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Implementing the EU renewable target through green certificate markets

Abstract:
The EU Parliament has agreed on a target of a 20 % share of renewables in the EU's total energy consumption by 2020. To achieve the target, the Council has adopted mandatory differentiated national targets for each of the Member States. In this paper we consider the potential for cost reductions by allowing for trade in green certificates across Member States. We show that differentiated national targets cannot ensure a cost effective implementation of the overall target for EU's green energy consumption. Trade in green certificates can ensure a cost effective distribution of green energy production, but the national targets prevents a cost effective distribution of energy consumption. Nevertheless, our numerical model indicates that EU-wide trade in green certificates may cut the EU's total cost of fulfilling the renewable target by as much as 70 % compared to a situation with no trade. However, the design of green certificate markets may have large impact on the distribution of costs across countries.

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1. Introduction

In December 2008, the EU Parliament agreed on a Climate and Energy Package which is designed to achieve the EU's overall *environmental target* of a 20 % reduction in greenhouse gas (GHG) emissions and the *renewable target* of a 20 % share of renewables in the EU's gross final energy consumption by 2020, see EU (2009a) and EU (2009b). EU (2009b) is henceforth referred to as *the Renewables Directive*, whereas the term *EU's Energy and Climate Package* covers both EU (2009a) and EU (2009b).

A green certificate system, also known as renewable portfolio standards or renewable obligations, requires consumers, retailers or producers to derive a certain percentage of final energy consumption/production from renewable sources. The purpose of this paper is to analyse the cost-effectiveness of various designs of green certificate systems to achieve EU's renewable target. In the light of our findings, we discuss EU's adopted policy of differentiated renewable national targets across Member States. As the GHG reduction target is not our main focus, we assume as a starting point for our analysis that all GHG emissions within the EU are restricted through a uniform price on emission, which ensures that the GHG emission reduction target is met.

According to the literature, if the goal is to secure a certain share of renewables in final consumption, a green certificate market provides a cost effective achievement (Bye, 2003, Haas et al., 2004, and Aune et al. 2008). Green certificates are currently introduced in several European countries (EU, 2008a). However, the literature also shows that if the purpose of the regulations is to achieve GHG emission reductions, a green certificate market is not the first best policy, neither alone (Palmer and Burtrow, 2005) or in combination with an emission trading scheme (Böhringer and Rosendahl, 2009, and del Río González, 2007).[1]

Stimulating green energy production can of course be motivated by objectives other than GHG emissions reductions. EU argues that the renewable target means a boost for high-tech industries, new economic opportunities and jobs (EU, 2008b). It is a well known result that private markets will under-invest in R&D due to firms' inability to appropriate the social returns of investment (Stoneman and Vickers, 1988). Hence, some kind of governmental funding of R&D may be appropriate to make investors internalize the positive externalities associated with R&D. These objectives could

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[1] For other studies on the performance of green certificates see, e.g. Amundsen and Nese (2009), Amundsen and Mortensen (2001), Morthorst (2001), Fischer (2006) and Bertoldi and Huld (2006).

nevertheless be met more cost effectively by R&D subsidies than by setting a fixed renewable target. As pointed out in Sorrell and Sijm (2003), the objectives must be explicit in order to design efficient policies. In this paper, we do not question whether a renewable target is a part of an efficient policy or the motivations for stimulating green energy production.[2] We simply take the renewable target as a premise for our study.

To achieve the target of a 20 % share of renewables in EU's total energy consumption, the European Council has adopted mandatory differentiated national targets for each of the Member States. The national targets range from 10 % to 49 %, but are consistent with EU's overall renewable target. According to the Renewable Energy Directive (EU, 2009b, article 5), the consumption of renewables is defined as electricity and heat *produced* from renewable sources, plus the consumption of other renewable energy sources, such as biofuels. Hence, the renewable target can be interpreted as a target for green energy production + net import of green energy, relative to final energy consumption.

EU's climate and energy package sets no restrictions on how countries may stimulate their green energy production. Currently, there is a wide range of policy instruments aimed at promoting renewable energy in use in the EU countries (Haas et al., 2004 and EU, 2008a). As a point of departure for our analysis, we consider a situation where the policy instrument to achieve the renewable target is a green certificate system in all countries. However, it is worth noticing that the market solution following from the green certificate system can be mimicked through a subsidy on green energy production and a tax on energy consumption under the restriction of budget neutrality (Aune et al., 2008, chapter 6.2).

The Renewables Directive states that the Member States may meet their national renewable targets by financing green energy production in other countries, so-called statistical transfers.[3] The option for statistical transfers is a means to reduce the total cost of meeting the renewable target by distributing green energy production across Member States more cost effectively, compared to a situation where each country has to meet its target by domestic renewable energy production. It is, however, yet unclear to which extent this option will be utilized by the Member States. According to EU (2010), only 5 EU countries will rely on non-domestic measures to meet their targets, and less than 1 per cent

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[2] Although a properly designed green certificates system leads to cost-effectiveness when the policy goal is to increase the share of renewables, it is not an efficient instrument for correcting for externalities (see Aune et al., 2008, chapter 6.2).
[3] See article 6 of EU (2009b).

of the renewable production will be traded between member countries or between EU countries and third party countries.

A potential system that fully exploits the benefit from a cost effective distribution of renewable energy production is an EU-wide green certificate system: All producers receive a green certificate for every unit green energy produced, and all consumers of energy must purchase green certificates corresponding to the specified share of renewable energy faced by their countries of origin.[4] The EU's system of statistical transfers can be seen as a first step towards a full green certificate system in the Community. To explore the impact of EU-wide trade, we compare a situation with full trade in green certificates with no trade in green certificates across Member States. Furthermore, to explore the impact of *differentiated* national renewable targets, we also consider a cost-effective policy which is ensured by a common renewable target for all EU members and full trade in green certificates.

This leaves us with an evaluation of three different relevant policy scenarios; *i*) a common renewable target for all Member States with EU-wide trade in green certificates, *ii*) differentiated national targets for each of the Member States with EU-wide trade in green certificates, and *iii*) differentiated national targets for each of the Member States with domestic trade in certificates only. To our knowledge, the present paper is the only study which *theoretically* and *empirically* evaluates the cost reducing potential of allowing for trade in green certificates across countries by comparing these three scenarios.[5]

By the use of a theoretical model, we find that the use of differentiated national targets is not a cost-effective policy to reach a certain renewable share. This conclusion holds also when there is EU-wide trade in green certificates. Hence, there is an important distinction between a green certificate market and an emissions permit market. With tradable emissions permits, cost effectiveness is achieved (in a competitive market) regardless of the initial allocation of permits (Montgomery, 1972). In a green certificate market the consumers' marginal costs of energy differ if the renewable targets vary across countries. This violates the conditions for a cost effective distribution of energy consumption. Cost-

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[4] In this paper we do not discriminate between "old" and "new" renewable energy, as is done in some green certificate markets. Plumb and Zamfir (2009) give a comparative analysis of different green certificate markets in the EU.

[5] Aune et al. (2008) calculate the outcome of national certificate markets in the EU and compare this with a common certificate market in the EU. EU (2008a) and Capros et al. (2008) compare a cost-effective implementation of the renewable target versus national renewable targets. However, their numerical simulations differ from ours in several ways: They do not employ a green certificate market, which implies that they do not have financial transactions across agents through a certificate market. Furthermore, they introduce several restrictions on the implementation of the renewable target. For instance, their simulations on national renewable targets restrict the renewable share of the individual countries exactly to the targets in the EU proposal, which imply higher greenhouse gas emissions reductions costs than without that restriction.

effectiveness is only achieved by imposing a common renewable target for all countries and allowing for free trade in green certificates.

We employ a numerical multi-market energy equilibrium model to assess the impact of the various designs of green certificate markets. The model simulations indicate large gains from trade in green certificates. Given the differentiated national targets set by the Council, the overall cost of achieving the EU's renewable target can be cut by almost 70 per cent by EU-wide trade in green certificates.

The efficiency loss related to differentiated targets, and hence differentiated increase in consumer prices across countries, is more modest. Given trade in green certificates, the EU's total cost can be further reduced by almost 4 per cent by having a common renewable target compared to differentiated national targets (scenario (*ii*) versus scenario (*i*)). The various designs of green certificate markets have large impacts on the distribution of costs across countries, and not all countries are better off with trade.

Section 0 provides our theoretical model to illustrate the qualitative results. Thereafter, in section 3, we present the numerical model and the results. Concluding remarks are given in section 4.

2. The Theoretical Model

To analyse the scenarios theoretically it is sufficient to consider a two country case. We also simplify the analysis by ignoring trade in energy with third countries (the numerical model provides a more realistic presentation of the energy market in the EU, including trade with countries outside the EU). Let e_1 and e_2 denote the consumption of energy from the two countries, 1 and 2. Let x_i and y_i denote country i's production of renewable (green) and fossil (brown) energy, respectively. For the consumers, we assume that both types of energy are perfect substitutes. Furthermore, let $c_i(x_i)$ and $f_i(y_i)$ be country i's cost functions for producing green and brown energy, respectively, whereas $B_i(e_i)$ denotes country i's benefit of consuming energy. We assume free trade, no transportation costs, and the following properties of the cost and benefit functions:
$c_i'(x_i) > 0, c_i''(x_i) > 0, f_i'(y_i) > 0, f_i''(y_i) > 0, B_i'(e_i) > 0,$ and $B_i''(e_i) < 0.$ The market equilibrium condition is:

(1) $$e_1 + e_2 = x_1 + x_2 + y_1 + y_2.$$

As a starting point we consider a situation where the two countries jointly have a target for emissions of CO_2 from the combustion of fossil fuels. As we only consider one type of fossil fuels in this theoretical part of the paper, this corresponds to a target ($\overline{Y}$) for total consumption of fossil fuels:

$$(2) \qquad\qquad y_1 + y_2 \leq \overline{Y}.$$

The countries have a common target for the share (α) of renewable green energy in their final consumption:

$$(3) \qquad\qquad x_1 + x_1 \geq \alpha \cdot (e_1 + e_2), \qquad 0 < \alpha < 1.$$

Throughout this theoretical analysis we only consider situations where both constraints are binding. Hence, (2) and (3) are satisfied with equality.

Total welfare (W) is given by:

$$(4) \qquad\qquad W = \sum_i B_i(e_i) - c_i(x_i) - f_i(y_i),$$

Maximizing
(4) w.r.t. e_i, x_i and y_i subject to (1), (2) and (3), yields the following optimality conditions:

$$(5) \qquad\qquad B_1' - \alpha\lambda_3 = B_2' - \alpha\lambda_3 = c_1' - \lambda_3 = c_2' - \lambda_3 = f_1' + \lambda_2 = f_2' + \lambda_2 = \lambda_1,$$

where λ_1 is the shadow cost of the market equilibrium constraint (1), λ_2 is the shadow cost of the fossil fuel target constraint, (2), and λ_3 is the shadow cost of the renewable target constraint, (3). Let $e_i^*, x_i^*, y_i^*, \lambda_1^*, \lambda_2^*$ and λ_3^* denote the outcome of the optimal solution following from (1), (2), (3) and (5), i=1,2.

We see from (5) that the marginal cost of producing green energy must exceed both the marginal benefit of consuming energy and the marginal cost of producing fossil fuels in optimum (as λ_3 and $\lambda_2 > 0$, and $0 < \alpha < 1$ by assumption). Furthermore, we see that the marginal benefit of consumption is equalized across consumers, the marginal cost of green energy production is equalized across green

energy producers, and finally, the marginal cost of fossil fuel production is equalized across fossil fuel producers.

In the next sections we consider three different scenarios for achieving the renewable target by the use of a green certificate system, given a common competitive energy market and a common competitive tradable emissions permits market. The scenarios correspond to *i)* - *iii)*, described in the introduction.

2.1. Scenario i): Common target - Common certificate market

The countries have a common target for the share (α) of renewable energy in their final consumption. This implies that all consumers of energy are obliged to purchase α green certificates for each unit of energy they consume. Let *β* denote the unit price on certificates. Renewable energy producers have the right to sell one green certificate per unit renewable energy produced. Let *p* denote the market price on energy. Let *t* denote the market price on emission permits, and let *p* denote the consumer price on energy. The net benefit from consumption (*w*) in country *i* is:

$$(6) \qquad\qquad w_i = B_i(e_i) - (p + \beta\alpha)e_i, \quad i = 1, 2$$

As we have assumed that both types of energy are perfect substitutes for the consumers, the consumer price cannot differ across energy types.

The producer price on each energy source equals the market price less of any net taxes (taxes minus subsidies). The producers of renewable energy also gain *β* on each unit of energy. Hence, the green and brown energy producers' profit functions, denoted π_{ix} and π_{iy}, are respectively:

$$(7) \qquad\qquad \pi_{ix} = (p + \beta)x_i - c_i(x_i) \quad i = 1, 2$$

$$(8) \qquad\qquad \pi_{iy} = (p - t)y_i - f_i(y_i) \quad i = 1, 2$$

The producer price on energy for fossil fuel producers equals *p-t*, whereas the producer price on green energy equals *p+ β*.

The first order conditions for consumers' welfare optimization and producers' profit maximization are found by maximising (6) w.r.t. e_i, maximizing (7) w.r.t. to x_i, and maximizing (8) w.r.t. to y_i:

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(9) $$B_1' - \alpha\beta = B_2' - \alpha\beta = c_1' - \beta = c_2' - \beta = f_1' + t = f_2' + t = p$$

Let $e_i(p + \alpha\beta), x_i(p + \beta)$ and $y_i(p - t)$ denote the demand and supply functions following from (9).

The renewable target constraint, (3), sets the market equilibrium condition for the certificate market:

(10) $$\alpha(e_1(p + \beta\alpha)) + \alpha(e_2(p + \beta\alpha)) = x_1(p + \beta) + x_2(p + \beta)$$

By inserting the demand and supply functions following from (9) into (1) and (2) we find the equilibrium conditions for p, t and β, denoted p^*, t^* and β^*, respectively from (1), (2) and (10). Hence, p^*, t^* and β^* ensure that the constraints regarding total consumption and production (eq. (1)- (3)) are satisfied. Furthermore, we see from (9) that a common green certificate market also ensures the optimal distribution of production and consumption across countries. Thus, it follows from (9) that $e_i(p^* + \alpha\beta^*) = e_i^*, x_i(p^* + \beta^*) = x_i^*$ and $y_i(p^* - t^*) = y_i^*$.

Hence, the green energy certificate market ensures the optimal solution, given a target for the share of green energy in final energy consumption (eq. (3)).

2.2. Scenario ii): Differentiated targets – A common certificate market

In this situation, each country has an individual target for its share of renewable energy in final consumption, α_i. There is a common green certificate market. This implies that the producer price on green energy equals $p + \beta$ in both countries, as in scenario i), whereas the consumer prices on energy $(p + \beta\alpha_i)$ differ. Replacing $p + \beta\alpha$ with $p + \beta\alpha_i$ in (6), the first order conditions for consumers' welfare maximization and producers' profit maximization are given by:

(11) $$B_1' - \alpha_1\beta = B_2' - \alpha_2\beta = c_1' - \beta = c_2' - \beta = f_1' + t = f_2' + t = p$$

We see from (11), that $B_1' \neq B_2'$ for $\alpha_1 \neq \alpha_2$ and $c_1' = c_2'$. Hence, we can derive the following proposition:

Proposition 1:

Consider a group of countries with a target for a specific share of total renewable energy in overall energy consumption. A green certificate market does not lead to a cost-effective achievement of the overall target if the individual countries are assigned differentiated targets. However, the production of green energy is cost effectively distributed across producers.

When the green certificates are tradable across countries, all green energy producers face the same producer price and a cost effective distribution of green energy production is ensured. Differentiated targets lead to differentiated consumer price on energy across consumers and the consumption of energy is thus not distributed optimally across consumers.

2.3. Scenario iii): Differentiated targets - National certificate markets

In this situation, each country has an individual target for its share of renewable energy in final consumption α_i, and each country has an individual certificate market. Let β_i denote the market price on certificates in country i. The consumer price on energy in country i is $p + \beta_i \alpha_i$. Replacing $p + \beta\alpha$ with $p + \beta_i \alpha_i$ in (6) and replacing β with β_i in (7), the first order conditions for consumers' welfare maximization and producers' profit maximization are given by:

(12) $$B_1' - \alpha_1\beta_1 = B_2' - \alpha_2\beta_2 = c_1' - \beta_1 = c_2' - \beta_2 = f_1' + t = f_2' + t = p$$

We see from (12) that the marginal benefit of energy is not equalized across consumers (countries), except by chance, as $B_1' \neq B_2'$ for $\dfrac{\alpha_1}{\alpha_2} \neq \dfrac{\beta_2}{\beta_1}$. Furthermore, marginal cost of green energy production is not equalized across producers, except by chance, as $c_1' \neq c_2'$ for $\beta_1 \neq \beta_2$. This leads to the following proposition:

Proposition 2:

Consider a group of countries with a target for a specific share of total renewable energy in overall energy consumption. Individual green certificate markets lead to an inefficient distribution of green energy production and an inefficient distribution of energy consumption.

3. Numerical illustrations

In order to evaluate the qualitative impact of the alternative scenarios, we need an energy market model that captures the main features of the different alternatives, and quantify the impact on main economic variables, such as total cost, consumer surplus, producer surplus, energy production and prices. To conduct this qualitative evaluation, we use the multi-market energy equilibrium model LIBEMOD. The model's focus is on the electricity and natural gas markets of Western Europe, but it also covers global markets for coal and oil. See Golombek et al. (2009) for a documentation of the present version of LIBEMOD, and Aune et al. (2008) for a more detailed description of LIBEMOD, including data sources.[6]

3.1. Detailed description of the numerical model

LIBEMOD distinguishes between 16 endogenous Western European model countries[7], three exogenous model countries which are important for the Western European gas market[8] ,and an exogenous region containing the rest of world. Only the endogenous model countries have a full set of energy markets. However, also the exogenous model countries possess endogenous supply of one or more fossil fuels.

As the EU's Energy and Climate Package covers all of the current 27 EU members, (EU-27), whereas LIBEMOD only reports CO_2 emissions and green energy production from the Western European countries, LIBEMOD has a limitation when it comes to simulating the full effects of EU's policy. However, we believe that LIBEMOD-simulations still provide a good picture of the impact of the various designs of green certificate markets in the EU, as LIBEMOD's endogenous model countries cover 85 % and 84 % of EU-27's energy consumption and production, respectively (Eurostat, 2008).[9]

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[6] The version of LIBEMOD used in the present paper – LIBEMOD 2000 CCS – differs somewhat from the one documented in Aune et al. (2008), the main differences being *i*) electricity is traded in two (not six) periods over the 24-hour cycle, *ii*) more electricity technologies are available (CCS technologies for coal and gas power plants), and *iii*) a more aggregated representation of coal markets is used.

[7] Austria, Belgium (incl. Luxembourg), Denmark, Finland, France, Germany, Greece, Great Britain and northern Ireland, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and Switzerland.

[8] Algeria, Russia and Ukraine

[9] The Renewables Directive is relevant for EEA. Norway is not an EU member, but a member of EEA. Therefore, it is reasonable to include Norway among countries covered by EU's climate and energy package. Switzerland on the other hand, is not a member of EEA. While Switzerland is not yet a part of the EU-ETS trading scheme, they aim to merge their national trading scheme with the European emissions trading scheme, see http://www.uvek.admin.ch/dokumentation/00474/00492/index.html?lang=en&msg-id=28680. The Renewables Directive, article 9 opens for joint projects in production of renewable electricity between EU member states and third countries. We therefore also include Switzerland among countries covered by EU's climate and energy package in our numerical analysis.

We have made some adjustment to the targets specified in EU's Energy and Climate Package to take into account that LIBEMOD's endogenous model countries differ from EU-27. The Renewables Directive sets differentiated national targets for the increase in renewables in each of the Member States, which are consistent with a target of at least a 20 % share of energy from renewable sources in the Community's final consumption, see Appendix A. When we sum up the Renewables Directive's national targets for LIBEMOD's endogenous model countries, we find these targets consistent with a target of a 19.7 % share of energy from renewable sources in the final consumption in LIBEMOD.[10]

We have also made an adjustment to incorporate EU's target of a 20 % reduction in GHG relative to 1990 levels. This target is achieved partly by a 21 % reduction below 2005 levels from sources covered by EU's emission trading scheme (EU-ETS), and partly by differentiated national targets for emission from sources not covered by EU-ETS. We find the total target for LIBEMOD's endogenous model countries by assuming a 21 % reduction relative to 2005, of emissions covered by EU-ETS in these countries. The sum of emissions reductions for sectors outside EU-ETS are found from summing up the differentiated national targets for the LIBEMOD's endogenous model countries, given in EU (2009a).[11]

As the Renewables Directive is the main focus of this paper, we have simplified the GHG emissions policy by assuming that all sources of emissions face the same price on emission, in terms of a common CO_2 tax, and this tax ensures that the target is fulfilled. Furthermore, we only consider emissions of CO_2, and assume that the percentage G HG reduction targets holds for CO_2-emissions.

All markets in LIBEMOD are competitive. In each endogenous model country there is investment in energy infrastructure, as well as production, consumption and trade of energy. In equilibrium all arbitrage possibilities are exploited and thus price differences for each good reflect cost differences only.

Seven energy goods are included; electricity, biomass, oil, natural gas, lignite, steam coal and coking coal. Natural gas and electricity are traded between endogenous model countries as well as a few exogenous model countries such as Russia. Oil, steam coal and coking coal are traded in global markets.

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[10] For Norway the national renewable target is set to 68 %. This is found from using the same method as employed by the EU for setting the national targets for EU Member States (see EU, 2008a, Annex 6). Point Carbon (2008), finds, by using this method that Norway should increase its renewable share with 14.5 percentage points. We apply the same increase in renewable share for Norway in our numerical simulations. The national renewable target for Switzerland is set to 0 (see footnote 9).

[11] For both Norway and Switzerland the national goals are set to a 20 percent reduction in national non EU-ETS CO_2 emissions in 2020 compared to 2005.

LIBEMOD offers a detailed description of production of electricity in each model country. In general, there are a number of technologies available for production of electricity in existing plants or in new plants. For steam coal power and gas power, a producer can install carbon capture and storage in an existing plant, or build a new power plant with CCS.

There are four groups of users of energy: Power producers, households/services, industry and transport. The first group represents intermediate demand; power plants demand a fuel as an input in production of electricity. This fuel could be steam coal, lignite, natural gas, oil or biomass. The three latter groups represent end-user demand.

LIBEMOD ignores the use of biomass in other sectors than the electricity sector. As we know that the use of biomass (biodiesel and bioethanol) can substitute fossil fuels in the transport sector and biomass can substitute gas or coal for heating, we have decided to exogenously determine the use of biomass in the transport sector and in the stationary energy sector. EU statistics provide information about the use of biomass in 2005 in these sectors for all endogenous model countries.[12] We have prolonged this use of biomass to 2020. Furthermore, from the EU Renewable Energy Directive we adopt that the use of biomass in the EU transport sector increases to 10 per cent of the total energy use in that sector in 2020. For the stationary energy sector, we assume that the percentage share of biomass in 2020 corresponds to the percentage renewable targets (19.7 %). The distribution across countries is determined by assuming the same percentage point increase from 2005 to 2020 across all countries. In total, this gives us a use of renewables in the stationary energy sector in 2020 approximately in line with EU's projections[13]. The absolute values of biomass in the transport sector and stationary energy sector are identical in all three scenarios. We do not consider any trade in biomass across countries. However, the biomass used as input factor in the production of electricity is endogenously determined in the model.

3.2. Simulations

Using the LIBEMOD model, we compare the costs of implementing EU's renewable target through the three different scenarios described in the theoretical model: *i*) an equal percentage renewable target for all countries and EU-wide trade in green certificates system, *ii*) individual renewable targets and EU-wide trade in green certificates and *iii*) individual renewable targets and no EU-wide trade in green certificates.

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[12] For each country, see Table 7, category "Final consumption of RES (excl. electricity)" in Eurostat (2008)

[13] See EU (2007), page 20, figure "Renewables growth: Heating and cooling projections by 2020".

As a starting point for our analysis, we first simulate a base scenario with no renewable target, but with a common EU-wide carbon tax sufficiently high to ensure a 20 % reduction of emissions of carbon dioxide in 2020. Thereafter, we simulate the three different scenarios for green certificates systems, given both the target for CO_2 emissions and the renewable target. Table 1 presents the impact of introducing a renewable target through the three different scenarios for green certificates. The absolute numbers represent the changes relative to the case with no renewable target (base scenario), whereas the percentage numbers in the brackets represents the percentage change in outcome of scenario *i*) and *ii*) relative to scenario *iii*). Hence, the percentage numbers show the effects of opening up for trade in green certificates, given a renewable target.

From Table 1 we see that opening up for EU-wide trade in green certificates strongly reduces the cost of introducing a renewable target compared to domestic certificate trade only. The cost of meeting the overall EU target is reduced by 69 % under system *ii*) compared to system *iii*). The cost effective solution with a common renewable target and EU-wide trade in certificates (system *i*) reduces the costs by 71 % compared to system *iii*). This tells us that the main driving force to reduce the cost of the renewable target is to allow for trade in green certificates.[14] Given free trade in green certificates, shifting from differentiated national targets to common national targets only reduces the costs further by approximately 4 %.

From Table 1, we also see that the introduction of the Renewables Directive causes large changes in the producer and consumer surplus.[15] The large increase in the producer surplus is mainly caused by increased incomes from green certificates. The producers of renewable energy receive an income from the green certificate system and therefore increase their producer surplus. We see that the producer surplus is very similar under system *i*) and *ii*), but is much higher under system *iii*). This is mainly driven by the higher prices on green certificates under scenario *iii*). The average price of green certificates equals € 47 in scenario *iii*), whereas the common certificate price has fallen to € 26 in scenario *i*) and *iii*), due to the EU-wide trade in green certificates.[16]

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[14] Our estimated gains from trade in certificates are somewhat higher than the estimate in EU (2008a), where the costs from achieving the renewable and greenhouse gas target are based on simulations using the PRIMES and GAINS models. They find that trade in green certificates, given differentiated renewable targets, can reduce costs by € 8 Bn compared with no trade in certificates. See table 36 in EU (2008a). Their results are not directly comparable with ours due to different countries being included in the analysis and different assumptions about the carbon costs in the non EU ETS sector.

[15] Consumer surplus is here understood as the surplus for all end-users of energy (households, the service industries, other industries and transportation).

[16] One certificate being equal to one MWh of renewable energy production.

The consumer surplus is substantially reduced in all three scenarios. Introducing a renewable target is costly for the consumers as they have to pay for green certificates in order to be able to consume energy. However, Table 1 shows that the loss in consumer surplus is considerably lower when the green certificates are tradable EU-wide. Again, this follows from a lower certificate price with EU-wide tradable green certificate systems compared to national green certificate systems.

In all three systems there is also a clear decrease in tax income. Taxes included in the model are energy taxes, VAT and carbon taxes. The renewable target leads to lower energy consumption in general and especially lower consumption of fossil energy. Hence, revenues from energy taxation are reduced due to a lower tax base. Furthermore, the renewable target increases the cost of consuming fossil energy. The level of the carbon tax necessary to achieve the target for CO_2 emissions is therefore lower in a situation with a renewable target compared to a situation without. In our model simulation, the carbon tax sufficient to achieve the 20 % reduction in carbon emissions target falls from € 59 to € 52 per tonne CO_2 when the renewable target is introduced. As green certificate schemes are revenue neutral, there is no "green tax" income to compensate for the loss in energy- and carbon tax revenues.[17]

From Table 1 we see that the choice of scenario for green certificate markets also affects total gross consumption of energy. By the introduction of the renewable target through scenario *iii*), the final gross consumption of renewable energy is reduced by 60 Mtoe, which corresponds to a reduction of 4 percent relative to the base scenario. With EU-wide trade in green certificate, the reduction in gross final consumption is 50 % less. Hence, as all scenarios must fulfill the renewable target, the amount of renewable energy consumption is larger under EU-wide certificate trade than under domestic certificate trade only.

Average producer price of electricity, weighted by each countries production share, is reduced with between € 2 and € 3 per MWh, equivalent to a reduction between 4 and 4.5 % in all three scenarios. The green certificate market can be viewed as a subsidy to green energy production and a tax on energy consumption. Both green energy production subsidies and taxes on consumption reduce producer prices (exclusive the certificate price) and the results are thus in accordance with theory.

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[17] Note that our simulation does not take into account how the loss of CO_2 tax revenues must be compensated by an increase in other producer or consumer taxes, or reduced governmental spending.

The effect on the end-user electricity price (electricity price plus certificate price) by introducing the green certificate market is not given from theory (see e.g. Amundsen and Mortensen, 2001, Bye, 2003 and Fischer, 2006). Depending on the slope of the nonrenewable energy supply curve relative to the renewable energy supply curve, the combination of a tax and a subsidy might lead to both increasing and decreasing end-user electricity prices. In our numerical model, the average end-user price on electricity, weighted by consumption, increases as a result of the renewable target being implemented. The increase is more than twice as large with national targets and no trade in green certificates as with trade in certificates.

Table 1: Effects of different implementations of the Renewables Directive in 2020 (annually).

	Domestic certificate trade only	EU-wide trade in certificates Number in brackets express the percentage changes relative to scenario *iii*)	
	System *iii*) Differentiated national targets and no EU-wide trade in green certificates	System *ii*) Differentiated national targets and EU-wide trade in green certificates	System *i*) Common renewable target and EU-wide trade in green certificates
Cost of introducing the renewable target (M€)	19522	5968 (-69 %)	5745 (-71 %)
Change in producer surplus (M€)	173895	84938 (-51 %)	84336 (-52 %)
Change in consumer surplus (M€)	-120535	-49401 (-59 %)	-48761 (-60 %)
Change in taxes (M€)	-33838	-29569 (-13 %)	-29831 (-12 %)
Change in carbon tax rate (€ per tonne CO_2)	-7.50	-7.44 (-0.8 %)	-7.44 (-0.8 %)
Change in renewable energy consumption (Mtoe)	30	34 (11 %)	33 (11 %)
Change in gross final consumption of energy (Mtoe)	-60	-29 (-51 %)	-30 (-50 %)
Change in electricity production (TWh)	-90	-34 (-62 %)	-26 (-71 %)
Change in end-user electricity prices (€ MWh)	7.39	3.35 (-55 %)	2.81 (-62 %)
Change in electricity prices (€/MWh)	-2.49	-2.74 (10 %)	-2.73 (9 %)

M€ = million 2007-€.

All our numerical results regarding different ways to implement the renewable target depend heavily on our assumptions about available technologies to ensure both the carbon reduction and renewable energy target. Our numerical model comprises the potential for using CCS technology, and this technology will be implemented on all new coal fired power plants for CO_2-taxes above 31 € per tonne

CO_2. Obviously, there are uncertainties related to the performance of this, still immature, technology. If it turns out that the CCS technology will be too costly to implement or that it is not an accepted abatement technology due to the uncertainties related to safe storage of CO_2, the cost of reaching a 20 % reduction in carbon emissions increases substantially. Due to the corresponding high carbon prices, renewable energy become more profitable and there is no added cost by implementing the renewable target as long as there is EU-wide trade in green certificates (the certificate price is zero). Without trade in certificates the total cost of reaching the renewable target is € 4225 million, i.e. the added cost of the renewable target is substantially lower than with CCS.

3.3. Results by country

The costs of the different ways of implementing the renewable target differ substantially between countries. In Figure 1 we see the cost reduction across countries from having EU-wide trade in green certificates. Cost in scenario *i*) and *ii*) are compared to the situation under scenario *iii*).

In scenario *ii*) and *iii*), the differentiated national renewable targets are identical, but scenario *ii*) allows for EU-wide certificate trade, whereas scenario *iii*) does not. Access to an EU-wide market is in itself beneficial for all countries. It is particularly beneficial for countries that become large traders in the certificate market. However, EU-wide trade in green certificates affects the equilibrium prices on all energy sources. Due to these terms of trade effects, some countries are worse off in scenario *ii*) compared to scenario *iii*).

Finland, Italy, Norway and Sweden will benefit most from a shift from scenario *iii*) to scenario *ii*). We see from Figure 2 that Italy has a high national price on green certificates in scenario *iii*). The high price is a reflection of high domestic costs of green energy production. Hence, the cost of meeting their renewable target is substantially reduced when they get access to green certificates at a much lower price in scenario *ii*). For Finland, Norway and Sweden, the gains from an EU-wide market for certificates follow from their capacity to produce green energy at low costs. We see from Figure 2, that their price on green certificates is zero under scenario *iii*), even though they have national targets way above the average (see appendix A). This indicates that these countries will become large sellers of certificates in scenario *ii*) and exploit the gains from trade.

Whether a country is better off in scenario *ii*) than in scenario *i*) depends mainly on whether its national target in scenario *ii*) is above or below the common target in scenario *i*). Sweden and Norway have the highest national targets, set at 40 % and 68 %, respectively, in our model. Surely, they will

both benefit substantially by a replacement of their national targets with the common targets of 19.7 % in scenario *i*).

Figure 1: Countries' yearly cost reduction in system *i*) and *ii*) compared to system *iii*), as share of their GDP (2009)
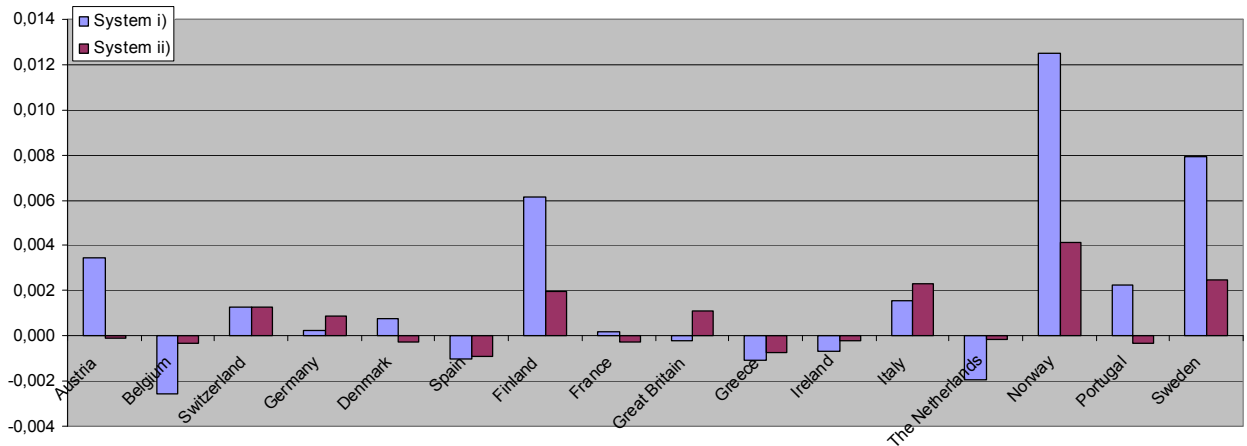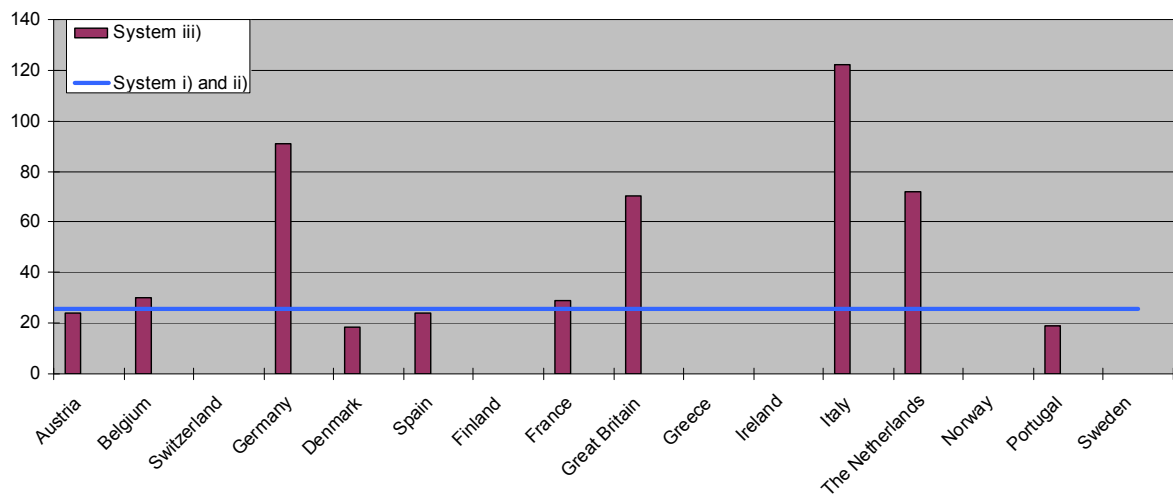

Figure 2: Green certificate prices. €/MWh.

4. Concluding remarks

The EU has agreed on differentiated renewable targets across Member States to achieve the *renewable target* of a 20 % share of renewables in the EU's *total* final energy consumption by 2020. We have shown that differentiated national targets do not lead to a cost effective implementation of EU's

renewable target (see proposition 1 and 2). However, an important result from our numerical model is that, given differentiated national targets, the overall cost of achieving the EU's renewable target can be cut by almost 70 per cent if the Member States are allowed to trade green certificates. The Renewable Energy Directive (EU, 2009b) allows for so called statistical transfers, which means that Member States may meet their national renewable targets by financing green energy production in other countries. Our paper shows the great potential for cost savings by developing this system into a well functioning green certificate market. Our numerical model also shows that the various designs of green certificate markets have great influence on the distribution of costs across countries. Hence, allowing for trade in green certificates (or statistical transfers) alters the distribution of costs across countries. If the EU also has a target for distribution of costs across countries, a development of a green certificate market may also necessitate a redistribution of the differentiated renewable targets across countries, if financial transfers/compensations are excluded. But then again, a redistribution of national targets affects the efficiency loss following from the corresponding differentiated consumer prices on energy. This is the well known result that distributional concerns must (in general) be separated from efficiency concerns when designing cost effective policy instruments.

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National renewable shares in LIBEMOD for 2005 and overall national targets in LIBEMOD for the share of energy from renewable sources in gross final consumption of energy in 2020

	Renewable share (2005)	Renewable target share (2020)
Austria	26.4 %	37.1 %
Belgium	1.8 %	12.6 %
Switzerland	20.2 %	0.0 %
Germany	4.4 %	16.6 %
Denmark	12.1 %	25.1 %
Spain	7.5 %	18.8 %
Finland	23.9 %	33.4 %
France	8.6 %	21.3 %
United Kingdom	1.2 %	14.9 %
Greece	6.8 %	17.9 %
Ireland	2.1 %	15.0 %
Italy	4.4 %	16.2 %
The Netherlands	1.3 %	12.9 %
Norway	53.4 %	67.9 %
Portugal	17.8 %	28.3 %
Sweden	30.9 %	40.1 %