85
Country C	6.0	30.8	34	2.8	3.0	24.6	0.8
Total	15.0	105.0	120	0.0		89.7	

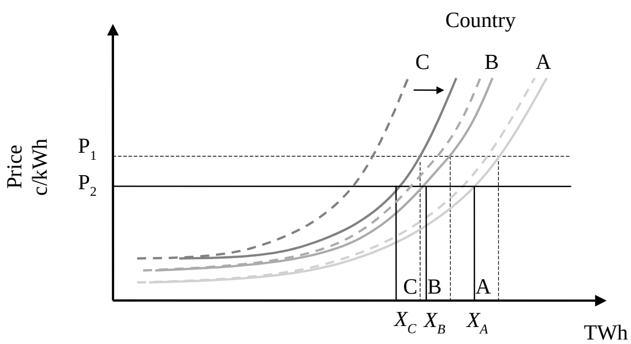

Fig. 1. Consequences at the spot market of an increased renewable power production in the three countries.

get the full value of the increase in renewable power production in terms of CO_2-reduction. As shown in Table 2 the total decrease in CO_2-reduction of 2.4 MT of CO_2 is distributed between the countries almost equally, although the major increase in renewable production did occur in country C. This is a consequence of the liberalised power trade taking place at the spot market, which will be further explained in the following.

What actually happens at the spot market is illustrated in Fig. 1. The supply of power from each of the three countries is shown at the horizontal axes, while the price is shown at the vertical axes. The increase in renewable power production shifts the supply curves for the three countries to the right. The major increase in renewable power production in country C shifts the supply curve for this country significantly to the right, while the curves are shifted only moderately for country A and B, because of the small renewable production increase in these countries. Due to the low marginal cost of renewable production more power can now be supplied at the same price (P_1). While the need for power in the three countries has not changed the surplus of power depresses the price at the spot market and a new equilibrium equalising supply with demand is found at a lower price (P_2). In this situation the conventional power production[4] has decreased in all three countries; in total by the amount of (A + B + C) shown in Fig. 1 equaling 2.7 TWh, which was the increase in renewable power production.

Thus as shown in Fig. 1 the marginal cost conditions at the spot market determine the decrease in conventional power production in the three countries. Observe that only the total increase in renewable production together with the marginal cost conditions at the spot market determines how the substitution of conventional power is split upon the three countries. How the total increase in renewable power production by itself is distributed upon the countries has no influence upon the realised substitution of conventional power, which depends totally on the marginal cost conditions at the spot market[5].

When conventional power is replaced by renewable energy emissions of CO_2 are reduced. The emission-reduction achieved will depend on the emission-coefficients related to the replaced conventional power. As shown in Table 2 a total CO_2-reduction of 2.4 MT was achieved, almost equally distributed upon the three countries. When emissions are related to the production of conventional power, the same observation as for the substituted power goes for CO_2-reductions: How the total increase in renewable power production by itself is distributed upon the countries has no influence upon the realised CO_2-reduction in each of the countries. This is totally determined by the marginal cost conditions at the spot market and the marginal emission-coefficients of the substituted power.

Thus, the main result of the ambitious renewable development in country C is that they have to share the achieved CO_2-reduction with the less ambitious countries, as shown in Table 2. Therefore, within a liberalised power market context the deployment of renewable energy technologies as an important instrument for obtaining significant CO_2-reductions cannot be recommended by itself. In general, this result stems from the fact that national reduction targets for CO_2-emissions do not go well together with a liberalised power market.

[4] The conventional power is decreased because it is the most expensive power at the spot market.

[5] As shown for emission permits by Montgomery (1972).

Table 2
The consequences for CO_2-emissions of an increase in renewable power production. Exchange rate: 1 €=7.45 DKK

	Increase in renewable power (TWh)	Renewable power production (TWh)	Conventional power production (TWh)	Export of power (TWh)	Spot price of power (c€/kWh)	CO_2-emissions (MT/year)	Change in CO_2-emissions (MT/year)
Country A	0.2	4.2	38.9	3.1	2.8	35.0	0.9
Country B	0.3	5.3	33.6	−7.1	2.8	28.5	0.7
Country C	2.2	8.2	29.8	4.0	2.8	23.8	0.8
Total	2.7	17.7	102.3	0.0		87.3	2.4

4. A case study on the introduction of a green certificate system into a liberalised power market

In this section the analysis is expanded to include a separate introduction of an international green certificate market into a liberalised electricity market. Again the three-country model is used for the analysis, but the following assumptions are added to those of the previous case study:

- All countries are assumed to have accepted the same rules for TGC trading and thus trade in certificate flows freely across the borders.
- It is assumed that no GHG-credits are attached to the green certificates.

The two markets—that is the international green certificate market and the international power market—are treated independently in the analysis. To do this it is assumed that changes in the spot market price of power are reflected immediately and totally in the TGC-price. The total marginal cost of new established renewable power would be equal to the spot price of electricity plus the green certificate price. Thus, if the spot power price falls the TGC-price will increase correspondingly and vice versa. This assumption is similar to ruling out short-run considerations in the model.

In the following the results of a small numerical example illustrate how the two markets interact and how these markets will behave in relation to reaching national GHG reduction targets. Due to limited space only results are reported here—details are found in Morthorst (2002a).

The starting point for the analysis is a pre-TGC situation, where all three countries previously have engaged in the development of renewable technologies, but no TGC-market yet exists. This starting point is shown as the left column in Table 3.

As shown in Table 3 all three countries previously have a renewable power production, which together with conventional fossil fuel-based power production is expected to cover the total demand for power in the region. Country C has the highest production of renewable power (6.0 TWh), while country A has the lowest production of 4.0 TWh.

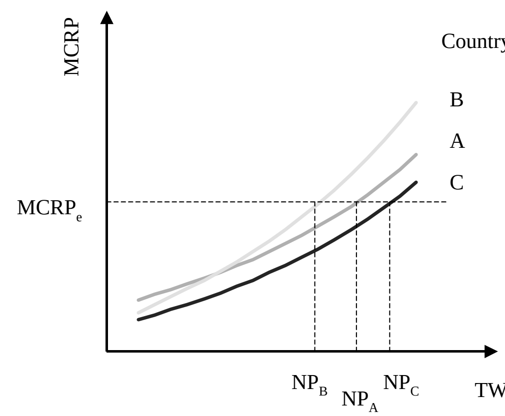

Fig. 2. Marginal production cost (MCRP) curves for the development of renewable technologies in the three countries.

Now, in common the three countries introduce an international tradable green certificate market, assigning quotas to the domestic use of renewable power. Thus, as shown in Table 3 country C is most ambitious in it's target setting for renewable development. Compared with the other countries the development of renewables is assumed to be fairly cheap in country C and therefore it increases its amount of renewable power by 2.2 TWh (36%) to an expected total of 8.2 TWh. The two other countries are less ambitious increasing their renewable target by 5% and 6%, respectively. The increase in TGC-quotas in the three countries signals a total increase in the amount of renewable produced electricity of 2.7 TWh or 18% (the same amount as in the previous case).

Now, in a TGC-market the total increase in renewable production is distributed across the three countries according to the marginal cost conditions of developing new renewable capacity. These conditions are illustrated in Fig. 2, showing the marginal production cost for new renewable power (MCRP-curves) for the three countries considered. In equilibrium the marginal production cost for new renewable power ($MCRP_e$) is equal to the spot

Table 3
Introducing a TGC-market separately into a liberalised power market

Country	Pre-TGC	Introducing a TGC-market		
	Renewable power production (TWh)	Renewable quota increase in renewable power (TWh)	Increase in actual renewable production (TWh)	Achieved CO_2 reduction (MT/a)
A	4.0	0.2	0.9	0.9
B	5.0	0.3	0.8	0.7
C	6.0	2.2	1.0	0.8
Total	15	2.7	2.7	2.4

market price of electricity plus the price of a certificate (all calculated per kWh).

How the total new development of renewables is split between the three countries is totally determined by the MCRP-conditions in those countries. According to Fig. 2 country B has the highest costs and therefore will have the lowest development of new renewables (NP_B). Similarly, country C has the lowest costs and thus will have the highest increase in the domestic implementation of renewable technologies (NP_C) at the equilibrium marginal production cost. Observe that only the total increase in the TGC-quota together with the MCRP-conditions determines how the implementation of new renewables is split between the three countries. How the total TGC-quota by itself is distributed between the countries has no impact upon the realised implementation.

Thus, assuming that the TGC-quotas are fulfilled[6] the introduction of the TGC-market increases the renewable power production by 2.7 TWh. Although country C has increased its target by 2.2 TWhs only 1.0 TWh is developed domestically. Although the development of renewables is fairly cheap in country C the residual part is more cost-efficient developed in the other countries. Thus, country C will not reach its renewable target by domestic supplies alone, but will have to import certificates corresponding to 1.2 TWh (cf. Table 3). The fact that the most ambitious country cannot expect to fulfil its quota only by domestic renewable development is perfectly in accordance with the idea of an international TGC-market.

What happens at the spot market is illustrated in Fig. 3. The supply of power from each of the three countries is shown at the horizontal axes, while the price is shown at the vertical axes. As in the previous case the increase in renewable power production shifts the supply curves for the three countries to the right—the price at the spot market is decreased and a new equilibrium equalising supply with demand is found at a lower price (P_2). In this situation the conventional power production has decreased in all three countries; in total by the

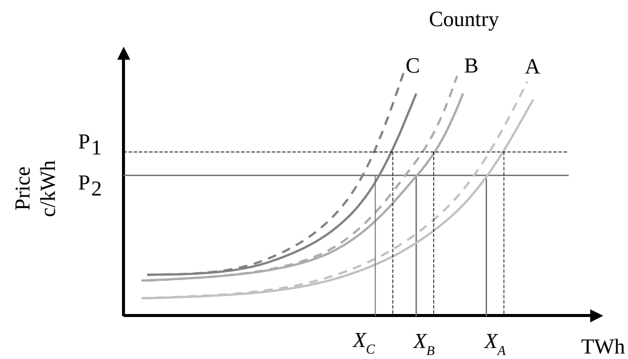

Fig. 3. The consequences at the spot market of introducing the TGC-market.

amount of 2.7 TWh, which was the increase in renewables power production.

Thus due to market conditions the strong increase in the TGC-quota for renewables production in country C has as its implication a lower conventional power production in all three countries. Observe that only the total increase in renewables production together with the marginal cost conditions at the spot market determines how the substitution of conventional power is split upon the three countries. How the total increase in renewables power production by itself is distributed upon the countries has no influence upon the realised substitution of conventional power, which depends totally on the marginal cost conditions at the spot market.

The replacement of conventional power reduces the emissions of CO_2. The emission-reduction achieved will depend on the emission-coefficients related to the replaced conventional power. As shown in Table 3 a total CO_2-reduction of 2.4 MT is achieved, almost equally distributed upon the three countries—exactly the same results as in the previous case. Thus again we see that how the total increase in renewables power production by itself is distributed upon the countries has no influence upon the realised CO_2-reduction in each of the countries. This is totally determined by the marginal cost conditions at the spot market and the emission-coefficients of the substituted power.

[6] Short-term considerations are not taken into account.

Thus, the main result of the ambitious renewables target setting in country C is that they have to share the achieved CO_2-reduction with the less ambitious countries, as shown in Table 3. In addition country C will have to pay an extra cost for importing that part of the TGC-quota, that is not fulfilled by their own domestically produced renewables power. This cost is only related to achieving a national target for renewables development, while no additional national CO_2-reduction is gained.

Thus, a separate introduction of an international green certificate system into a liberalised electricity market cannot be recommended either, if the TGC-market is expected to contribute to achieving the national CO_2-reduction targets. But of course the development of renewable sources in general does contribute to overall European greenhouse gas reductions.

5. A case study on the interactions of a tradable permits market with a green certificate system in a liberalised power context

As shown in the two previous cases the problem of renewable power development not contributing in full in reaching a national GHG-reduction target is related both to the use of a TGC-system and to a deployment of renewables based on country specific support schemes[7]. In both cases the problem is caused by the fact that a national emission reduction target does not go well together with a liberalised power market. Thus a general remedy has to be found. One solution is to introduce a tradable permit scheme as the one recently suggested by the European Commission[8].

How the tradable permits scheme works in relation to a TGC- market is illustrated in Fig. 4.

The total power supply is split into two parts: A conventional part, based on fossil fuel fired plants, and a renewable part covered by the TGC-market. The emission of CO_2 corresponds closely to the conventional produced power (cf. Fig. 4). The tradable permit (TEP) quota is introduced to lower emissions from the conventional power industry and for that reason the quota assigns a lower volume of emissions than previously experienced. If other environmental regulations are not restricting trade in CO_2 permits, then CO_2-reductions will be carried out where it is least costly and trade in permits will secure a cost-effective utilisation of CO_2-reducing options within the power industry.

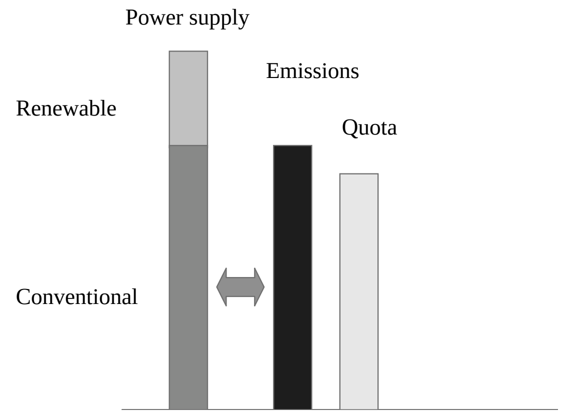

Fig. 4. The functioning of a tradable permits scheme in relation to a TGC-market.

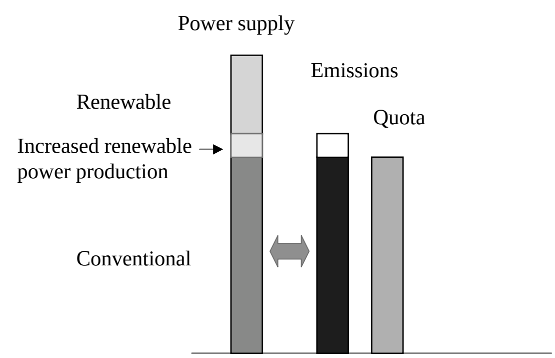

Fig. 5. A non co-ordinated development of the TGC-market in relation to the tradable permits market.

What is important for the combined system of TGCs and TEPs is a close co-ordination of the use of these two instruments. The importance of this with regard to achieving CO_2 reductions is illustrated in Fig. 5.

In Fig. 5 are shown the consequences of an non-co-ordinated increase in the renewable power production undertaken by an increased quota for renewable capacity. Renewable power production takes on a higher share of total power supply, thereby decreasing conventional power production. As the quota for tradable permits is kept at the previous level, this eases the situation for the conventional power industry: The TEP-quotas assign allowable emissions in relation to an expected level of power production. The increase in power production from renewables substitutes conventional power production and although the power industry has to produce less electricity, the emission quotas are unchanged. Thus, compared to the needed power relatively less CO_2-reductions are required in the power industry.

Thus when a TEP-quota is determined it has to take into account *both* the CO_2-reduction possibilities *and* the required level of conventional electricity production, thus the TGC- and TEP-quotas should be adjusted in a

[7] Actually the problem is exactly the same in an ordinary planning system or in an approach based on feed-in tariffs.

[8] To simplify the analyses the emission-trading scheme in this section is related only to the power industry. Assuming that the power industry is dominant in terms of CO_2-emissions, the inclusion of other industries will not change results significantly.

co-ordinated manner. Otherwise the full value of the expected CO_2-reductions will not be achieved. When the green power production is increased, the TEP-quota should be decreased correspondingly. Although this of course requires a strong co-ordination of policies it is a possible way to use the two instruments in combination in contributing to achieving national greenhouse gas reduction targets. As for the TGC-quota it is expected that the TEP-quota are decided by the authorities some years in advance and all that is required is a co-ordination of the future development of these two quotas.

To further illustrate the interactions of these two markets the analysis of the three-country model in this section is expanded to include the introduction of an international green certificate market and a tradable permits market in combination into a liberalised electricity market[9]. With regard to the model the following assumptions are additional to those put forward in the previous section:

- All countries are assumed to have accepted the same rules for TEP trading and trade in tradable permits flows freely across the borders.
- For simplicity the TEP-scheme only covers the power industry. Other energy intensive industries are not included.
- To get a non-biased price-determination at the three markets the TEP-market is assumed organised as a bidding-system (see Morthorst, 2001a).

The important part of the analysis is to show how the *development* of the two quotas interacts, that is the quotas for TGCs and TEPs. For this reason two periods are considered in the following, shown in Tables 4–7.

The starting point is Table 4 showing the initial situation. The demand for power is kept constant (at 120 TWh for all the three countries). Both the TGC- and the TEP-markets are in play with total quotas of 15.0 TWh for green certificates and 89 MT of CO_2-emissions for the considered period. Total power demand of 120 TWh in the three countries is covered partly by renewables (15.0 TWh) and partly by conventional power production (105.0 TWh). Trade between the countries is taking place in both green certificates and emission permits as shown in Table 4. The national CO_2-emission[10] is equal to the national TEP-quota adjusted for TEP trade and correspondingly the national production of renewable power is equal to the TGC-quota adjusted for TGC-trade. Thus country C is an importer of certificates and an exporter of TEPs, for country A and B the situation is reversed.

Going to period two both instruments are used actively in all three countries. The quotas for CO_2-permits are reduced in all three countries to a total of 83.0 MT (cf. Table 5). Similarly the quotas for renewable power production are increased. As shown in Table 5 country C is again most ambitious in its target setting for the renewable development, while the other two countries are more moderate (as in the previous cases). Installing new renewable capacity according to the MCRP-conditions in the three countries fulfils the TGC-quotas. The increase in renewable production replaces conventional power in all three countries, totally determined by the marginal conditions at the spot market, including the marginal costs of CO_2-reductions. As shown in Table 5 CO_2-emissions are reduced, but *only to the level determined by the emission quotas.* That is CO_2-emissions are reduced to 83.0 MT as intended by the tradable permit scheme, but *no additional CO_2-reductions are achieved through the initiatives at the green certificate market.*

Of course, it can be argued that the renewable development is part of fulfilling the CO_2-reduction targets as set forward by the tradable permit scheme. Thus deploying renewable power is one possible option for the power companies in reducing their CO_2-emissions and therefore no additional CO_2-reduction is to be expected. The renewable development simply eases the power companies in complying with the TEP-quotas.

Of course this may be correct. However, seen from this perspective a new problem arises. As shown in Table 5 country C is ambitious in its target setting for renewable development, but this development does not only help the power industry in country C to fulfil the TEP quotas. It eases the situation for power companies in all three countries. *What matters is only the total new development of renewable technologies—where this renewable deployment takes place with in the three countries does not matter at all.* As in the previous two cases the marginal conditions at the spot market determine how the environmental benefit of renewable development is distributed among the three countries, although in this case the marginal emission coefficients and the marginal costs of CO_2-reductions influence the marginal costs at the spot market as well. Thus, in accordance with this there seems to be no or little incentive to ambitiously use the green certificate market, because the ambitious countries will have to share the environmental benefits with the less ambitious ones.

However, as mentioned above the solution to the problem is not far away. The TGC- and TEP-quotas should be adjusted in a co-ordinated manner. Otherwise the individual countries will not achieve the full value of the expected CO_2-reductions. When the green power production is increased, the TEP-quota should be decreased correspondingly. This is shown in Table 6 below.

[9] A detailed model description can be found in Morthorst (2002b).

[10] Because of the introduction of the TEP-scheme and thereby constraints on CO_2-emissions, the emission-coefficients for the three countries are endogenously determined in this section. Although the starting point is those emission-coefficients shown in Table 1.

Table 4
Period one—interactions of an international TEP-market with an international TGC-market in a liberalised power market

	Quotas		Power production		Trade		CO_2-emissions
	TGC (TWh)	TEP (MT/y)	Renewable (TWh)	Conventional (TWh)	TGC (TWh)	TEP (MT/y)	(MT/y)
Country A	4.0	35	4.27	39.8	0.27	−0.50	35.50
Country B	5.0	29	5.05	34.4	0.05	−0.09	29.09
Country C	6.0	25	5.68	30.8	−0.32	0.59	24.41
Total	15.0	89	15.0	105.0	0.0	0.0	89.0

Table 5
Period two—consequences of an non-co-ordinated development of quotas in the TEP- and the TGC-markets

	Quotas		Power production		Trade		CO_2-emissions
	TGC (TWh)	TEP (MT/y)	Renewable (TWh)	Conventional (TWh)	TGC (TWh)	TEP (MT/y)	(MT/y)
Country A	4.2	33	4.92	38.9	0.72	0.04	32.96
Country B	5.3	27	5.77	33.6	0.47	−0.55	27.55
Country C	8.2	23	7.01	29.8	−1.19	0.51	22.49
Total	17.7	83	17.7	102.3	0.0	0.0	83.0

Table 6
Period two – consequences of a co-ordinated development of quotas in the TEP- and the TGC-markets in all participating countries

	Quotas		Power production		Trade		CO_2-emissions
	TGC TWh	TEP MT/y	Renewable TWh	Conventional TWh	TGC TWh	TEP MT/y	MT/y
Country A	4.2	32.83	4.92	38.9	0.72	0.76	32.07
Country B	5.3	26.75	5.77	33.6	0.47	−0.27	27.02
Country C	8.2	21.34	7.01	29.8	−1.19	−0.48	21.82
Total	17.7	80.93	17.7	102.3	0.0	0.01	80.91

Table 7
Period two—consequences of a co-ordinated development of quotas in the TEP- and the TGC-markets for country C only

	Quotas		Power production		Trade		CO_2-emissions
	TGC (TWh)	TEP (MT/y)	Renewable (TWh)	Conventional (TWh)	TGC (TWh)	TEP (MT/y)	(MT/y)
Country A	4.2	33.0	4.92	38.9	0.72	0.75	32.25
Country B	5.3	27.0	5.77	33.6	0.47	−0.14	27.14
Country C	8.2	21.34	7.01	29.8	−1.19	−0.61	21.95
Total	17.7	81.34	17.7	102.3	0.0	0.0	81.34

In this situation the TEP-quotas are adjusted according to the planned development in renewable power production in the three countries. That is, for country C the planned increase in renewable power production of 2.2 TWh is calculated to an expected decrease in domestic CO_2 emissions of 1.66 MT/y using the country specific emission-coefficient. Thus, the initial TEP-quota for country C is decreased by this amount, from 23 to 21.34 MT/y. Similar corrections are carried out for the other two countries as well.

As shown in Table 6 the regional CO_2 emissions in the co-ordinated situation are further reduced to 80.91 MT/y compared to 83 MT/y if no co-ordination of the two instruments did take place. This amount is equivalent to the increased renewable power production of 2.7 TWh converted into emission reductions by the relevant emission-coefficients. In Table 6 all TGC as TEP quotas are fulfilled through a significant trade in tradable permits as well as green certificates. Country C buys certificates corresponding to 1.19 TWh and permits corresponding to 0.48 MT/y.

If the two instruments are to be used simultaneously and efficiently in GHG-reduction strategies, all participating countries are supposed to undertake the co-ordinated development of the TGC- and the TEP-markets, where the important issue is the pace of development of the two quotas for each country. But a co-ordinated development needs not to be undertaken on an international scale to be efficient in a national GHG-reduction strategy. The situation of only one country co-ordinating the use of the TGC- and TEP-markets is shown in Table 7 below.

In Table 7 only country C has co-ordinated the development of the two markets, whilst this is not the case for country A and B. Because the initial changes in renewable power production in country A and B are fairly small only marginal changes take place in this situation compared to the previous one. According to Table 7 all countries increase their domestic CO_2 emissions compared to the totally co-ordinated situation[11], but country C increases the purchase of tradable permits to fulfil the TEP-quota compared with the previous case, while this is not seen for the other two countries. Thus, although country C stands alone co-ordinating the TEP—and the TGC-markets it does receive the full value of the CO_2-reduction related to the increase in the TGC-quota through trade at the TEP-market, while this is not the case for country A and B.

Summarising, if the intentions are to utilise the two instruments—TGCs and TEPs—in a national GHG-reduction strategy all that is required is a national co-ordination of the two instruments. An international co-ordination of the two instruments is not needed, although on a global scale of course more CO_2-reductions are achieved by doing so.

Finally, as described in case one above (Section 3) the problem of gaining the full benefit of a national implementation of renewable power is not restricted to green certificate markets, but is a general problem no matter what deployment scheme is used if the country takes part in a liberalised power market. Those countries most ambitious in implementing renewables sources might see part of the expected CO_2 benefit disappearing to other less ambitious countries participating in the same power market. In these cases as well the introduction of tradable permits scheme is the solution if the necessary co-ordination of measures is undertaken.

[11] Total emission increase of 0.43 MT/y corresponding to the renewable power increase in country A and B of 0.5 TWh.

6. Conclusions

As well known the European Union in the Kyoto protocol has agreed on a common greenhouse gas reduction of 8% by the years 2008–12 compared with 1990. According to the agreed burden sharing within the EU this overall EU-target is converted into national GHG-targets for each of the member states. At the same time there is a trend in European policy of liberalising the power markets, establishing power exchanges especially in northern Europe. But national targets for GHG-reduction and being part of a liberalised international power market do not necessarily go well together.

A main conclusion from this paper is that neither the use of national renewable support schemes nor the introduction of a TGC-market into a liberalised power market can be recommended, if these initiatives efficiently are expected to contribute to achieving the national CO_2-reduction targets:

- Countries most ambitious in implementing renewable energy technologies will only partly be gaining the CO_2-reduction benefits themselves. How much they gain will totally be determined by the marginal conditions at the spot markets and the emission-coefficients of the replaced power. Thus, the ambitious countries support the less ambitious ones in achieving their GHG-reduction targets.
- In the case of a TGC-market the most ambitious countries to fulfil their TGC-quotas will have to buy certificates from the less ambitious ones, although this only contributes to fulfilling a national target for renewable development, not in reaching their national CO_2-reduction targets.

A remedy to this problem is found by introducing a tradable permits market. In the case of a combined green certificate system and a tradable permits market it requires that the quotas of the two markets be adjusted in a co-ordinated manner: When the green power production is increased, the tradable permits quota should be decreased correspondingly. Otherwise the expected CO_2-reductions will not contribute by the full value in achieving the national targets for greenhouse gas reductions. Although this requires a strong co-ordination of these policy instruments it might show the necessary way forward if renewable power is to contribute significantly to achieving the national emission reduction targets.

Finally, as mentioned above, the problem of gaining the full CO_2 benefit of a national implementation of renewable power is not only related to green certificate markets, but is general in character if the country takes part in a liberalised power market. Those countries most ambitious in implementing renewable sources might see part of the expected CO_2 benefit disappearing to other less ambitious countries participating in the same power market. If the necessary co-ordination of measures is undertaken the introduction of a tradable permits scheme may be the solution in these cases as well.

References

European Commission, 2000. Proposal for a directive of the European parliament and of the council on the promotion of electricity from renewable energy sources in the internal electricity market.

European Commission, 2001. Proposal for a directive of the European parliament and of the council establishing a framework for greenhouse gas emissions trading within the European Community and amending Council Directive 96/61/EC.

Montgomery, W.D., 1972. Markets in licenses and efficient pollution control programs. Journal of Economic Theory 5 (3), 395–418.

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

Morthorst, P.E., 2001a. Interactions of a tradable green certificate market with a tradable permits market. Energy Policy 29/5, 345–353.

Morthorst, P.E., 2002a. A green certificate market combined with a liberalised power market, forthcoming.

Morthorst, P.E., 2002b. Interactions of instruments and national Kyoto-targets, forthcoming.