TARGETS FOR RES-E DEPLOYMENT AND CO₂ MITIGATION: IMPACT AND INTERACTION OF DIFFERENT MEASURES

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Abstract—This paper first qualitatively discusses price and quantity based measures for RES-E deployment as well as CO₂ mitigation. A simulation model is further developed to quantitatively discuss the effects of a tradable green certificate system, a tradable CO₂ allowance system and a CO₂ tax on both RES-E deployment and CO₂ mitigation. A three regional model implementation representing the Benelux, France and Germany is used. Significant indirect effects are demonstrated, especially for RES-E supporting measures on the reduction of CO₂ emissions.

Index Terms— Renewable energy; Greenhouse gas emissions; Tradable green certificates; Premium; CO₂ emission allowances; CO₂ tax

I. INTRODUCTION

European legislation is forcing Member States towards a secure, sustainable and competitive energy market. On the one hand, electricity from renewable energy sources (RES-E) is expected to contribute strongly to those three pillars of energy policy. On the other hand, the deployment of renewables can be seen as only an interim step towards the final objective of reducing CO₂ emissions.

The importance of RES-E has been stressed from the first moment steps were taken towards the liberalization of the European electricity sector [1]. Member states were allowed to grant an exemption to the non-discriminatory grid access principle for RES-E producers. Additionally, consumers were obliged to purchase a certain percentage of their electricity demand, originating from renewables. Later, an indicative target to produce 21% of the electricity from RES by 2010 was set in the Renewables Directive [2]. Other directives focused on the promotion of biofuels [3] and taxation of energy products [4] and two communications emphasized the need to make RES-E technologies competitive or to bring them to the market [5][6]. Recently, the European parliament has gone one step further and sealed the climate action plan [7]. This approval aims to ensure the achievement of the 2020 targets [8].

The importance of CO₂ mitigation has first been stressed in

the 1990's. Many countries joined the international treaty to consider what could be done to reduce global warming and to cope with inevitable temperature increases. This resulted in the United Nations Framework Convention on Climate (UNFCCC) following the Rio Earth Summit on May 9, 1992. This convention has been extended and updated to the Kyoto Protocol on 11 December 1997. The recently signed European climate action plan also enforces a 20% CO₂ emission reduction, which can even be strengthened to 30% in case of an international agreement.

On the one hand, different measures can be suggested to facilitate the introduction of RES-E into the electricity market. Feed-in and quota restrictions based on tradable green certificates (TGC) are installed in different member states [9]. These measures are often supplemented with fiscal incentives, investment grants or tendering schemes. On the other hand, measures are needed to reduce CO₂ emissions, aiming to limit the global average temperature increase below 2°C [10]. Quantity-based emission allowances or a price-based CO₂ tax could contribute to reaching the targets imposed.

In literature, research is mainly theoretical, focusing on the effectiveness and cost-efficiency of different measures. With regard to RES-E deployment, current success stories with great effectiveness of the stable feed-in system are contrasted with least cost installation and harmonization opportunities that can be expected under tradable green certificates. Besides, the latter is said to have a higher level of market conformity [11]. Further, the interactions between those measures and CO₂ mitigation measures are also mainly theoretically studied [12][13][14]. As a consequence this paper aims to study the effect of, and interactions between different measures quantitatively. Additionally, direct and indirect effects are analyzed. Towards this aim, a three nodal welfare maximizing simulation model is developed, with each node having significantly deviating characteristics.

In the next section, an overview of both measures with regard to RES-E and CO₂ is first qualitatively given. In the following section, the model, used to investigate the effect of those measures quantitatively, is briefly described. Thereafter, simulation results are presented, based on which, conclusions are drawn in the final section.

II. MEASURES FOR RES-E SUPPORT AND CO₂ MITIGATION

This section briefly presents the characteristics of different measures that can be taken. Additionally, possible interactions

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between the direct RES-E support and the CO₂ measures are qualitatively described.

A. Measures for RES-E support

RES-E support is a subsidy that makes renewable energy technologies relatively cheaper and consequently reduces the price gap between this technology and the conventional technologies. The subsidy to push RES-E into the market is offered as an additional price for the green label of RES-E. This remuneration corresponds to a shift from long run marginal cost curve for renewables 1 (LRMC res1) to a lower level LRMC res2 in Figure 1. RES-E technologies end up to be more competitive and get introduced into the market. As this additional remuneration is offered outside of the wholesale electricity market, the energy price is not expected to be strongly influenced in contrast to the retail price, faced by final consumers [15]. Through the deployment of RES-E technologies, polluting conventional technologies are replaced, indirectly inducing a decrease in CO₂ emissions. The effectiveness of the indirect influence is however uncertain [16].

1) Quantity-based

Policy makers can decide on the level of RES-E that has to be deployed into the market. When this level is expressed as a percentage of final consumption, it is referred to as a quantity-based measure. The TGC system is the quantity-based measure offering direct RES-E support. Certificates, which can be seen as financial instruments, are traded on an artificial market to facilitate reaching previously defined targets [11]. Market-conformity is introduced by establishing a target for a share of RES-E, with or without an intermediate trajectory. As the target is expressed as a percentage of RES-E for total demand, policy makers also have the incentive to reduce demand and consequently improve energy efficiency. It is often mentioned that significant price uncertainty is introduced through this supporting measure. Two volatile remunerations can be expected for the electricity generated and the green label, respectively.

2) Price-based

Price uncertainty can be reduced when policy makers decide to offer a fixed price or a premium for the green label. This makes that only one element, i.e., the electricity price, is determined on the unpredictable market.

Risks involved with electricity price fluctuations can even be fully eliminated. In this final case one fixed price is offered for the electricity generated using RES-E technologies. This feed-in system creates significant stability in the system with the inherent lack of market-conformity. No additional market is created for the remuneration of the green label, nor do RES-E power generators bid into the energy market.

The cost-efficiency and effectiveness of the TGC and the feed-in system is strongly debated and mostly driven by chauvinistic preferences. The price-based feed-in system is strongly supported based on its proven effectiveness. This can be seen as a direct result of increased stability and reduced investment risks. It also easily facilitates encouraging

technological diversity and the development of a diversified RES-E portfolio. The fixed price level, however, has the disadvantage that the amount of RES-E that is finally generated remains uncertain.

B. Measures for CO₂ mitigation

CO₂ emissions can be reduced by several means. For each case, external social costs, due to the emission of CO₂, are priced and make polluting thermal technologies more expensive. Consequently, RES-E technologies become relatively less expensive and therefore more competitive. However, in this case, the conventional technologies are made more expensive, shifting from LRMC conv1 to conv2 in Figure 1. Even though no additional remuneration is offered to electricity generators using RES-E technologies, the RES-E share of final demand can be expected to increase.

1) Quantity-based

Whereas member states are highly inconclusive about the best instrument to introduce RES-E directly into the market, one single European wide approach for CO₂ mitigation exists. Following the Kyoto protocol, Europe has decided to install the European Union Emission Trading Scheme (EU ETS). For every ton of CO₂ emission, an allowance has to be surrendered. Similar to the quantity-based RES-E measure, an artificial market is created to trade emission allowances, which can be seen as financial products.

2) Price-based

The price-based alternative for CO₂ emission reduction is a CO₂ tax. A fixed price must be paid for a certain amount of CO₂ emitted (e.g. one ton), creating a stable opportunity cost for investments in emission reductions.

Figure 1: RES-E and CO₂ measures

C. Interactions between supporting measures

As explained above, both RES-E and CO₂ measures reduce the cost gap between renewable and conventional generating technologies. Whereas one could have a relatively clear idea of the impact of each system separately on the installation of renewables and the reduction of CO₂ emissions [17], this might not be the case if both are simultaneously put in place.

If one price-based and one quantity-based measure is installed, the fixed price level of one measure could influence the market price of the quantity-based measure. If two quantity-based measures are installed, it is not clear whether

one or both quota restrictions will be binding [18].

III. MODEL IMPLEMENTATION AND SIMULATION

A. Model implementation

For this analysis, a welfare maximization model has been set up, considering demand and supply of electricity. Demand for electricity can be met by conventional technologies (having certain CO₂ emission) and by RES-E implementation. Different measures can be added to the standard form of the model, to support RES-E or to mitigate CO₂. Regions with mutual strongly differing characteristics are used. This allows for evaluating the impact and interactions of measures in different regions. A three regional model is employed representing France, Germany and the Benelux (i.e., Belgium, the Netherlands and Luxemburg). With regard to conventional power generation, based on Eurelectric data [19], France is the region dominated by nuclear power whereas the shares of gas and coal/lignite are significant in the Benelux and Germany, respectively.

Differences do also exist between the level of RES-E potential [20]. Within the Benelux only a noticeable offshore wind power potential exists, especially. Potentials in Germany and France are comparable, apart from the much larger hydro potential in France.

Initial demand levels are also based on Eurelectric data and an inelastic -0.1 price elasticity of demand is considered.

Marginal CO₂ pollution takes the current conventional generation portfolios into account for each region.

A triangular network is considered, with all three lines having equal reactances and a capacity of 3000 MW. A schematic overview of the implementation of the model is presented in Figure 2.

Figure 2. Representation of model structure

B. Simulation description

The three regional model is deployed in several simulations. The first part concerns RES-E support. The effect of a RES-E target for the three regions together is investigated. This overall quota has been varied from zero up to 60%.

The second part concerns the CO₂ mitigation measures. Both

a limitation on overall emissions (zero up to 60%) as well as a price on CO₂ (zero up to 100 €/ton) are investigated.

The third and final part of the simulations involves combinations of both a RES-E support and a CO₂ mitigation measure. A quota on RES-E is at first instance combined with a price on CO₂ (tax), and second, with a cap on CO₂ emissions. The interactions between these measures are extensively discussed, mainly focusing on RES-E deployment and CO₂ emission reduction. The supporting measures are implemented over the three regions, corresponding to a harmonized system.

IV. RESULTS

The results of the different model simulations as described above are presented in this section.

A. Measures for RES-E support: TGC

Imposing targets for a certain percentage of RES-E is facilitated by certificates, having a price equal to the dual price of the quota restriction. A target of a 0-60% RES-E share is implemented in the model. This target can be reached through demand reduction, e.g., as a result of energy efficiency, or by increasing the absolute level of RES-E. Lower targets are mainly reached by installation of RES-E, while for higher targets it becomes more interesting to reduce consumers' demand. Based on the different potentials for RES-E, France reaches the highest RES-E share and the Benelux the lowest (Figure 3). This is an illustration of the least cost installation principle when a harmonized support system is in place. Figure 3 presents the impact on the overall emission of CO₂, which is significant.

Figure 3. Overall CO₂ emissions, with a TGC system.

Imposed targets also have an impact on the wholesale and retail price (Figure 4, upper row). The wholesale price, equal to the marginal cost of conventional power generation, is reduced, as part of the conventional generation is replaced by renewables. Therefore, the marginal conventional technology becomes less expensive. The retail price faced by final consumers, however, increases, because of the incorporation of the price of TGC.

B. Measures for CO₂ mitigation

CO₂ emissions can be reduced by decreasing electricity generation from polluting technologies. Therefore, one can switch to renewables, reduce demand or increase the share of nuclear power generation. Generation can be shifted to a region with different characteristics. However, due to limited

Figure 4. Price levels with TGC system (upper row) and with a CO₂ emission trading scheme. Note that the legend presented in the middle lower panel also applies for all panels.

interconnector capacity¹, the opportunities to replace power generation originating from coal (Germany) or gas (Benelux) are restricted.

1) Emission allowance trading

A target is imposed for a certain percentage of CO₂ emission reduction, by means of emission trading. Allowances have a price equal to the dual price of the restriction on overall emissions. The target has an impact on the energy (wholesale) and retail price. In this case, the retail and the energy price are the same, but the energy price is no longer equal to the marginal conventional generation cost. The level of pollution of the marginal technology and the allowance price for CO₂ emissions have to be taken into account:

Figure 4 (lower row) shows that France is strongly protected against an increase in the imposed quota for CO₂ emission reduction. No renewables need to be installed in France and a stable level of conventional power generation is maintained. Due to the least cost emission reduction principle when a harmonized system is in place, the Benelux and especially Germany install significant amounts of renewables (Figure 5). The level of conventional power generation is strongly reduced in these two regions, which can be deducted from the significant decrease in the thermal prices. Therefore both a demand reduction and a RES-E deployment took place.

Figure 5: RES-E shares in different regions with a CO₂ emission trading scheme.

¹ If unlimited interconnector capacity would be modeled, France would increase the nuclear power generation significantly and export major amounts of power to the other regions. Since nuclear power is less expensive than installing renewables, RES-E deployment would be strongly delayed. Consequently, it can be stated that in case of unlimited interconnector capacity, the indirect support of renewables is not effective if nuclear power generation is an option.

2) CO₂ tax

Comparable results are found with the CO₂ tax. Again, France does not really experience a strong impact of this measure with almost unaffected demand and no renewables deployment. While a convex renewables share can be seen in Figure 5 for Germany and the Benelux, concave curves can be seen in Figure 6. This can be explained as follows. In case of the quantity-based allowance mechanism, each additional CO₂ emission reduction is more expensive, resulting in a more than linear renewables deployment. In case of a CO₂ tax, an additional tax increase results in a decreasing slope of renewables deployment due to increasing LPMC for renewables.

Finally, there exists a difference in how the amount of CO₂ emissions is reduced. In case of the allowance mechanism, a linear emission reduction is found, conform with the decrease of the cap. On the other hand, the total level of emissions is convex decreasing in case of an increasing CO₂ tax. This is the consequence of the low hanging fruit concept, which states that the first reductions in emissions are easier achievable compared to the following.

Figure 6: RES-E shares in different regions and overall CO₂ emissions with a CO₂ tax.

C. Interactions between supporting measures

With two measures simultaneously implemented, it is not always clear in advance whether a quota restriction will be binding. If a restriction is not binding, the dual price is zero, which results in a zero certificate or allowance price. First, only one quantity-based measure, TGCs, is studied together with a CO₂ tax which always has an impact. Second, two quantity-based measures are studied. The impact on the installation of RES-E and the reduction of CO₂ remain the main interest.

1) TGC and CO₂ tax

Different combinations of RES-E quota and CO₂ tax levels are studied. Figure 7 shows that the renewables quota is not binding for a triangular group of combinations. With a higher CO₂ tax, a higher renewables quota needs to be implemented to become binding.

Consequently, it can be seen in Figure 8 that for this triangle of non-binding renewables quota, the RES-E share is only driven by the CO₂ tax, while for other combinations both instrument determine the total RES-E share. Additionally, Figure 7 shows that the TGC price is lower when a higher CO₂ tax is in place. This results out of the fact that a higher CO₂ tax

Figure 7: Certificate price for combinations of TGC and CO₂ tax.

Figure 8: RES-E share in region 1 and overall CO₂ emissions for combinations of TGC and a CO₂ tax. Note that both the X and Y axis have a reversed direction in the lower panel.

already reduces the cost gap between conventional and renewable power generating technologies to a higher extend.

A smaller additional support, by means of the certificate price, is therefore required for an even higher renewables share (Figure 8). The non-binding triangle can also be recognized in the lower panel of Figure 8. Combinations can be seen where for a certain CO₂ tax, the quota levels do not have an impact on the total emissions. It can also be seen that the influence of a CO₂ tax fades as quota levels on RES-E increase.

2) TGC and emission allowances

Two quantity-based measures can also simultaneously be installed with quota restrictions on the amount of emission reduction and the share of renewables. It can be seen on Figure 9 that three planes exist for both the certificate and the allowance price. These planes represent the quota combinations for which only one or both restrictions are binding. From Figure 9 it can be seen that for a relatively high quota on renewables, the certificate price is only dependent on this quota, while being independent from the restriction on CO₂ emissions. On the other hand, at relatively low RES-E quota and high CO₂ emission restrictions, the RES-E quota restriction becomes a non-binding constraint, and hence, yields a zero certificate price. Figure 9 also presents the allowance price. A large plane with a zero allowance price can be seen, which corresponds to the plane in the upper panel that is independent from the CO₂ emission restriction. Only a narrow plane exists at relatively high CO₂ restrictions and low RES-E quota, which has a significant allowance price, and a non binding RES-E constraint. The slanting planes in both panels correspond to the situation where both the RES-E quota and the CO₂ emission restriction are binding constraints.

Figure 10 presents the renewables share in the Benelux. Comparing Figure 10 with Figure 8 clearly illustrates that a tax always has its impact. Even at very high quota for renewables, it still influences the share of renewables (and hence the certificate price). When, on the other hand, two quantity based measures are simultaneously implemented with one being highly stringent, the other becomes non-binding and loses its impact. This creates significant uncertainty when certain investments are fully based on the remuneration through one measure².

V. CONCLUSION

The impact of price-based and quantity-based measures concerning RES-E support and CO₂ mitigation is investigated, in combination with the interactions between these measures. It can be concluded that quantity-based measures offer an incentive to reduce demand and stimulate energy efficiency. In

² Note that there are other sectors subject to EU ETS, next to the power sector. These are, however, not covered in this model. As sort of a residual quota on CO₂ emissions is modeled for the power sector solely, the price of allowances can drop to zero at sufficiently high levels of quota on RES-E. In reality, there will be interaction with the other ETS sectors, and the allowance price will not drop to zero that easily.

Figure 9: Certificate price and allowance price for combinations of TGC and CO₂ allowances. Note that the X axis has a reversed direction in the lower panel.

Figure 10: RES-E share in region 1 and overall CO₂ emissions for combinations of TGC and CO₂ allowances. Note that both the X and Y axis have a reversed direction in the lower panel.

general, a single measure (either RES-E support or CO₂ mitigation) induces both the installation of renewables and the reduction of CO₂ emissions. Although a measure should be used in essence to contribute directly to meeting its targets, it also has an indirect impact. In this regard, an increased target for a RES-E share is more effective in reducing CO₂ compared to using a CO₂ approach for increasing the RES-E share. When a CO₂ measure is implemented, it is clear that nuclear is an interesting option. Consequently, countries with a high nuclear power share face almost no RES-E deployment.

Finally, it can be concluded that different support measures influence each other. Price-based measures always have an

impact, in contrast to quantity-based measures. In the latter, the outcome can significantly be influenced as the price for certificates or allowances can become zero with non-binding restrictions. This creates significant uncertainty when investment decisions in renewables or in emission reductions are based on only one remuneration measure.

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