Greening Electricity More Than Necessary:

On the Cost Implications of Overlapping Regulation in EU Climate Policy

Abstract. Without tangible prospects for a global deal on climate protection the EU is under domestic policy pressure to justify ambitious unilateral emissions reduction targets. Cost effectiveness of EU-wide emission abatement becomes increasingly important in order to sustain EU leadership in climate policy. We argue that administered EU targets for renewable energies are doomed to make emission reduction much more costly than necessary. Therefore, they could rather hinder than promote public support to unilateral climate policy action in the long run.

1. Introduction

In June 2009 the *Climate Action and Renewable Energy Package* became effective committing the European Union (EU) to greenhouse gas emission reduction by at least 20 % below 1990 levels (European Commission 2008a). The driving force behind this commitment was the EU's ambition to push an international greenhouse gas emission reduction agreement during the Copenhagen climate change conference in December 2009 as a follow-up to the Kyoto Protocol which will expire in 2012. However, Copenhagen failed and likewise the more recent international negotiations at Cancún in December 2010 did not bring forth a tangible global deal on climate protection. As a consequence, the potential economic burden of unilateral abatement action is more sceptically assessed by EU decision makers. If EU unilateral climate policy turns out to be excessively expensive, public support may critically decrease. Against this background, cost-effectiveness becomes increasingly important to sustain EU leadership in climate policy.

To achieve the mandated EU-wide emission reduction target at minimum costs, a comprehensive cap-and-trade system alone would be sufficient. Emissions trading promotes cost-effectiveness by equalizing the marginal costs of abatement across different options for reducing emissions such as enhanced renewable energy use, energy savings or energy efficiency improvements. While emissions trading between energy-intensive industries is a central pillar in EU climate policy, there are additional regulatory schemes being pushed under the *Climate Action and Renewable Energy Package*. Most

notably, there is the obligation to increase the share of renewable energy in total EU energy consumption to 20 % over the next decade.[1]

From the sole perspective of climate policy, supplementing an emission cap-and-trade system with an explicit renewable energy target is either redundant or cost-increasing. If the renewable energy target is already achieved under the cost-effective outcome of the emission cap-and-trade system it is redundant. If the renewable energy target becomes a binding constraint, it leads to an outcome different from the cost-effective solution. In this case the costs of climate policy increase as binding green targets induce excessive emission abatement from the expansion of renewable energy and too little abatement from other options.

This paper elaborates on the cost implications of EU climate policy triggered by targets for renewable energy (green quota) in electricity markets which are already regulated by an emission cap-and-trade system (black quota). We first derive analytical results and then substantiate our theoretical findings with numerical simulations for the EU power sector, quantifying the implications of overlapping green and black quotas for total compliance costs, electricity prices and electricity demand, emission prices as well as the power generation mix. Our simulation results indicate substantial additional costs due to mandated target shares for renewable energy which make electricity production "greener" than necessary in order to achieve the emission reduction target.

One can argue that renewable energy support could be desirable for other reasons than (just) emission reduction. As a matter of fact, policy makers invoke a variety of reasons for promoting renewable energy ranging from energy security to green jobs and innovation. From this perspective, the additional costs provide a price tag to green quotas for the composite of objectives different from emission reduction. However, the bigger this price tag is the more it calls for an explicit and coherent policy justification in order not to jeopardize public support for emission control policies where the reason for market failure and the need for mandatory regulation are clear cut.

2. Background

Since the early nineties the EU has pushed for climate protection at the international level. It has become a leader of the global climate policy agenda through its pivotal role in the ratification and implementation of the Kyoto Protocol, the sole international climate agreement to date with binding emission reduction targets for major industrialized countries. However, the United Nations climate change conference of parties (COP 15) at Copenhagen in December 2009 turned out to be a severe backslash to the EU's aspiration for winning "the battle against global climate change" (European Commission 2005, 2008b). In the run-up of COP 15 the EU had worked hard towards a Post-Kyoto

---

[1] Beyond the emission reduction target and the renewable promotion target the package furthermore states the objective to increase energy efficiency by 20% as compared to the business-as-usual development in 2020.

treaty. As a distinct signal the EU had agreed on unilateral greenhouse gas emission reductions of at least 20 % until 2020 (compared to 1990 emission levels) within the so-called *Climate Action and Renewable Energy Package*. The EU's decision on leading the way with unilateral action was strongly motivated by the hope to foster a successful multilateral agreement at Copenhagen. However, instead of binding emission reduction commitments for major industrialized and developing regions, Copenhagen brought about only a voluntary system of pledge-and-review. The follow-up meeting at Cancún in December 2010 reached agreement on the need to limit average global temperature increase to no more than 2°C above pre-industrial levels but again did not bring forth a tangible international deal on future climate protection. The EU thus is under increasing domestic policy pressure to relax its ambitious emissions reduction targets – not at least because various Central and Eastern European member states had questioned the strictness of unilateral EU climate policy already beforehand. Major concerns refer to the economic costs of unilateral abatement for the EU with non-EU regions taking a free-ride and the direct environmental impacts of EU emission reductions on global climate change being negligible anyway. While defection from the 2020 commitment does nota appear as a viable policy option, the EU should rigorously aim at cost-effectiveness of emission reduction – both to sustain domestic climate policy support as well as to set a good example for other countries outside the EU that contemplate comparable abatement efforts.

However, EU climate policy practice violates basic principles of cost-effectiveness (see Böhringer et al. 2009 for a summary assessment). Firstly, the *Climate Action and Renewable Energy Package* which is the central piece of legislation to achieve the overall EU emission reduction target does not accommodate comprehensive EU-wide emissions trading. The EU foresees explicit emissions trading only between energy-intensive installations (sectors) under the EU Emissions Trading Scheme (EU ETS) which covers just around 40 % of EU greenhouse gas emissions. Each EU member state must therefore specify additional domestic abatement policies for the non-ETS sectors outside the EU ETS in order to comply with the overall EU emission reduction target.[2] Since there are no tight links between the ETS emission market on the one hand and the multiple non-ETS emission "markets" on the other hand, the Coase theorem no longer applies. WHAT MEANS COASE THEOREM IN THIS RESPECT? Without the possibility of comprehensive trading, the initial allocation of abatement burden between ETS and non-ETS sectors matters for the economic efficiency of overall emission reduction. Insofar, marginal

---

[2] More specifically, the targeted EU greenhouse gas reduction of 20% by 2020 (vis-à-vis 1990) is split between ETS and non-ETS segments of the EU economies as follows: From 2013 onwards the EU ETS sectors will be centrally regulated by the EU Commission to achieve a target reduction for this segment of -21% (compared to 2005) by 2020. Emissions outside the EU ETS are unregulated at the EU level, but subject to emissions control measures by individual member states. The average reduction target for non-ETS greenhouse gas emissions until 2020 amounts to -10% (compared to 2005). The mandated individual member state targets for non-ETS sectors range from a 20% decrease to a 20% increase relative to 2005 emission levels depending on differences in per-capita income.

abatement costs between the ETS sectors and the multiple non-ETS segments are likely to diverge and thereby induce excess costs (Böhringer et al. 2005).[3]

Secondly – and not at least due to the incomplete coverage of the EU ETS – the EU employs a broader policy mix instead of one single instrument to meet its climate policy target. Beyond (partial) emissions trading the EU builds in particular upon the promotion of renewable energy production. The *Climate Action and Renewable Energy Package* includes the explicit objective to raise the share of renewable energy in total EU energy consumption to 20 % by 2020 which constitutes the world's most visible and farthest-reaching agreement to promote renewable energy (EU 2009b). The EU legislation specifies national renewable targets for each member state, which in principle can be met by over-fulfilment in other countries through transfer of guarantees of origin. The guarantees-of-origin system can be combined with renewable support mechanisms such as feed-in tariffs or tradable green certificates, also referred to as renewable portfolio standards (Neuhoff et al. 2008). A few EU member states (Sweden, Belgium, and the United Kingdom) have implemented domestic green certificate schemes to reach their respective 2020 renewable energy target. Most EU member states, however, have adopted feed-in tariffs as the primary instrument to support renewable energy production. Renewable energy installations thereby are guaranteed access to the electricity grid at administered prices. Feed-in tariffs are generally differentiated across renewable energy sources with higher prices for more expensive technologies such as offshore wind and in particular solar photovoltaics which otherwise would not become "competitive" (for a detailed description of feed-in tariff programs see IEA 2009).

A fundamental principle in economics established through the seminal work by Tinbergen (1952) is the equalization of the number of policy instruments with the number of policy targets. While more targets than instruments make targets incompatible, more instruments than targets make instruments alternative, i.e. one instrument may be used instead of another or a combination of others. In other words: A single market failure is best addressed with one instrument, while multiple market failures call for multiple instruments.[4] With respect to climate policy, a comprehensive emissions cap-and-trade system is the "first-best" policy response and the promotion of renewable energy is likely to be counterproductive whenever it generates an outcome different from the cost-effective solution generated by comprehensive emissions trading stand-alone (Sijm 2005 or Pethig and Wittlich 2009).[5]

Additional market distortions and market failures, beyond the greenhouse gas externality, provide in principle an economic rationale for complementary renewable energy promotion (for an overview of policy arguments see Fischer and Preonas 2010). One possible rationale for green quotas is energy

---

[3] As pointed out by Neuhoff et al. (2006), allocation rules in the EU ETS have also led to distortions, causing diverging marginal abatement costs even among EU ETS installations. This problem will however be substantially reduced from 2013 when the power sector (with some exceptions) no longer will receive free allowances.

[4] See Hahn (1986) for a discussion of designing markets in the case with multiple objectives, and Bennear and Stavins (2007) for a discussion of using multiple instruments in a second-best world.

security in terms of reduced import dependence for oil and gas (Aune et al. 2008). However, it proves difficult to translate energy security arguments into monetary economic benefits that may offset the additional costs of green quotas. Another wide-spread justification is that the market penetration of renewable energy under an emission cap-and-trade system is too limited due to the existence of technology spillovers. To date, however, there is little empirical evidence on the magnitude of these knowledge spillovers for relatively new technologies like wind and solar, so it is difficult to judge what level (if any) of *green* subsidies is desirable.[6] Note that these other objectives – if properly defined – are nevertheless likely to be met in a more cost-effective way. For example, promotion of research and development (R&D) in green technologies would call for specific R&D subsidies rather than broad-based subsidies to renewable energy production.

While the EU stresses climate protection as the primary justification for renewable energy promotion, it also refers to additional arguments such as innovation, job creation and energy security.[7] Yet, the policy debate lacks a clear-cut efficiency rationale both in terms of the mandated target levels for renewable energy use as well as the myriad of regulatory instruments to push renewable energy. When the costs of renewable energy promotion become more visible to citizens without evidence on the associated benefits, regulation runs the risk not only to forfeit support for green policy initiatives. It also jeopardizes societal acceptance of stringent emission reduction as compliance costs get amplified through counterproductive overlapping regulation. A prime example is the German feed-in-tariff system for electricity generation from renewable energy. High subsidy rates for renewable power production (in particular photovoltaics) increased the electricity price markedly over the last years as subsidy payments need to be covered through the revenues from electricity sales. At the same time the climate benefits are nil because emissions from power production are already ceiled under the EU ETS (Frondel et al. 2010).

There is a meanwhile a bulk of literature on the interaction between climate policy and renewable support schemes (see Gonzalez 2007 or Fischer and Preonas 2010 for surveys). Our analysis provides further quantitative evidence on the potential cost implication of overlapping regulation under the EU *Climate Action and Renewable Energy Package* with a focus on the EU electricity system which is at the core of emission regulation as well as renewable energy promotion.[8]

---

[5] This reasoning applies tightly to the EU ETS while renewable energy promotion in non ETS sectors will effect emission reduction in the absence of a binding emission constraint (yet again at potentially higher costs as compared to a situation where all sectors would be covered by a cap-and-trade system.

[6] The general argument of market failure due to external knowledge spillovers furthermore applies to all markets so it is not clear at all if prioritization towards renewable energy subsidies is desirable from an economy-wide perspective

[7] For example, the European Parliament justifies renewable targets as ''promoting the security of energy supply, promoting technological development and innovation and providing opportunities for employment and regional development, especially in rural and isolated areas. . . , [increasing] export prospects, social cohesion and employment opportunities. . . [for small] independent energy producers'' (EU 2009a)

[8] Complementary simulation studies at the single-country level include work by Amundsen and Mortensen (2001), Jensen and Skytte (2003).and Unger and Ahlgren (2005) for Scandinavian countries, Rathmann (2007) and Abrell and Weigt (2008) for Germany, or Lineares et al. (2008) for Spain.

3. Theoretical analysis

In our simple theoretical analysis we show that binding target shares for renewable energies (green quota) imposed on top of an emission constraint (black quota) will lead to additional costs of meeting the black quota. For the sake of simplicity, the formal analysis adopts a partial equilibrium approach but we also discuss the implications of overlapping regulation in an economy-wide context.

Following Böhringer and Rosendahl (2010) we consider a partial equilibrium model of a closed, competitive power market, with m producers of 'green' power and n producers of 'black' (non-green) power. Let G and B denote the set of green and black power producers, respectively. Power producers have cost functions $c^i(q^i)$, where q^i denotes production in firm i. As usual, cost functions are assumed to be twice differentiable and convex with $c_q^i > 0$ and $c_{qq}^i > 0$. Emissions e^i in each firm are proportional to production (i.e., $e^i = \gamma^i \cdot q^i$, where γ^i denotes the emission intensity of firm i).[9] There are no emissions from green power production, i.e., $\gamma^i = 0$ for $i \in G$. Black power producers may either have strictly positive emissions (i.e., those based on fossil fuels), or no emissions (e.g., nuclear), i.e., $\gamma^i \geq 0$ for $i \in B$. Let $p^E = D(q)$ ($D_q < 0$) denote the inverse demand function, where p^E is the end-user price of electricity.

We assume that the government wants to maximize economic welfare in the power market, subject to a cap $\hat{e}$ on total emissions from this sector (i.e., a black quota). Economic welfare consists of consumer and producer surplus, and net government revenues. Money transfers between consumers, producers and the government cancel out, and so the maximization problem becomes:

$$(1) \qquad \underset{q^i}{\text{Max}} \ W = \int_0^q D(s)ds - \sum_{i \in B,G} c^i(q^i),$$

subject to:

$$(2) \qquad \sum_{i \in B} \gamma^i q^i \leq \hat{e},$$

where $q = \sum_{i \in B,G} q^i$.

This gives the following first-order conditions:

$$(3) \qquad \frac{\partial W}{\partial q^i} = D(q^i) - c_{q^i}^i(q^i) - \lambda \gamma^i = 0 \iff p^E = c_{q^i}^i(q^i) + \lambda \gamma^i,$$

where λ is the shadow price on the emission constraint in (2). It is straightforward to see that the welfare maximum can be reached by introducing an emissions trading system with $\hat{e}$ quotas (or a tax on emissions), in which case the first-order conditions for the firms become (σ is the price of quotas):

$$(4) \qquad p^E = c_{q^i}^i(q^i) + \sigma \gamma^i.$$

Obviously, as the total number of quota is set equal to $\hat{e}$, we will get $\sigma = \lambda$.

---

[9] This assumption reflects technical and physical restrictions in power production, where each power plant has a fairly fixed conversion rate between energy input and electricity output (except in start-up periods).

What happens to economic welfare if the government in addition implements a green quota through a suitable set of new instruments? By a green quota we mean a minimum share α of green power production in total power generation. If the green quota is binding (i.e., the share of green power in the welfare maximizing outcome is less than α) economic welfare will have to fall as the market outcome is moved away from this welfare maximizing outcome. Assume, for example, that the government introduces subsidies $\pi^i \geq 0$ to green producers and possibly a tax $t \geq 0$ on electricity consumption in order to implement the green quota.[10] The firms' first-order conditions are then:

(5) $\qquad p^E = c_{q^i}^i(q^i) + t + \sigma\gamma^i \quad (i \in B)$

(6) $\qquad p^E = c_{q^i}^i(q^i) + t - \pi^i \quad (i \in G)$.

Comparing (5)-(6) with (3), we see that the welfare maximum is no longer obtained unless we set $\pi^i = 0$ and $t = 0$, in which case the green quota will not be reached (by assumption).

The effects on total production and the end-user price of electricity of implementing the green quota are ambiguous as long as $t > 0$ (Böhringer and Rosendahl 2010). Therefore, we first assume that p^E and q are unchanged, and focus on the welfare effects of shifting production between producers. Böhringer and Rosendahl (2010) show that the green quota will lead to higher production from the most emission-intensive technologies ($\gamma^i > \gamma^*$), and of course from the green technologies, and to less production from the least emission-intensive technologies ($\gamma^i < \gamma^*$). The former effect follows because the price of emissions drops. The welfare loss will therefore equal the cost increases from higher production by green producers and the most emission-intensive black producers, minus the cost decreases from less production by the least emission-intensive black producers. In other words:

(7) $\qquad \Delta W = \sum_{i \in G} \Delta c^i(q^i) + \sum_{i \in B, \gamma^i > \gamma^*} \Delta c^i(q^i) + \sum_{i \in B, \gamma^i < \gamma^*} \Delta c^i(q^i)$,

where the two first terms are positive and the third term is negative. Remember that in this case we have $\sum_{i \in G} \Delta q^i + \sum_{i \in B, \gamma^i > \gamma^*} \Delta q^i + \sum_{i \in B, \gamma^i < \gamma^*} \Delta q^i = 0$. This is illustrated in Figures 1a-c with two black producers and one green producer where emission intensity of black producer B_1 is twice as high as the emission intensity of black producer B_2 ($\gamma^{B1} = 2\gamma^{B2}$).

In this example the black producer B_1 and the green producer will increase their output by the same amount when we go from the Black (B) scenario to the Black&Green (B&G) scenario (i.e., a green quota imposed in addition to the black quota), and hence black producer B_2 decreases its output by twice this amount so that total output is unchanged. The marginal costs of production (excluding emissions costs) for B_2 are initially equal to the average marginal costs of production for B_1 and G (cf.

---

[10] Note that a green certificate market can be mimicked by a combination of a subsidy to green production and a tax on elecitricity consumption, where net public revenues from these instruments are zero (Böhringer and Rosendahl 2010).

(4) with $\gamma^{B1} = 2\gamma^{B2}$), and thus we get a deadweight loss by shifting some production from B_2 to B_1 and G.[11] The total welfare (deadweight) loss is illustrated as the sum of the three triangles in Figures 1a-c.

Figure 2 provides a complementary graphical illustration of the additional costs induced by a binding green quota on top of a black quota. The black quota prescribes the targeted emission abatement which can be either achieved through the increase of green power production or the decrease of black power production. In the cost-effective solution marginal abatement costs across both options are equalized. As an exogenous green quota becomes binding it crowds out cheaper abatement from black power producers through more expensive abatement from green producers. The additional costs of the green quota are captured by the shaded area. Furthermore, it can be seen that the marginal abatement costs for black producers (i.e., the emission price) decreases.

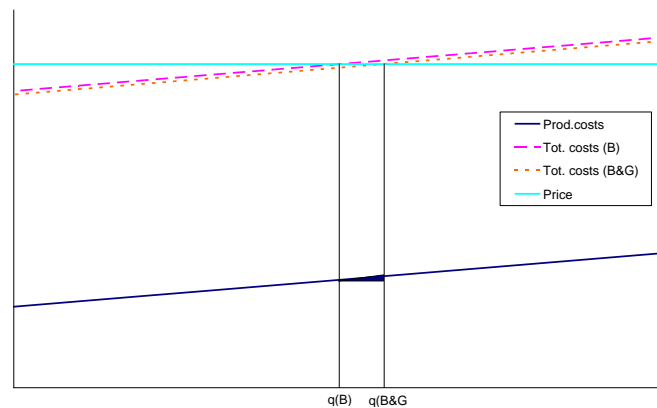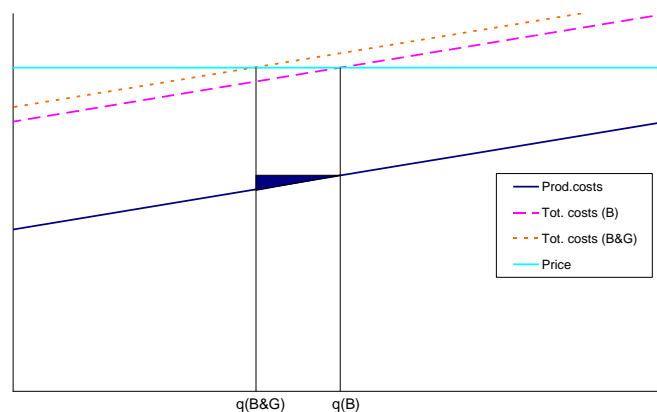Figure 1a.: B_1 production in Black (B) and Black&Green (B&G) scenarios

Figure 1b.: B_2 production in Black (B) and Black&Green (B&G) scenarios

---

[11] Obviously, shifting production only from B_2 to B_1 (and not to G) would reduce total production costs, but then the emission constraint would be violated because B_1 has higher emission intensity than B_2.

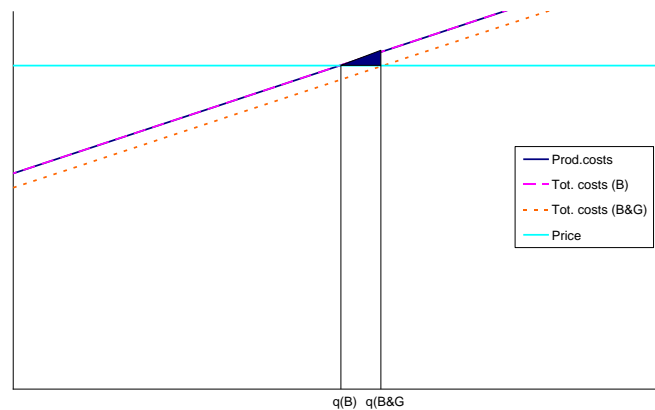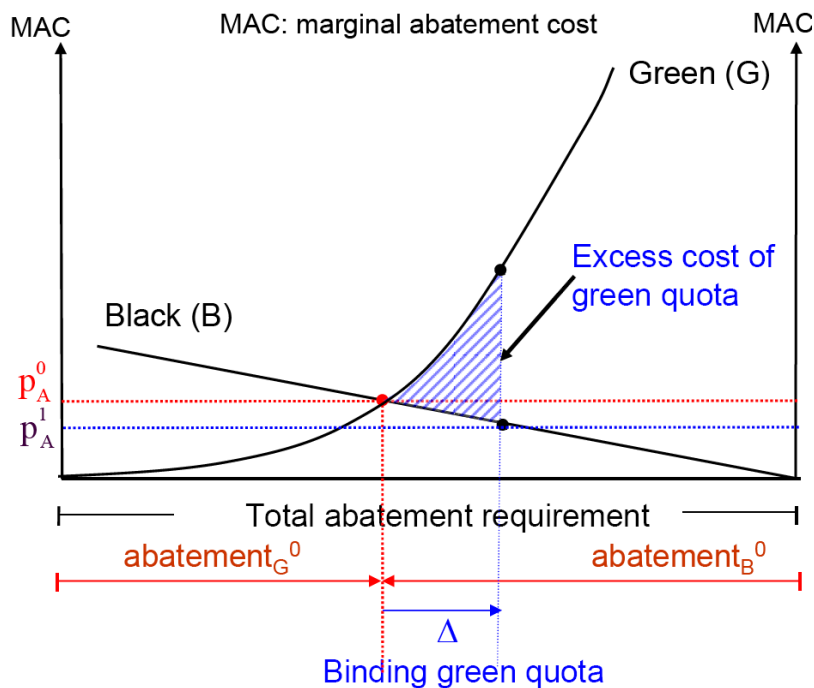Figure 1c.: *G* production in Black (B) and Black&Green (B&G) scenarios

Figure 2: Additional costs of binding green quota on top of black quota

Within an economy-wide model WHAT KIND OF MODEL, ASSUMPTIONS? the excess costs in the electricity market will translate into lower overall income to consumers (e.g., through lower profits to electricity producers). This will reduce the consumption of all normal goods at given prices. Thus, even if the end-user price of electricity remains unchanged in the partial equilibrium framework discussed above, consumption may fall because of economy-wide income effects. If the price of electricity falls or rises, we may get additional welfare losses. For instance, if the price falls and consumption increases, the additional costs of producing the extra units will exceed the consumers' willingness to pay for these units.

4. Numerical analysis

4.1 Model structure and parameterization

In order to illustrate the implications of overlapping green and black quotas and thereby assess the policy relevance of our theoretical analysis, we perform numerical simulations with a partial equilibrium model of the EU electricity market. Electricity production is based on a set of discrete power generation technologies covering non-renewable thermal power plants (hard coal, lignite, gas, oil, nuclear) as well as power plants that operate on renewable energies (hydro, wind, solar, biomass, biogas, PHOTOVOLATICS IN GERMANY!). There is a distinction between extant technologies operating on existing capacities and new vintage technologies that require new investment. Each technology is associated to base, middle, or peak load. The different load supplies are then combined towards a constant-elasticity-of-substitution aggregate of electricity supply capturing imperfect substitutability between different loads. After accounting for taxes and grid fees the electricity supply together with net imports must satisfy price-responsive electricity demand.

The electricity market model is formulated as a mixed complementarity problem (i.e., a system of (weak) inequalities and complementary slackness conditions – see Rutherford 1995).[12] Two classes of conditions characterize the (competitive) equilibrium for our model: zero profit conditions and market clearance conditions. The former class determines activity levels (quantities) and the latter determines prices. The economic equilibrium features complementarity between equilibrium variables and equilibrium conditions: Activities will be operated as long as they break even, positive market prices imply market clearance – otherwise commodities are in excess supply and the respective prices fall to zero.[13]

The model is calibrated to base-year data for 2004, as a reference year before the EU electricity sector became subject to CO_2 emission reduction constraints under the EU emissions trading scheme. Market data on installed capacities, power supply by technology, electricity imports and exports, final demand as well as electricity prices is taken from the International Energy Agency (IEA 2010). Technical and economic information on the different power plants is based on the IER technology database (IER 2008), which includes detailed technology-specific data on installation costs, operating and maintenance costs, thermal efficiencies, and emission coefficients. Future potential capacities for renewable energies stem from the EU GreenX project (GreenX 2008). The appendix provides an algebraic summary of the model logic (see also Böhringer et al. 2007 for a more detailed description of the numerical model and its parameterization).

---

[12] A major advantage of the mixed complementarity formulation is that it allows for the incorporation of second-best phenomena by relaxing integrability conditions which are inherent to economic models formulated as optimization problem.

[13] The appendix provides a detailed algebraic model formulation. Numerically, the model is implemented in GAMS (Brooke et al. 1987) using PATH (Dirkse and Ferris 1995) as a solver. The GAMS file and the EXCEL reporting sheet to replicate our results are available from the authors upon request.

4.2 Policy scenarios and numerical results

The policy background for our central case scenarios is provided by the EU *Climate Action and Renewable Energy Package.* Therein, the EU commits itsself to reduce EU-wide greenhouse gas emissions by 20 % below 1990 levels by 2020 with an overproportional contribution from the power sector as the major emitter. The package also includes the policy objective of increasing the share of renewable energy in total EU energy use to 20 % by 2020 (European Commission 2008b), which translates into substantially higher target shares of renewable energy in electricity production.

Against this policy background we illustrate the implications of overlapping black and green quotas for the EU electricity sector taking a 25 % CO_2 emission reduction vis-à-vis the base-year emission level as a starting point (scenario BLACK). We then impose a sequential increase in the renewable energy share of up to 10 percentage points on top of the cost-effective renewable share emerging from BLACK only (scenario BLACK&GREEN). Scenario BMK captures the base-year situation of the EU power sector in the absence of black and green quotas.[14]

Table 1: Overview of central case scenarios

Scenarios	Black quota	Green quota
BMK	Not assigned	Not assigned
BLACK	25 % below BMK emission level	Not assigned
BLACK&GREEN	25 % below BMK emission level	n percentage points increase compared to BLACK, $n \in \{1,10\}$

With the emission constraint in place under scenario BLACK, the share of green power production in the EU endogenously increases from 16 % to 18.6 %. Thus, in scenario BLACK&GREEN the share of green power production is imposed to go up from 18.6 % to 28.6 % thereby keeping the emission constraint fixed (the emission constraint is always binding in our policy scenarios). Figure 3, clearly indicates that the imposition of a green quota on top of the black quota induces substantial additional economic costs. This must be considered as an excess burden if emission reduction is the only policy objective.[15] Without a green quota, the compliance costs of a 25 % cutback of emissions in the EU electricity system amounts to roughly 7.25 billion €.[16] Towards higher shares of green power the costs rise up to around 11.85 billion € (i.e., compliance costs increase by more than 60 % as the green quota is increased by 10 percentage points). It is important to bear in mind that our model implementation of renewable energy targets provides a lower bound estimate for the additional costs. With a single (EU-wide) target for the renewable energy share in electricity production, the "greening" of power

---

[14] The EU ETS does not only cover the electricity sector but also energy-intensive industries. Moreover, the renewable target applies to the whole economy, and not just the electricity sector. Nevertheless, the bulk part of emission reduction and increased renewable energy production will take place in the electricity sector.

[15] As elaborated in section 2, we may refer to the additional costs as a price tag that must be attached to the value of other policy objectives such as decreased reliance on fossil fuels, enhanced technological progress etc.

production will take place where it is cheapest (i.e., at equalized marginal costs per additional unit power production from renewables). To achieve such an outcome EU member states must render their individual green qutoas fully tradable across national borders or likewise apply a uniform feed-in tariff across all renewable energy technologies and members states. However, in policy practice there is neither an EU-wide tradable green certificate system nor marginal costs of green power production are equalized within those EU member states that have differentiated feed-in tariffs across renewable energy technologies. If we apply for example Germany's feed-in tariffs (BDEW 2010) for the whole of the EU, compliance costs further increase compared to uniform subsidies (uniform feed-in tariffs) implied with Figure 3.

The additional costs of renewable energy targets obviously not only depend on the actual policy implementation (e.g. uniform versus differentiated feed-in tariffs) but also on the initial cost disadvantage of renewable technologies. However, applying sensitivity analysis for technology-specific learning rates based on empirical estimates (IEA 2008) we find only modest cost savings compared to the core scenarios without technology learning.

In our central case simulations the end-user price of electricity increases by around 28 % for the emission quota stand-alone (scenario BLACK). When the green quota is imposed on top of the black quota the price declines markedly, and is then only 11.5 % higher than the BMK price (cf. Figure 4). The imposition of an additional green quota leads to increased electricity demand/production as compared to the BLACK scenario.[17] Consistent with reduced end-user prices, total electricity production increases in BLACK&GREEN compared to the BLACK scenario. This is depicted in Figure 5 which also shows that total black production falls and total green production rises. The price of CO_2 is 41 € per ton of CO_2 in the BLACK scenario, but declines to 16 € per ton when the green quota is also imposed (cf. Figure 6) since the increased share of renewables reduces the pressure on the emission quota. As a consequence, the green quota does not only increase renewable power generation but benefits the most CO_2-intensive power producers at the expense of non-renewable technologies with low or zero CO_2 intensity (Böhringer and Rosendahl 2010). Lignite (soft coal) has the highest CO_2 emissions per kWh electricity produced, and we therefore term it the dirtiest technology. When the emission constraint is imposed, power production by lignite power plants decreases by around 80 % if no additional green quota is in place (scenario BLACK). When policy regulation requires the share of green power to increase further beyond the cost-effective level obtained in scenario BLACK, the adverse impacts of the carbon constraint on lignite power production get attenuated (scenario BLACK&GREEN). This is shown in Figure 7 which sketches the change in output of the dirtiest technology compared to the BMK scenario. When the green quota is increased by 10 percentage points,

---

[16] Compliance costs are calculated as loss in economic surplus, i.e., the sum of producer surplus, consumer surplus and quota revenues.

[17] The price effect of introducing a green quota is in general ambiguous, but the likelihood of a price reduction is higher than in the case without any emission constraint in place.

output from lignite power plants only decreases by roughly 25 % below the BMK level compared to around 80 % in scenario BLACK.

So far, we have quantified the effects of an overlapping green quota for a fixed emission constraint of 25 % below BMK emissions. Figures 8 provides a sensitivity analysis on the additional costs of renewable energy targets across alternative emission reduction targets (note that the green quota in the figures should be read as *n* percentage points increase in the share of green power production compared to a scenario with the same emission constraint but no green quota). We see that the costs of the green quota go up with its stringency but are declining in the emission reduction target. As the black quota becomes more binding the electricity price goes up which decrease the cost disadvantage of renewable technologies – nevertheless, the additional costs induced by renewable energy targets imposed on top of emission constraints remain substantial.

Figure 3: Percentage change in compliance costs for BLACK&GREEN compared to BLACK
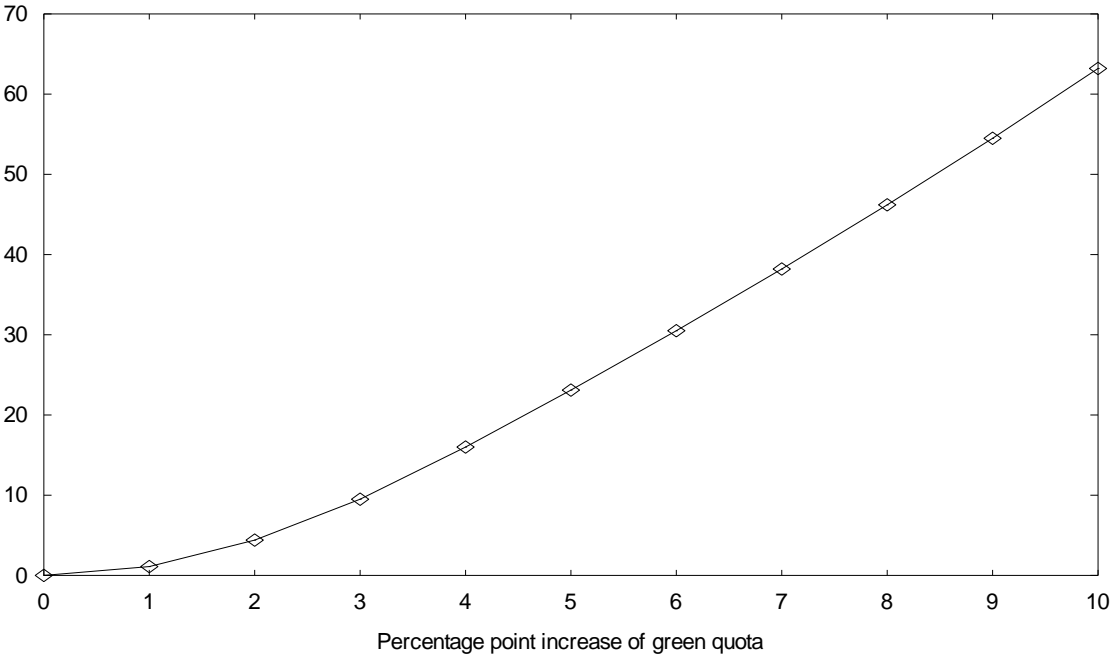

Percentage point increase of green quota

Figure 4: Percentage change in end-user electricity price for BLACK&GREEN compared to BMK

13

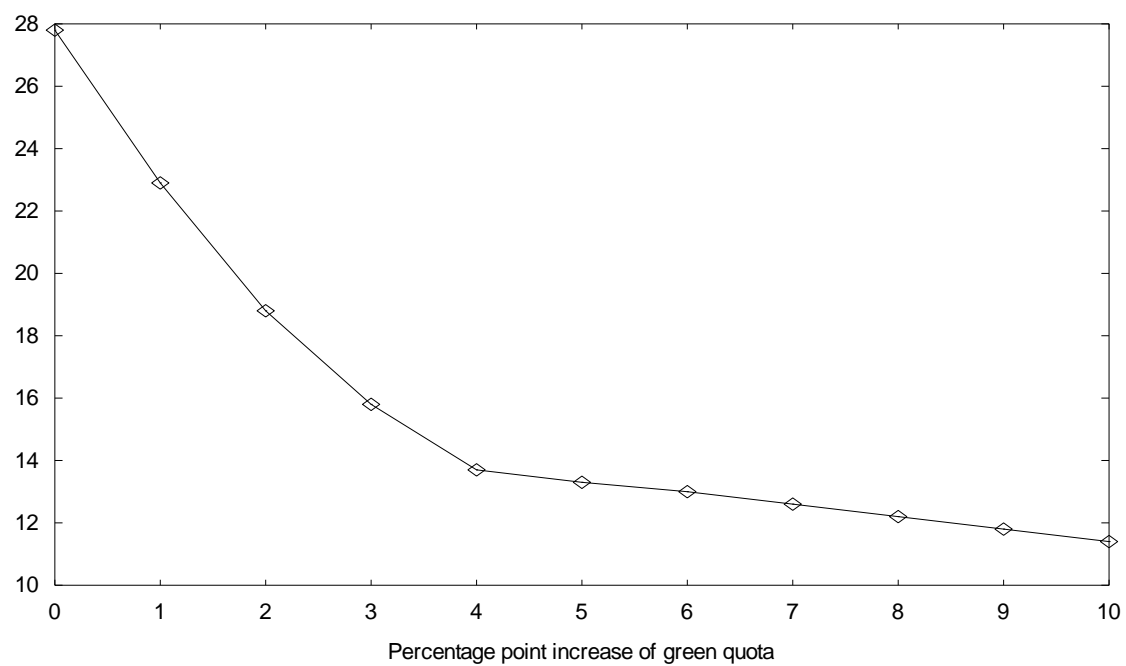Percentage point increase of green quota

Figure 5: Percentage change in electricity production for BLACK&GREEN compared to BMK
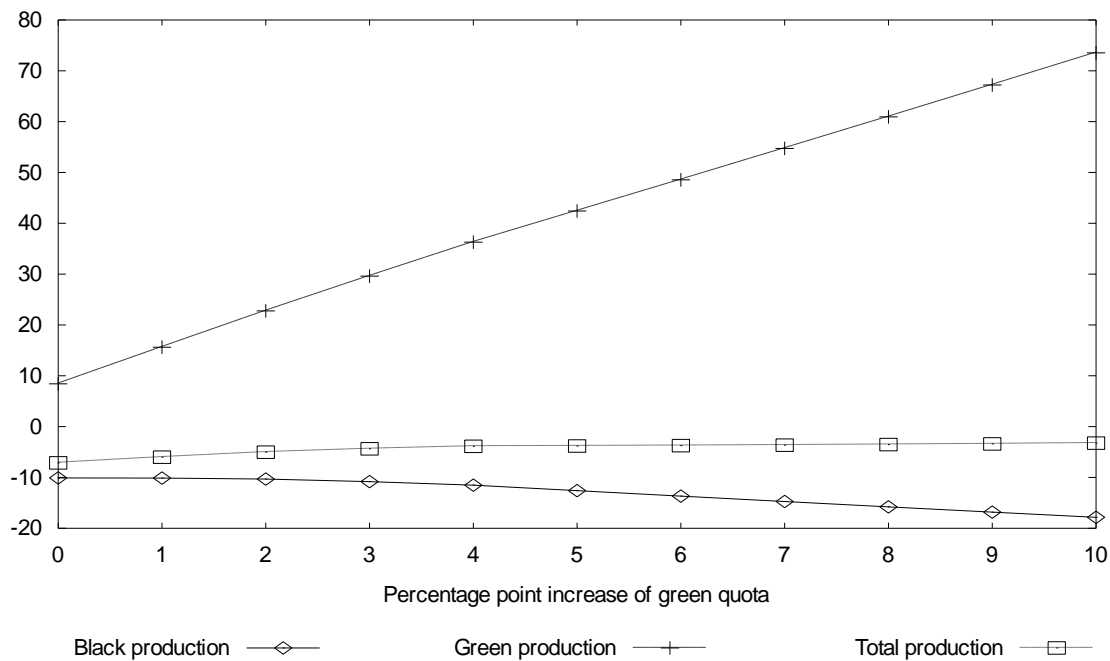

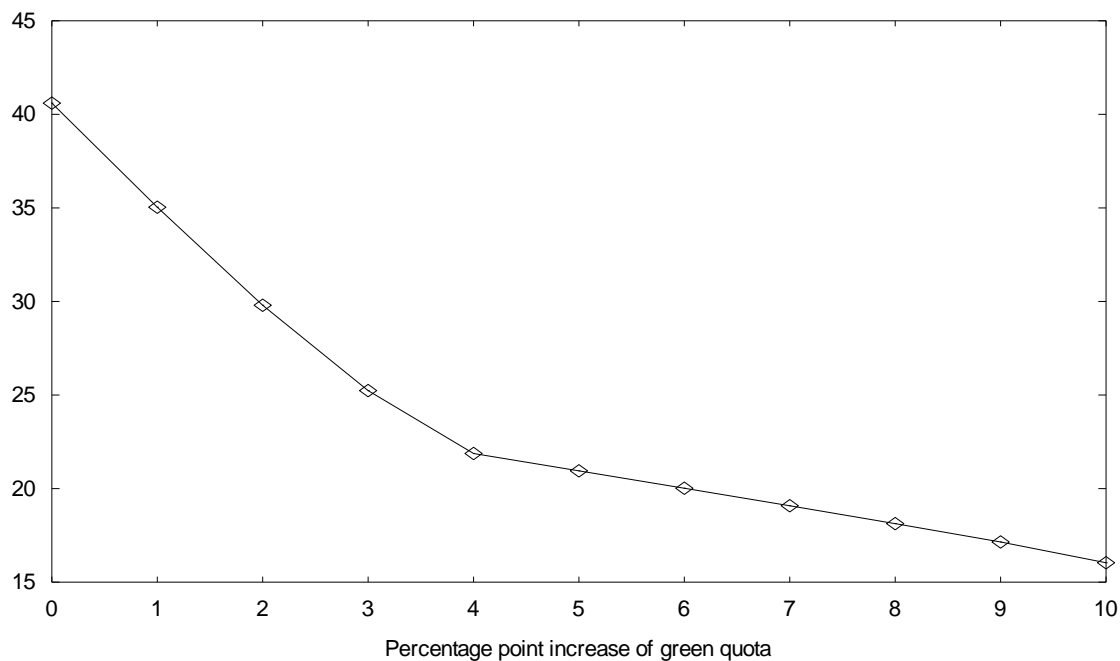Figure 6: CO_2 price in BLACK&GREEN (€ per ton of CO_2)

Figure 7: Percentage change in lignite power production for BLACK&GREEN compared to BMK
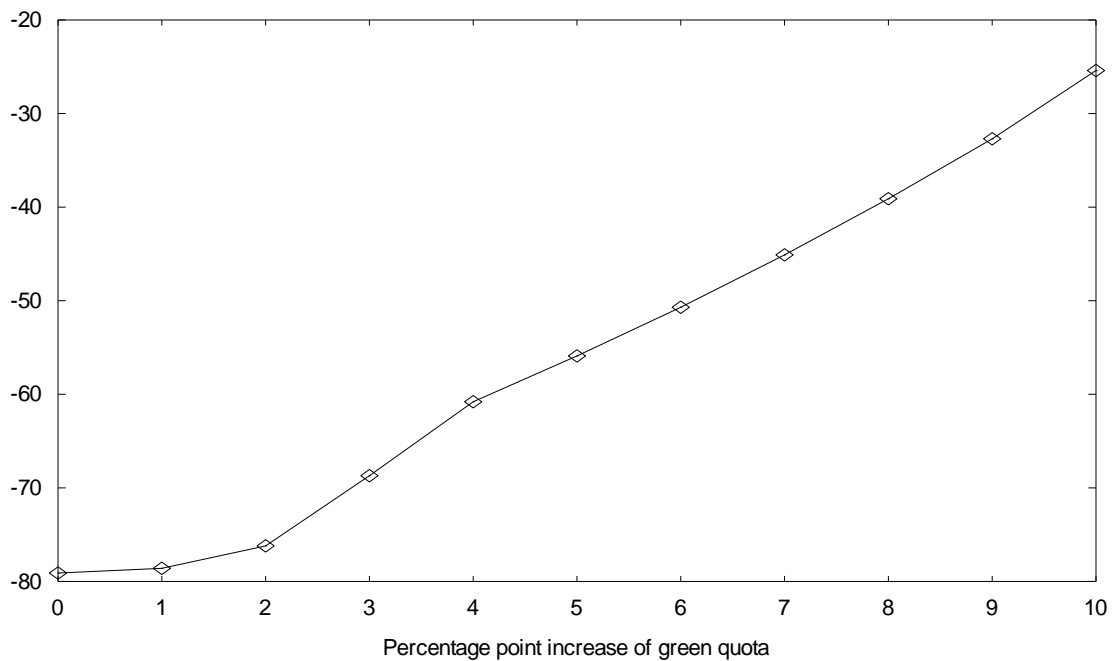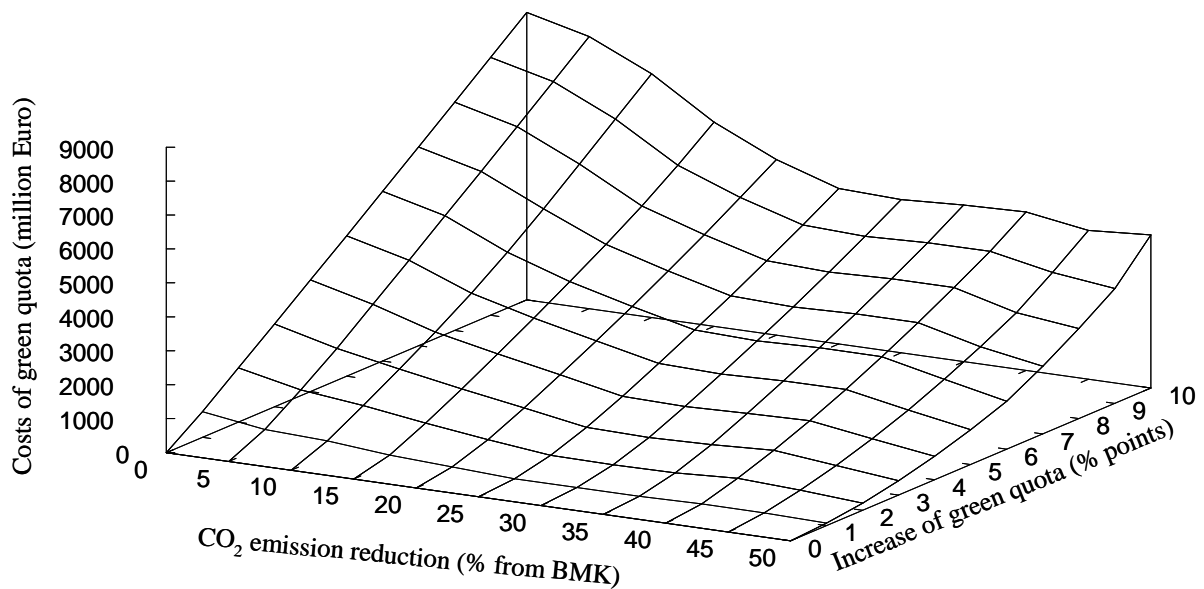

Figure 8: Additional costs of green quota on top of black quota (in million €)

5. Conclusions

In 2009 the European Union launched the *Climate Action and Renewable Energy Package* with the objective to reduce greenhouse gas emissions by at least 20 % below 1990 levels until 2020. The central

16

policy instrument to cut back emissions is the EU Emissions Trading Scheme covering energy-intensive installations across all EU member states. As a complementary instrument for emission reduction the package prescribes the promotion of renewable energy towards a 20 % share in total EU energy consumption by 2020. From the sole perspective of climate policy supplementing an emissions cap-and-trade system with stringent renewable energy targets is likely to create additional costs as this induces "excessive" emission abatement from the expansion of renewable energy and too little abatement from other options.

In this paper, we have used a numerical model of the EU electricity system to substantiate basic theoretical propositions with quantitative evidence on the additional costs of overlapping regulation in EU climate policy. Our simulations indicate that the costs of imposing renewable support schemes on top of an emissions cap-and trade system can be substantial. If the objective of the EU package is to curb emissions in a cost-effective manner, these additional costs must be regarded as excess burden which renders emission reduction more costly than necessary, possibly jeopardizing public support for unilateral EU leadership in international climate policy. From a broader policy perspective, the additional costs of renewable energy promotion may be justifiable through other market failures beyond the greenhouse gas externality. Common arguments for renewable energy support range from energy security concerns to the creation of green jobs or innovation spillovers. In this case one can view the additional costs of renewable energy promotion as a price tag for the composite of objectives different from emission reduction. Nevertheless, policymakers should be explicit on the rationale for green subsidies building upon rigorous cost-benefit analysis rather than referring in vague terms to popular catchwords.

Beyond our straight cost-effectiveness analysis, overlapping regulation in EU climate policy has an important political economy dimension. Policy makers do not only face the pressure to implement ambitious emission reduction targets in a cost-effective manner but respond to the vested interests of important societal groups and stakeholders through additional regulatory measures such as green subsidies.

We close with the usual caveat on the merits of applied modeling. While our model captures the fundamental cost implications of overlapping regulation in EU climate policy, it is inevitably a simplification of complex real world relationships. We therefore caution against too literal an interpretation of the numerical results.

Acknowledgements

References

Amundsen, E.S. and J.B. Mortensen (2001): The Danish Green Certificate Market: Some Simple Analytical Results, *Energy Economics* 23, 489–509.

Abrell, J. and H. Weigt (2008): The Interaction of Emissions Trading and Renewable Energy Promotion,.Working Paper No. WP-EGW-05. Dresden, Germany: Dresden University of Technology.

Aune, F.R., R. Golombek, S.A.C. Kittelsen and K.E. Rosendahl (2008): *Liberalizing European Energy Markets. An Economic Analysis,* Cheltham, UK: Edward Elgar Publisher.

BDEW (2010), Bundesverband der Energie- und Wasserwirtschaft e.V., Foliensatz zur Energie-Info Erneuerbare Energien und das EEG in Zahlen (2010), Berlin. 2/12/2010.

Bennear, L. and R. Stavins (2007): Second-best theory and the use of multiple policy instruments. *Environmental and Resource Economics* 37, 111-129.

Böhringer, C., Hoffmann, T., Lange, A., Löschel, A., and U. Moslener (2005), Assessing Emission Allocation in Europe: An Interactive Simulation Approach, *The Energy Journal* 26 (4), 1-22.

Böhringer, C., Tol, R.S.J. and T.F. Rutherford (2009), The EU 20/20/2020 Targets: An overview of the EMF22 assessment, *Energy Economics* 31(2), 268-273.

Böhringer, C., T. Hoffmann and T.F. Rutherford (2007), Alternative Strategies for Promoting Renewable Energy in EU Electricity Markets, *Applied Economics Quarterly* 58 Supplement, 9-26.

Böhringer, C. and K.E. Rosendahl (2010), Green Promotes the Dirtiest: On the Interaction between Black and Green Quotas in Energy Markets, *Journal of Regulatory Economics* 37, 316-325.

Brooke, A., D. Kendrick, and A. Meeraus (1987): GAMS: A User's Guide. Scientific Press, S.F.

Dirkse, S. and M. Ferris (1995): "The PATH Solver: A Non-monotone Stabilization Scheme for Mixed Complementarity Problems," *Optimization Methods and Software* 5, 123-156.

EU (2009a): Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC, available at: http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN

EU (2009b): Climate Action. Europa: Gateway to the European Union, available at: http://ec.europa.eu/environment/climat/climate action.htm

European Commission (2005), Winning the battle against global climate change, Commission Staff Working Paper, available at: http://ec.europa.eu/environment/climat/pdf/staffworkpapersec2005 1803.pdf

European Commission (2008a): The Climate Action and Renewable Energy Package, Europe's climate change opportunity, available at: http://ec.europa.eu/environment/climat/climate_action.htm.

European Commission (2008b): Winning the Fight against Climate Change: an EU Perspective, Cambridge – UK, available at:http://www.europe.org.sg/en/pdf2008/Winning%20the%20Fight%20against%20Climate%20Change-%20an%20EU%20Perspective.pdf

Fischer, C. and L. Preonas (2010): Combining Policies for Renewable Energy: Is the Whole Less Than the Sum of Its Parts?, *International Review of Environmental and Resource Economics* 4, 51–92.

Frondel, M., N. Ritter, C. M. Schmidt and C. Vance (2010): Economic Impacts from the Promotion of Renewable Energy Technologies: The German Experience, *Energy Policy* 38, 4048-4056.

González, P. del Río (2007): The interaction between emissions trading and renewable electricity support schemes. An overview of the literature, *Mitigation and Adaptation Strategies for Global Change* 12, 1363-1390.

GreenX (2008): Deriving optimal promotion strategies for increasing the share of RES-E in a dynamic European electricity market, Final Report, Vienna, available at: http://www.green-x.at/

Hahn, R. (1986): Trade-offs in Designing Markets with Multiple Objectives, *Journal of Environmental Economics and Management* 13, 1-12.

IEA (2008): Energy Technology Perspective. Paris: International Energy Agency, available at: http://www.iea.org/textbase/nppdf/free/2008/etp2008.pdf

IEA (2009): Global Renewable Energy Policies and Measures Database. Paris: International Energy Agency, available at: http://iea.org/Textbase/pm/grindex.aspx

IEA (2010): Energy Balances, Statistics, Prices and Taxes, available at: http://www.iea.org/stats/

IER (2008): Stromerzeugungskosten im Vergleich, Working Paper, Institute of Energy Economics and the Rational Use of Energy, Stuttgart.

Jensen, S. G. and K. Skytte (2003): Simultaneous Attainment of Energy Goals by Means of Green Certificates and Emission Permits, *Energy Policy* 31(1), 63–71.

Linares, P., F. J. Santos and M. Ventosa (2008): Coordination of carbon reduction and renewable energy support policies, *Climate Policy* 8, 377–394.

Neuhoff, K., K. Keats Martinez and M. Sato (2006): Allocation, incentives and distortions: the impact of EU ETS emissions allowance allocations to the electricity sector, *Climate Policy* 6, 73–91.

Neuhoff, K., A. Johnston, D. Fouquet, M. Ragwitz and G. Resch (2008): The proposed new EU renewables directive: an interpretation, Discussion paper April 2008, available at: http://www.electricitypolicy.org.uk/pubs/misc/neuhoff_renewables_directive.pdf

Pethig, R. and C. Wittlich (2009): Interaction of Carbon Reduction and Green Energy Promotion in a Small Fossil-Fuel Importing Economy, CESifoWorking Paper Series No. 2749.

Rathmann, M. (2007): Do support systems for RES-E reduce EU-ETS-driven electricity prices? *Energy Policy* 35, 342–349.

Rutherford, T.F. (1995): Extensions of GAMS for Complementarity Problems Arising in Applied Economics, *Journal of Economic Dynamics and Control* 19, 1299-1324.

Sijm, J. (2005): The Interaction between the EU Emissions Trading Scheme and National Energy Policies, *Climate Policy* 5(1), 79–96.

Tinbergen, J. (1952): *On the theory of economic policy*, Amsterdam: North Holland.

Unger, T. and E. O. Ahlgren (2005): Impacts of a Common Green Certificate Market on Electricity and CO2-emission markets in the Nordic countries, *Energy Policy* 33(16), 2152–2163.

Appendix: Algebraic summary of numerical model

The appendix presents the algebraic formulation of the electricity market model underlying the numerical simulations in the core paper. Tables A.1-3 provide a summary of the notations for sets, parameters, and variables of the model. Sections A.1-2 state the two classes of economic equilibrium conditions for the partial market model: zero-profit conditions and market-clearance conditions. Complementarity between equilibrium conditions and decision variables of the model are indicated by means of the "$\perp$"-operator. Furthermore, the "$\rightarrow$"-operator is used to signal a logical mapping between sets (e.g., "$i \rightarrow l$" means that there is a mapping from technology i to load l.

Table A.1: Sets

I	Set of all generation technologies (with index $i \in I$)
$XT(I)$	Subset of extant technologies (with index $xt \in XT \subset I$)
$NT(I)$	Subset of new vintage technologies (with index $nt \in NT \subset I$)
$R(I)$	Subset of renewable technologies (with index $r \in R \subset I$)
L	Set of load types (with index $l \in L$)

Table A.2: Parameters

$\bar{y}_i$	Base-year electricity output by technology i (TWh)
$\bar{s}_l$	Base-year electricity supply by load l (TWh)
$\bar{z}$	Base-year aggregate domestic electricity supply (TWh)
$\bar{x}$	Base-year electricity exports (TWh)
$\bar{m}$	Base-year electricity imports (TWh)
$\bar{d}$	Base-year final demand of electricity (TWh)
$\bar{p}_i$	Base-year output price for power generation by technology i (Cent/KWh)
$\bar{p}_l$	Base-year load-specific price of electricity (Cent/KWh)
$\bar{p}$	Base-year consumer price of electricity (Cent/KWh)
$\bar{p}_{Int}$	Base-year International electricity price (Cent/KWh)
$\bar{t}$	Base-year electricity taxes and fees (Cent/KWh)
$\bar{g}$	Base-year electricity grid fee (Cent/KWh)
$\bar{c}_i$	Per-unit costs of electricity production by technology i (Cent/KWh)
$\overline{\overline{y_i}}$	Upper capacity limit on electricity production by technology i (TWh)
$\overline{co2c_i}$	Per-unit CO_2 emissions of electricity production by technology i (kg/KWh)
$\overline{co2\lim}$	Mandated CO_2 emission limit – black quota (Mt CO_2)
$\bar{r}$	Mandated minimum share of renewable electricity in final electricity demand – green quota (in %)
θ_i^l	Base-year value share of technology i supply in total domestic load supply
θ_l	Base-year value share of load supply l in aggregate domestic electricity supply
σ	Elasticity of substitution across different loads (core value: 2)
σ_l	Elasticity of substitution across extant technologies entering load l (core value: 10)
η	Price elasticity of electricity final demand (core value: 0.3)

ε^X	Elasticity of export demand (core value: 0.1)
ε^M	Elasticity of import supply (core value: 0.1)

Table A.3: Variables

Quantity variables:	
y_i	Electricity output by technology i (TWh)
s_l	Electricity supply by load l (TWh)
s_i^l	Electricity load supply by new vintage technology $i \in NT$ (TWh)
z	Aggregate domestic electricity supply (TWh)
x	Electricity exports (TWh)
m	Electricity imports (TWh)
Price variables:	
p_i	Output price for power generation by technology i (Cent/KWh)
p_l	Load-specific price of electricity (Cent/KWh)
p	Consumer price of electricity (Cent/KWh)
p_{co2}	CO_2 price (Euro/t)
p_r	Price premium for renewable energy (Cent/KWh)
μ_i	Scarcity rent on production capacity limit of technology i (Cent/KWh)

A.1 Zero-profit conditions

The zero-profit conditions for the model are as follows:

- Zero-profit conditions for electricity production by technology i $\left(\perp y_i \right)$:

$$\bar{c}_i + \mu_i + p_{co2} \frac{\overline{co2c}_i}{10} - p_r \big|_{i \in R} + \frac{\bar{r}}{(1-\bar{r})} p_r \bigg|_{i \notin R} \geq p_i$$

- Zero-profit condition for load supply by new vintage technology $i \in NT$ $\left(\perp s_i^l \right)$:

$$p_i \geq \sum_{i \to l} p_l \quad i \in NT$$

- Zero-profit condition for load aggregation $\left(\perp s_l \right)$:

$$\left[\sum_i \theta_i^l \left(\frac{p_i}{\overline{\overline{p}}_i} \right)^{(1-\sigma_l)} \right]^{\left(\frac{1}{1-\sigma_l} \right)} \geq \frac{p_l}{\overline{\overline{p}}_l}$$

- Zero-profit condition for final demand supply $\left(\perp z \right)$:

$$\left[\sum_l \theta_l \left(\frac{\left(p_l + \bar{t} + \bar{g} \right)}{\left(\overline{p} + \bar{t} + \bar{g} \right)} \right)^{(1-\sigma)} \right]^{\left(\frac{1}{1-\sigma} \right)} \geq \frac{p}{\overline{p}}$$

21

- Zero-profit condition for electricity imports $(\perp m)$:

$$m \geq \overline{m} \left[\frac{\left(p - \dfrac{\overline{r}}{1-\overline{r}} p_r \right) \overline{p}_{Int}}{\overline{p}} \right]^{\varepsilon^M}$$

- Zero-profit condition for electricity exports $(\perp x)$:

$$x \geq \overline{x} \left[\frac{\left(p - \dfrac{\overline{r}}{1-\overline{r}} p_r \right) \overline{p}_{Int}}{\overline{p}} \right]^{-\varepsilon^X}$$

A.2 Market-clearance conditions

The market-clearance conditions for the model are as follows:

- Market-clearance condition for electricity generated by technology i $(\perp p_i)$:

$$y_i \geq \overline{y}_i \sum_{\substack{l \\ i \to l}} s_l^l \left[\left(\frac{p_l}{\overline{p}_l} \frac{\overline{p}_i}{p_i} \right) \right]^{\sigma_l} \Bigg|_{i \in XT} + s_i^l \Big|_{i \in NT}$$

- Market-clearance condition for electricity load l $(\perp p_l)$:

$$s_l \overline{s}_l + \sum_{\substack{i \in NT \\ i \to l}} s_i^l \geq \overline{z} \overline{s}_l \left[\frac{(p-t-g)}{(\overline{p}-t-g)} \frac{\overline{p}_l}{p_l} \right]^{\sigma}$$

- Market-clearance condition for final electricity $(\perp p)$:

$$z \overline{z} + m - x \geq \overline{d} \left(\frac{p}{\overline{p}} \right)^{\eta}$$

- Market-clearance condition for output capacity constraint by technology i $(\perp \mu_i)$:

$$\overline{y}_i \geq y_i$$

- Market-clearance condition for CO_2 emission constraint, that is the black quota $\left(\perp p^{CO2} \right)$:

$$\overline{co2\lim} \geq \sum_i \overline{co2c}_i \, y_i$$

- Market-clearance condition for renewable energy share, that is the green quota $\left(\perp p^R \right)$:

$$\sum_{i \in R} y_i \geq \overline{r} \overline{d} \left(\frac{p}{\overline{p}} \right)^{\eta}$$