Alternative Strategies for Promoting Renewable Energy in EU Electricity Markets

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March 4, 2006

1 Introduction

Political support for renewable energy technologies has a history of over 30 years within the EU. Motives as well as favoured policies and measures to promote the market penetration of electricity from renewable energy sources (RES-E) have differed largely.

The first major impetus for the promotion of renewable energies can be traced back to the oil crises in the early 70ies and 80ies: Renewable energy from EU-internal sources was seen as an appropriate long-term substitution to exhaustible and mainly imported fossil fuels in order to secure EU-wide energy supply. A second central push is linked to the negative environmental externalities associated with the combustion of fossil fuels. In the mid 80ies environmental concerns were mainly related to local and regional problems of air quality and acidification. These problems were handeled largely through end-of-pipe technologies for electricity production from coal but also prodived additional political support to renewable energies. Much more substantially had been and still are the implications of anthropogenic carbon emissions from fossil fuel combustion for global warming turning out as the most challening problem for environmental policy over the next decades and maybe even centuries. Carbon-free energy supply technologies are considered as the central response to cope with the problem of global warming in the long run. More recently - and complementary to energy security as well as environmental objectives - "green" policy makers push renewable energy in order to create new jobs and strengthen competitiveness of the EU economy in terms of lead technologies that might be promoted on world markets.

As to policy measures for the promotion of renewable energies there had been a shift - as more generally in environmental policy desing - from command-and-control policies to market-based instruments such as taxes, subsidies, and tradable quotas. In the context of renewable energy promotion, taxation of energy in many EU countries meanwhile comes along with tax breaks or tax exemptions to renewable energy working as implicit subsidies to correct relative prices with respect to energy security and environmental targets. In addition, direct subsidies for renewable energy are warranted – typically differentiated by the type of green energy, i.e., hydropower, wind, biomass, solar, etc. A relatively new strand of policy regulation is the use of tradable green quotas where energy supplies are required to produce a certain share of energy services from renewable energy but are flexible to trade these shares between each other in order to exploit potential difference in specific compliance costs.

In this paper, we investigate the economic consequences of promoting the increased market penetration of electricity produced from renewable energy sources within the EU. We focus on two alternative policy instruments which are central to the EU stratgey for the promotion of RES-E: Feed-in tariffs, i.e. direct subsidies to electricity production from renewable energy, on the one hand; and quota obligation systems with tradable green certificates (TGC) on the other hand. Based on large-scale partial equilibrium model of the EU electricity market calibrated to empirical data, we find that differentiated feed-in tariffs (as most commonly applied to date) incur substantial excess cost compared to an EU-wide tradable green quota. In broader terms, this excess cost can be interpreted as the price tag that policy makers have to attach to other objectives than the pure greening of electricity. Such objectives might include pursuits to reduce additional market failures associated with market barriers to specific infant renewable technologies, knowledge spillovers from private R&D or aspects of strategic and regional policies.

The remainder of this paper is as follows: Section 2 provides a brief summary of the EU policy initiatives for the promotion of renewable energy in electricity production and sketches obstacles to efficient RES-E promotion. Section 4 lays out the basic efficiency considerations for the design of promotion strategies. Section 4 describes the analytical framework and the database underlying our numerical analysis. Section Section 5 presents illustrative policy scenarios and discusses the results. Section 6 concludes.

2 Background: RES-E promotion in Europe

The Directive on the Promotion of Electricity produced from Renewable Energy Sources (RES-E) in the internal electricity market, is the main legislation affecting RES-E at the EU level (EU 2001). The Directive aims at facilitating a significant increase in RES-E production within the EU. The indicative objective of the Directive is a doubling of the share of renewable energy in Europe's gross energy consumption from approximately 6% in 1997 to 12% in 2010. The share of 12% of renewable energy in gross energy consumption has been translated into a specific share for consumption of RES-E, i.e. the consumption of electricity from renewable energy sources in final EU electricity consumption, of 22.1% in 2010 (as compared to 14% in 1997). This objective was set in the 1997 White Paper on renewable energy sources (European Commission 1997) and endorsed by the Energy Council in May 1998. The Directive also establishes indicative targets for the penetration of RES-E in each Member State (see column "RES-E target" in table 1).

To date, Member States employ a myriad of support schemes. Some of them stimulate the supply of renewable electricity, while others directly affect the demand. Furthermore, support schemes can be distinguished according to the supported activity, i.e., either capacity installation is promoted or the generation of green electricity. Figure 1 classifies the support schemes regarding the dimension of support. A recent survey published by the European Commission ((European Commission 2005c)) shows that feed-in tariffs are the most common promotion measure (in seven out of the EU-15 Member States) followed by quota obligation systems with tradable green certificates (TGC) (in four out of the EU-15 Member States). In contrast, tender schemes, investment subsidies and fiscal measures only play a minor role (see also table 1).

From an economist's point of view the promotion of RES-E - as well as other

Table 1: Indicative RES-E targets in 2010 and national support schemes to achieve them

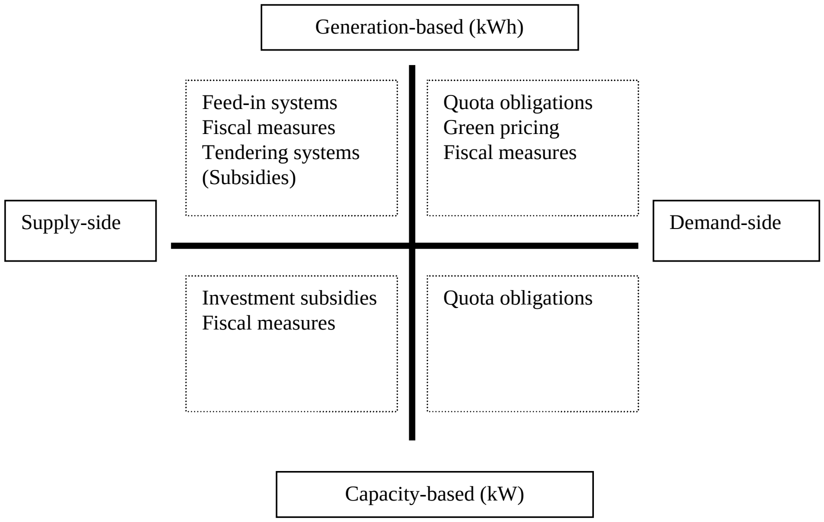
	RES-E target [in %]	National support schemes		
		Feed-in tariffs	Quota obligations / TGC	Other
Austria	78.1	yes		
Belgium	6.0		yes	Minimum price for renewables
Denmark	29.0	yes		Tender schemes for offshore wind
Finland	31.3			Tax exemptions and investment incentives
France	21.0	yes		
Germany	12.5	yes		
Greece	20.1	yes		investment incentives
Ireland	13.2	yes (announced)		Tender schemes
Italy	25.0	yes (for PV)	yes	
Luxembourg	5.7	yes		
Netherlands	9.0	yes		
Portugal	39.0	yes		Investment incentives
Spain	29.4	yes		
Sweden	60.0		yes	
United Kingdom	10.0		yes	
European Union	*21.7*			

Source: EU 2005

regulatory policies - must be justified by market failures, i.e. the inability of markets to capture all the social benefits and social costs associated with economic activities. These failures, typically referred to as externalities, require mandatory regulations for internalization in order to assure more efficient use of scarce resources. For policy making the identification of appropriate instruments to cure market failures is crucial. In simplistic terms, each externality can be addressed by one targeted policy instrument such as taxes, subsidies, definition of property rights, liability rules etc. However, promotion of renewable energies obviously can contribute to ameliorate simultaneously various discrete externalities and serve strategic individual interests (such as the market penetration of specific infant renewable technologies, the creation of knowledge spillovers from private R&D or the consideration of strategic aspects of industrial and regional policies).

There are various obstacles to the design and implementation of efficient RES-E promotion policies. Obviously, there is imperfect information or uncertainty which can affect the appropriate choice of instruments. Assuming an exogenous target such as a minimum share of RES-E, a quota obligation will assure effectiveness whereas

Figure 1: Classification of RES-E Policy Support Mechanisms



Source: Uytelinde et al. 2003

a feed-in tariff system would require to have perfect information on all technologies, their costs and potentials, price developments on the electricity market, consumer preferences, etc.[1] But feed-in tariffs allow for a differentiated treatment of alternative renewable technologies taking into account other objectives than just the greenness of the electricity system. In policy practice, feed-in tariff systems stand out for a large discrimination across different green technologies.[2] The consequence is that less efficient more costly technologies such as solar or geothermic energy are much more subsidized than more competitive renewables such as hydro- or wind-power. If the policy objective was simply the greenness of energy production, such a differentiated feed-in-tariff system is likely to create huge excess costs which may be interpreted as an additional premium that policy makers have to attach to other objectives than the pure greening of electricity. Such objectives might include pursuits to reduce market barriers to specific infant renewable technologies, knowledge spillovers from private R&D or strategic aspects of industrial or regional policies (e.g. for domestic export industries of renewable technologies).

In contrast, quota obligation systems with tradable green certificates (TGC) make use of decentralized market mechanisms in order to meet overall national (or EU-wide) targets in an efficient way.[3] The quota system implicitly assigns a

[1] Against this background it is not surprising, that - according to recent studies (e.g. Uyterlinde et al. 2003) most of the Member States who employ feed-in tariff systems will not reach their indicative targets until 2010.

[2] As an example: The German Renewable Energy Sources Act defines a premium for solar electricity which is roughly 4 times higher than for electricity produced from biomass (Bundestag 2001).

[3] Such systems distinguish between the commodity (electricity) and the service of this commodity (the environmental friendliness or "greenness") and - in case of a tradable certificate system - create a secondary market for the service. The commodity is sold at respective power-market prices

scarcity price to the "greenness" of electricity (or *green value*) as an explicit policy objective. There is no differentiation between alternative renewable energies and the market will sort out what type and quantity of renewable energy will serve most efficient the policy objective of green electricity. However, green certificates may pose a higher risk for investors and long-term, currently high cost technologies are not easily developed under such schemes.

On a supra-national level not only the choice of appropriate promotion schemes affects the efficiency but also the geographic scope. E.g. an EU-wide market for TGCs would allow for an increased regional flexibility and inevitybely cut costs for meeting the overall EU target. Against the background of the development of a single European market for electricity - stipulated by the liberalization Directive (EU 2003) - the Renewable Energy Directive also provides a framework for the future harmonization of renewable energy support schemes within in the EU.[4] However, in its communication from 7 December 2005 the European Commission concluded that at this stage a harmonised European system would not be appropriate. The main reason against an EU-wide feed-in tariff system is the information problem as described above which would be even more challenging on a wider EU-level. A common TGC market is considered as problematic since uncertainties in the future development of the green value may lead to potentially high investment risk, and thus hinder the development of RES-E penetration in the future ((European Commission 2005c, European Commission 2005b)).

3 Analytical Framework

We set up a stylized partial equilibrium model of the electricity market that demonstrates the effects of the two most common RES-E promotion policies in Europe. i.e. feed-in tariff systems and quota obligations. Let a (competitive) electricity market be determined by the electricity price p, a nonlinear demand function $D(p)$ and the activity levels x_c, x_{r1} and x_{r2} of three discrete power generation technologies - a conventional thermal technology c and two renewables technologies $r1$ and $r2$. Production costs are depicted by the cost-function $C(x_c, x_{r1}, x_{r2})$ where $0 \leq MC(x_c) \leq MC(x_{r1}) \leq MC(x_{r2}) \leq +\infty$.[5] A minimum share rq of RES-E in total electricity demand or production implicitly sets a lower bound on the electricity production from renewables. Initially RES-E technologies are inactive (i.e. $MC(x_{r1}) > p$ and $MC(x_{r2}) > p$)

We mimic a feed-in tariff scheme by (i) granting a (per-unit) subsidy λ to RES-E production that ensures the minimum share of renewables in total electricity demand, and by (ii) imposing an ad-valorem tax ψ that allocates the overall magnitude of RES-E promotion to the customers, such that $p \cdot \psi \cdot D(p \cdot (1+\psi) \geq \lambda \cdot (x_{r1} + x_{r2})$.

and the corresponding *greenness* of electricity can either be sold or purchased on the certificate market.

[4]The Directive announced a decision on a community framework for support schemes by the end of 2005, with a following transition period of at least 7 years where existing support schemes could be maintained for already installed capacity.

[5]And where $MC'(x_c) = MC'(x_{r1}) = MC'(x_{r2}) = 0$

When we allow for technology-specific promotion, the subsidy level λ translates into technology-specific premiums through the adjustment factors a_{r1} and a_{r2}. A central planner's problem is now to find x_c, x_{r1}, x_{r2}, p, λ and ψ that maximize the economic surplus:

$$\text{max:} \int_0^D p(D)dD - p\cdot(1+\psi)\cdot D(p\cdot(1+\psi)) + p(x_c + x_{r1}, +x_{r2}) - C(x_c, x_{r1}, x_{r2}) \quad (1)$$

$$\begin{aligned} s.t. \qquad & (x_{r1} + x_{r2}) \geq rq \cdot D(p(1+\psi) \\ & p \cdot \psi \cdot D(p \cdot (1+\psi) \geq \lambda \cdot (x_{r1} + x_{r2}) \end{aligned}$$

Setting up the Lagrangian and differnetiating with respect to x_c, x_{r1} and x_{r2} we can transform the central planner's maximization problem into the (market) equilibrium conditions:[6]

$$\begin{aligned} 0 \leq x_c \quad &\perp \quad MC(x_c) - p \geq 0 \qquad (2) \\ 0 \leq x_{r1} \quad &\perp \quad MC(x_{r1}) - a_{r1} \cdot \lambda - p \geq 0 \\ 0 \leq x_{r2} \quad &\perp \quad MC(x_{r2}) - a_{r2} \cdot \lambda - p \geq 0 \\ 0 \leq p \quad &\perp \quad (x_c + x_{r1} + x_{r1}) \geq D\left(p \cdot (1+\psi)\right) \\ 0 \leq \lambda \quad &\perp \quad x_{r1} + x_{r2} \geq rq \cdot D\left(p \cdot (1+\psi)\right) \\ 0 \leq \psi \quad &\perp \quad p \cdot \psi \cdot D(p \cdot (1+\psi) \geq \lambda \cdot (x_{r1} + x_{r2}) \end{aligned}$$

In contrast, a quota obligation system sets a lower bound on the activity levels of $r1$ and $r2$, such that $(x_{r1} + x_{r2}) \geq rq \cdot (x_c + x_{r1} + x_{r1})$. No subsidy is granted for RES-E deployment, thus no re-fincaning via an electricity tax is needed. Economic surplus is maximized by:

$$\begin{aligned} max: \qquad & \int_0^D p(D)dD - C(x_c, x_{r1}, x_{r2}) \qquad (3) \\ s.t. \qquad & (x_{r1} + x_{r2}) \geq rq \cdot (x_c + x_{r1} + x_{r1}) \end{aligned}$$

Again, the Lagrangian and differentiation leads to the equilibrium conditions:

$$\begin{aligned} 0 \leq x_c \quad &\perp \quad MC(x_c) + rq \cdot \lambda - p \geq 0 \qquad (4) \\ 0 \leq x_{r1} \quad &\perp \quad MC(x_{r1}) + rq \cdot \lambda - \lambda - p \geq 0 \\ 0 \leq x_{r2} \quad &\perp \quad MC(x_{r2}) + rq \cdot \lambda - \lambda - p \geq 0 \\ 0 \leq p \quad &\perp \quad (x_c + x_{r1} + x_{r1}) \geq D\left(p\right) \end{aligned}$$

[6]Where the orthogonality symbol ($\perp$) expresses that the inner product of a variable and a function must be zero, e.g when $0 \leq x_c \perp MC(x_c) - p \geq 0$ also $x_c\left(MC(x_c) - p\right) = 0$ must hold.

$$0 \leq \lambda \quad \perp \quad x_{r1} + x_{r2} \geq rq \cdot (x_c + x_{r1} + x_{r1})$$

Figure 2 displys our theoretical considerations. Figure 2 a) shows the effects of a feed-in tariff scheme with uniform premiums. When we assume perfectly competitive markets and full information the feed-in tariff system with uniform premiums is equivalent to a quota obligation scheme with trade in TGCs. In our stylized example only technology $r1$ is used to meet the target. The subsidy level λ^F for $r1$ under a feed-in tariff system equals the subsidy level λ^Q when we impose a quota obligation. Under both regulations the total RES-E production level x_r (i.e. $x_{r1}+x_{r2}$) accounts for the desired share of renewables in production respectively consumption. In case of a quota system, the higher costs of RES-E production (measured as $\lambda^Q \cdot x_r$) is distributed across all active technologies such that $\lambda^Q \cdot x_r = rq \cdot \lambda^Q \cdot x^{Q*}$. In other words, marginal cost of electricity supply rise by $rq \cdot \lambda^Q$. Clearly, higher costs of supply inevitably lead to higher electricity prices and, thus, to a lower electricity demand - in our simple example the price rises from p_0^* to $p_0^* + rq \cdot \lambda^Q = p^{Q*}$ and demand drops from x_0^* to x^{Q*}.

Under a feed-in tariff scheme the regulator re-finances the total magnitude of RES-E promotion or subsidies (measured as $\lambda^F \cdot x_r$) via an ad-valorem tax on the electricity consumption. The electricity tax ψ (in our example given as:[7] $\psi = \lambda^F \cdot rq/p_0^*$) increases the electricity price by $\psi \cdot p_0^* = \lambda^F \cdot rq$ to p^{F*} and, consequently decreases electricity demand from x_0^* to x^{F*}. Under both regulations the loss in economic surplus amounts to the shaded area *abc*.

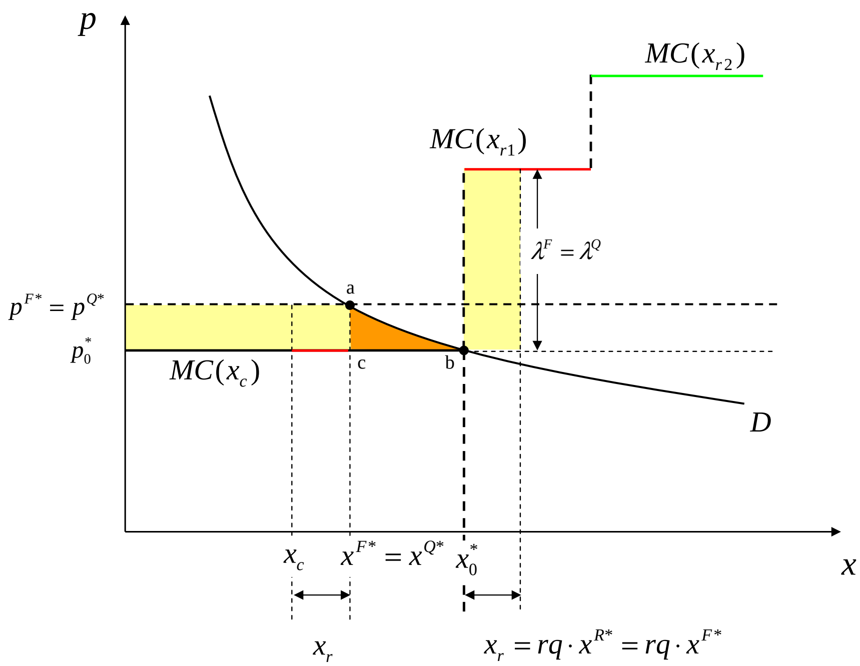
The results change when we allow for technology specific premiums (see figure 2 b). Let us assume that the more costly technology $r2$ receives 110% and technology $r1$ only 50% of the total subsidies (i.e. $a_{r1} = 0.5$ and $a_{r2} = 1.1$).[8] Though higher than in the cases before, the shadow price λ^{AF} on the renewables constraint does not facilitiate the deployment of - the initially cheaper - technology $r1$. Instead, technology $r2$ is solely used to meet the given RES-E target. Technology $r2$ now receives an overall subsidy of $1.1 \cdot \lambda \cdot x_r$ which is considerably higher than in the case of a uniform tariff and, accordingly, leads to a higher electricity tax. We see that the adjustment leads to higher prices $p^{AF*} \geq p^{F*}$ and to lower electricity demand $x^{AF*} \geq x^{F*}$ as compared to uniform premiums. Consequently, the loss in economic surplus - depicted by the shaded area def in figure 2 b - is also larger. Following our considerations in the previous section this additional costs can be interpreted as the price for technological diversity.

[7]Derived from: $\psi = \frac{\lambda^F \cdot (x_{r1}+x_{r2})}{p_0^* \cdot D(p_0^* + (1 \cdot \psi))}$ when we assume market clearance such that $D(p_0^*+(1 \cdot \psi)) = (x_c + x_{r1} + x_{r2})$.

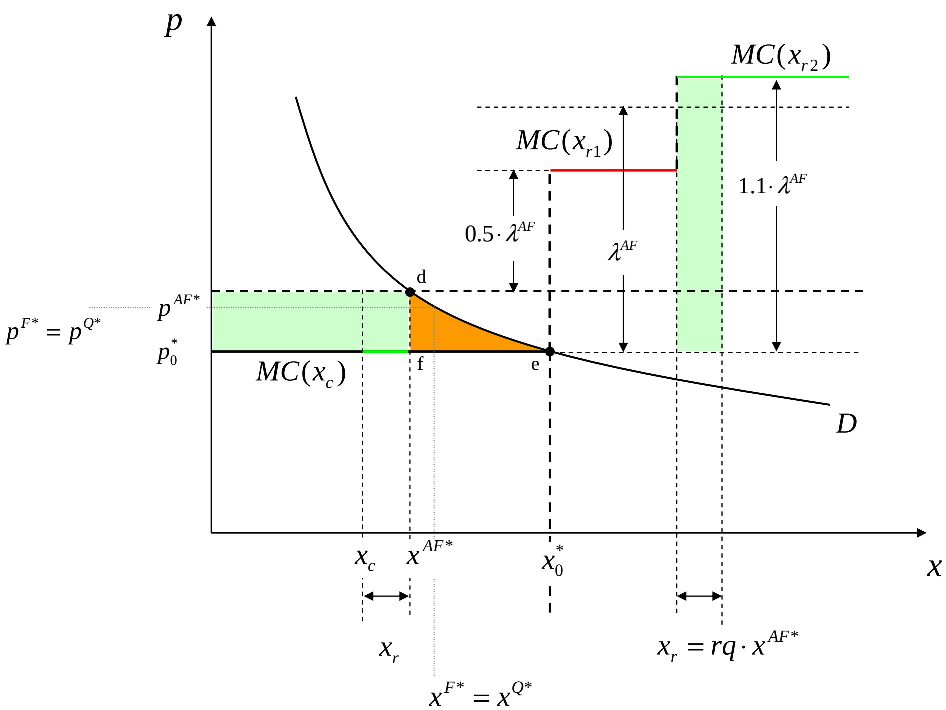
[8]Note that in this case the feed-in tariff for $r2$ effectively is 2.2 times higher than the tariff for technology $r1$.

Figure 2: Effects of feed-in systems and quota obligation

a) Feed-in tariff system with uniform tariff and quota obligation



b) Feed-in tariff system with technology-specific (adjusted) tariffs



4 Numerical Framework

4.1 Model Summary

Our numerical analysis of different RES-E promotion strategies is based on a (static) large-scale partial equilibrium model of the European electricity sectors where a set of strategically acting firms competes for market shares on regional markets. In each region firms own a fixed stock of generation capacity that consists of a discrete set of different power plants characterized by specific generation technologies. Electricity markets in each of the regions are further segmented into markets for electricity supplied to residential- and industrial customers. In addition, industrial customers face differentiated pricing over the load-curve which accomodates differentiated electricity products and, hence, mimics to some extend the existence of a spot market for electricity where industrial customers may buy electricity in the short term. In contrast, residential customers - who are usually supplied on basis of long-term power purchase contracts - pay a flat fee for electricity delivered at any point of the load-curve. Notwithstanding, residential customers demand electricity in base- and peak-load. For the sake of simplicity we introduce two load segments - one for demand in base-load and one for peak-load demand. The resulting regional demand segments are characterized by iso-elastic demand functions.

Firms supply domestic demand either by using their domestic generation capacities or by importing electricity from other regions as well as they might supply electricity to other regions. Cross-border electricity trade is thereby limited by the availability and the capacity contraints of inter-regional exchange points. Each region covered by our model represents one electricity network. Transmission and distribution of electricity is priced with (exogenous) grid charges. Costs for inter-regional electricity exchange also account for the scarcity of exchange capacities.

Electricity production and supply are subject to different technical and political constraints. Plant-specific capacity limits impose an upper bound on the electricity production and supply of each firm. Furthermore, suppliers are obliged to assure a certain level of reserve capacity (determined as a fraction of total electricity supply in a region). Suppliers may either be constrained by regional maximum emission (CO_2) levels or by emission taxes. Electricity markets are subject to minimum targets for the deployment of RES-E capacities and respective policies to reach them. RES-E supply options are captured by regional cost-potential curves. Feed-in tariff systems and quota obligations have been implemented as described in the previous section. In addition, we introduce a (secondary) international market for tradable green certificates. Regions can meet their RES-E target either by domestic production or by importing TGCs. On the other hand, regions can produce more RES-E than they are obliged to and become exporters of TGCs.

Numerically, our model is formulated as a mixed complementarity problem (MCP). The algebraic formulation is implemented in GAMS (Brooke, Kendrick and Meeraus (1987)) using PATH (Dirkse and Ferris (1995)) as a solver. The algebraic description of the model can be found in the Appendix.

4.2 Parameterization

We parameterized the model for 23 regions (23 EU countries[9] representing the enlarged EU-25 without Malta and Cyprus). Regional electricity demand was obtained from recent UCTE (2005), NORDEL (2005) and IEA (2005) statistics. In order to facilitate the disaggregation of the overall regional demand figures into residential and industrial demand we used detailed energy balance data from IEA/OECD (2004). In addition, we employed detailed statistics on hourly load values provided by international associations (UCTE, NORDEL) and and several national grid operators in order to determine the load-specific demand for both demand segments in each region. Regional electricity prices were obtained from the 4^{th} Benchmarking Report of the European Commission (EU, 2004).

The supply side of the model covers over 1100 conventional thermal power plants. Each of the plant is owned by one of over 220 firms. Information on the installed capacity of each plant and on the ownership structure was obtained from an extensive power plant database that covers all 23 regions of the model (Glückauf, 2005). Technical and economic information on the power plants stem from IKARUS (KFA, 2002), a comprehensive data base that has been developed for the German Ministry for Technology and Research over the last years. The database provides data on installation costs, operating and maintenance costs and the thermal efficiencies of the power plants. We carefully mapped the technologies provided in the power-plant database to a set of 11 selected IKARUS technologies (covering fossil fuel-fired and nuclear plants) and used a dynamic investment calculus in order to obtain technology-specific electricity production costs. Fuel prices and data on personnel costs needed for the calculation were obtained from Eurostat (EU, 2005). Technology-specific carbon emission-coefficients also stem from IKARUS.

We introduced a set of 16 RES-E technologies. Cost and potential data stem from the ADMIRE-REBUS model, a large scale partial equilibrium model of the European renewable energy system (Uyterlinde et al. 2003 and DeNoord et al. 2004). Each renewables technology is further sub-divided into "technology-bands" in order to account for different site qualities (e.g. different wind speed) and potentials or availability of renewable fuels (e.g. wood or other biomass). We attributed the available technology-specific potentials in each region to the firms according to their shares of conventional capacity in a regions' total generation capacity. Information on inter-regional electricity trade and exchange capacity limits were obtained from recent UCTE, NORDEL and ETSO statistics.

[9] Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, The Netherlands and The United Kingdom

Table 2: Summary of policy scenarios

	Feed-In tariff schemes		Quota systems	
	FEED_D	*FEED_H*	*QUOTA_R*	*QUOTA_EU*
Promotion scheme	Regional and technology-specific feed-in tariffs	Harmonized feed-in tariff in all regions	Regional quota	Regional quotas and trade in TGC's
Financing of promotion	Through electricity tax	Through electricity tax	Through the electricity market	Through the electricity market and the TGC market
Harmonized green value	No	Yes (national/regional)	Yes (national/regional)	Yes (EU-wide)
Trade in TGC's	No	No	No	Yes

5 Policy Scenarios and Results

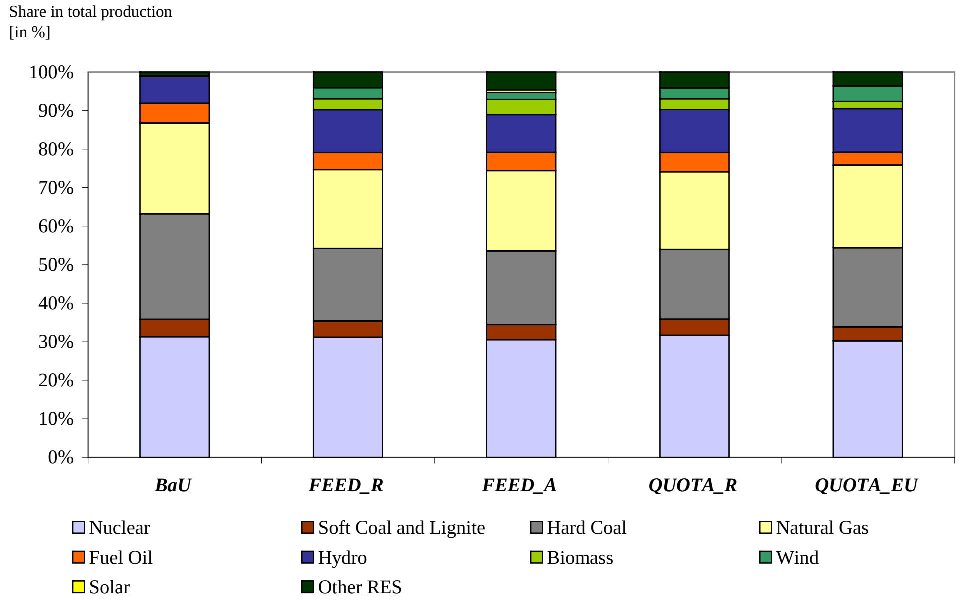
5.1 Policy scenarios

We investigate the economic consequences of promoting the increased market penetration of RES-E along a business as usual development (scenario *BaU*) and four illustrative policy scenarios *FEED_D*, *FEED_H*, *QUOTA_R* and *QUOTA_EU*. Scenario *BaU* reflects an extreme situation where no political support is given to RES-E production.

Scenario *FEED_D* mimics the situation where Member States employ diversified support schemes for RES-E. Different technologies receive support at different levels. The induced diversity may imply an inefficient distribution of the overall support level of RES-E across different technologies. Member States achieve their indicative targets but possibly at high costs. This scenario reflects the present situation in most of the EU-15 Member States. Scenario *FEED_H* reflects a regulation where Member States employ harmonized regional feed-in tariffs. In other words: Each technology receives the same premium. This tariff reflects the regional scarcity of RES-E options. According to the differences in regional potentials and costs of RES-E production these levels will vary across the EU Member Sates. Subsidiation and re-financing is the same as in scenario I.

In scenario *QUOTA_R* Member States achieve their indicative RES-E targets by a quota system which obliges the market parties to ensure the regional targets. No subsidy is payed, thus no tax on the electricity price is needed. Suppliers in the Member States produce the needed level of RES-E according to the national targets. The induced increase in the costs of electricity supply are transferred to the customers via potentially higher electricity prices. The scenario leads to a harmonized national/regional certificate price or green value.The results of this scenario should not considerably deviate from those of scenario *FEED_H*. Notwithstanding, differences may occur due to cross-border electricity trade or market power of

Figure 3: Technology mix of European electricity supply



suppliers.

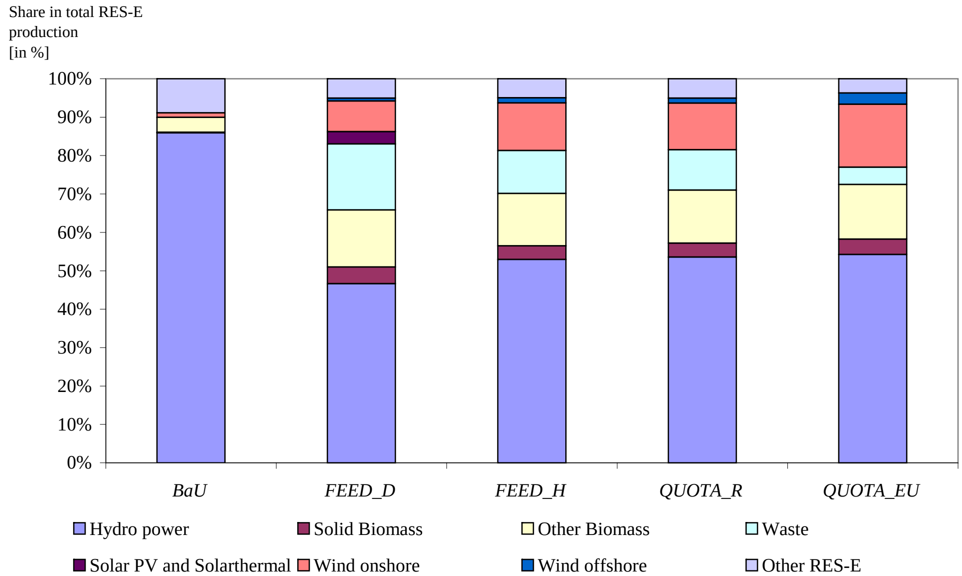
Finally, in scenario $QUOTA\_EU$ a completely harmonized situation is simulated by introducing a common support framework (and level of support) across Europe. As in the case of regional quotas, market parties are obliged to meet national targets but, in addition, a market for tradable green certificates is introduced. Regional targets can either be met by production of RES-E or by importing TGCs. In addition, certificates may be sold at the market if domestic costs are lower than the international certificate price. Hence, this scenario provides a haromized value of green electricity for all countries across Europe. The quota system for renewable electricity will ensure that the EU reaches its overall RES-E target of approximately 22% in a cost-efficient way.

5.2 Electricity production and technology mix

Figure 3 displays the changes in the European electricity supply system. The administered market penetration of green electricity production inevitably affects the use of conventional thermal production capacity. Additional RES-E production mainly influences the use of coal (hard coal as well as soft coal and lignite) and fuel oil. In each of the scenarios the share of coal in total production of EU-15 countries decreases by approximately 10 % vs. BaU. Clearly, green production substitutes the most expensive technologies at first. Due to additional electricity taxes under $FEED\_D$ and $FEED\_R$ and higher overall production costs under $QUOTA\_R$ or $QUOTA\_EU$ expensive technologies become unprofitable. Nevertheless, nuclear capacities and coal plants still provide more than 50 % of the total electricity supplied to customers.

Different promotion schemes explicitly influence the deployment of RES-E tech-

Figure 4: Technology mix of European green electricity supply



nologies. Figure 4 shows the shares of green technologies in total green electricity production (detailed regional RES-E production is given in 6). In the BaU scenario hydropower accounts for over 85 % of total RES-E production. Only a small fraction of electricity is produced from wind, the remaining 13 % are produced from biomass and waste. When technology-specific feed-in tariffs are employed in scenario $FEED\_D$ hydropower still accounts for the major share of green production (45 %), however, the RES-E-mix exhibits much more technological diversity. Biomass and waste constitute roughly 36 % of green production. Even relatively costly solar potentials are utilized (approximately 3 %).

Uniform feed-in tariffs ($FEED\_H$) and regional quota obligations ($QUOTA\_R$) the diversity prevails, but especially windpower (onshore) profits from uniform regional green values at the expense of waste and biomass. This indicates a regional over-funding of biomass and waste under differentiated feed-in tariffs, whereas windpower receives insufficient support according to its relative profitability. Solar potentials are no longer employed as regional green values are not high enough for solar capacities to break even.

The described trend continues, when EU-15 countries are subject to a harmonized quota system with TGC trade. The equalization of marginal costs of RES-E production across all participating regions ensures that the most profitable potentials are used at first. Scenario $QUOTA\_EU$ facilitates the additional use of wind potentials in France, Greece (onshore) and the Nordic region (onshore and offshore) - but now almost solely at the expense of waste.

5.3 Impacts on the electricity markets

Table 3 shows the effects of RES-E promotion on the development of industrial (base- and peak-load) and residential electricity prices as well as the total electricity consumption in the regions. An administered increase of green production implicitly causes higher electricity prices. Not only primarily unprofitable capacities are phased-in; these capacities also substitute initially more profitable technologies. Consequently, most regions are subject to significantly increasing electricity prices. Under scenario $FEED\_D$ industrial base-load prices rise up to 17.3% (Nordic market) above their BaU level. Peak-load prices and prices for residential customers increase up to 28.9% and 19.5% vis-à-vis BaU in Spain and Portugal. Accordingly, the increase in electricity prices has a negative impact on electricity demand. Total electricity consumption decreases by 7.4%. Inter-regional electricity trade to some extent compensates these effects. Countries that are not subject to RES-E regulation may even face decreasing electricity prices. A switch to uniform feed-in tariffs ($FEED\_H$) mitigates the decrease in electricity consumption on the EU-wide level (-6.2% vs. BaU). The increase in electricity prices is less pronounced than under $FFED\_D$.

Table 4 displays the results of the four scenarios regarding green values λ (or the per-unit support level for renewables), induced electricity taxes ψ, the direct costs of RES-E promotion ($\lambda \cdot x_r$) and the efficiency costs (measured as the loss in economic surplus). Obviously, regional green values differ in each of the scenarios where inter-regional TGC trade is not possible, thereby reflecting each regions' scarcity of RES-E production facilities. E.g. in scenario $FEED\_A$ green values range from 0 €/MWh in Greece to 108.4 €/MWh in Spain and Portugal. In comparison to BaU the Greek RES-E target does not induce an increase in the magnitude of RES-E production, although the share of RES-E production in the total electricity supply increases. Greece reaches its target by a slight decrease in electricity demand. The needed total support for renewables within the EU-15 amounts to approximately 19.6 bn.€ (see column "Direct costs" in table 4). Re-financing these costs significantly effects consumer's electricity bills. In case of scenario $FEED\_D$ the ad-valorem tax ranges from 2.8 % in the BeNeLux region to 40.2 % in Spain and Portugal - or to put it differently: in the latter case 40.2 % of the total expenditures for electricity are used to re-finance RES-E promotion. But the magnitude of this share is not solely influenced by the total support for renewables in a region. The ad-valorem tax depends on the electricity price, the per-unit support paid to green electricity producers and the indicative RES-E target in a region. In other words: the higher the obliged relative share of green electricity in the total supply to a region is, the higher is, ceteris paribus, the ad-valorem tax in this region. This is clearly reflected by our results. Regions like Austria, the Nordic market or Spain and Portugal with relatively high indicative targets of 78.1 %, 46.6 % and 30.9 % face the highest taxation (27.5 % for Austria, 20.2 % for the Nordic market and 40.2 % for Portugal and Spain), whereas the share of renewables promotion in total expenditures is

Table 3: Changes in electricity prices and electricity demand

	Changes in electricity price			Change in demand	Changes in electricity price			Change in demand
	Industrial		Residential	Total	Industrial		Residential	Total
	Base-load	Peak-load			Base-load	Peak-load		
	[in % vs. BaU]							
	FEED_D				*FEED_H*			
EEA*	-0.1	-1.1	0.0	0.2	0.0	-1.0	0.1	0.1
Austria	15.8	22.1	18.7	-16.5	14.2	20.0	16.9	-15.1
Czech Republic	0.0	-0.2	-0.5	0.2	0.2	-0.3	-0.5	0.1
France	8.7	7.2	7.2	-7.6	6.7	4.9	4.9	-5.5
Greece	0.5	-0.8	0.7	-0.3	0.5	-0.8	0.7	-0.3
Italy	8.3	10.7	8.7	-8.9	8.2	10.7	8.7	-8.9
Poland	0.5	-3.2	-0.9	0.7	0.1	-4.1	-1.2	1.2
Nordic region**	17.3	13.5	14.1	-14.4	12.1	10.4	11.0	-11.0
Baltic Region***	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
UK and Ireland	2.8	3.4	3.3	-3.2	1.6	2.1	2.0	-2.0
Germany	5.8	5.5	5.6	-5.8	5.0	2.6	3.7	-4.2
BeNeLux****	-0.1	3.2	1.2	-1.1	-1.4	2.6	0.1	0.0
Spain and Portugal	12.8	28.9	19.5	-16.4	13.5	27.5	19.5	-16.5
Total				**-7,4**				**-6,2**
	QUOTA_R				*QUOTA_EU*			
EEA*	0.1	0.3	0.2	-0.2	0.0	0.3	-0.4	0.1
Austria	15.1	18.9	16.9	-15.1	16.2	22.4	19.1	-16.7
Czech Republic	0.2	-0.3	0.1	-0.1	0.2	-0.4	0.1	-0.1
France	9.0	7.4	6.6	-7.4	9.9	7.3	7.3	-8.0
Greece	-0.7	2.7	0.8	-0.6	9.1	8.4	6.7	-8.1
Italy	10.8	7.5	8.7	-9.2	9.9	7.4	8.0	-8.6
Poland	-0.4	0.4	-0.3	0.3	-0.5	0.5	-0.2	0.2
Nordic region**	15.4	10.8	11.5	-12.4	22.7	15.9	16.5	-17.2
Baltic Region***	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
UK and Ireland	2.2	1.8	2.0	-2.2	2.4	2.9	3.1	-2.9
Germany	7.3	0.8	3.7	-4.8	5.9	1.7	3.6	-4.4
BeNeLux****	-1.1	2.4	0.1	-0.1	-0.4	2.5	0.7	-0.6
Spain and Portugal	19.3	22.5	20.4	-18.2	7.4	10.6	8.7	-8.4
Total				**-7,0**				**-6,4**

*Rest of Eastern European accession countries (Slovakia, Slovenia, Hungary)
** Finland, Sweden and Denmark
***Estonia, Latvia, Lithuania
**** Belgium, The Netherlands and Luxemburg

Table 4: Green values, induced electricity taxes and direct compliance costs

	Green Value λ [EUR/ MWh]	Electricity tax ψ [in % of electricity price]	Direct costs $\lambda \cdot x_r$ [mill. EUR]	Efficiency costs vs. BaU [mill. EUR]
Feed-in tariff systems		*FEED_D*		
Austria	40,3	27,5	748,9	769,6
France	49,0	7,2	1812,6	2312,0
Greece				15,5
Italy	60,1	10,7	2597,9	3250,4
Nordic Market*	37,1	20,2	2629,6	2480,6
UK and Ireland	45,9	4,8	1267,7	698,1
Germany	85,6	9,4	3691,9	3005,2
BeNeLux**	45,1	2,8	403,6	330,4
Spain and Portugal	108,4	40,2	6385,8	4993,7
Total EU-15			19537,9	17855,5
		FEED_H		
Austria	37,2	25,3	702,9	717,1
France	32,9	4,9	1245,5	1581,8
Greece				15,0
Italy	59,7	10,7	2584,3	3237,0
Nordic Market*	28,9	15,7	2127,2	1804,2
UK and Ireland	33,7	3,5	942,7	259,9
Germany	66,5	7,3	2915,0	2269,3
BeNeLux**	32,8	2,1	296,9	186,9
Spain and Portugal	104,0	38,0	6122,0	5027,8
Total EU-15			16936,4	15099,0
Quota systems		*QUOTA_R*		
Austria	38,7	-	731,5	798,0
France	32,9	-	1220,6	2383,6
Greece		-		26,5
Italy	59,7	-	2574,6	3016,0
Nordic Market*	28,9	-	2093,7	1820,3
UK and Ireland	33,8	-	943,2	227,0
Germany	66,5	-	2896,9	1807,4
BeNeLux**	33,0	-	298,5	187,6
Spain and Portugal	99,3	-	5728,0	4421,5
Total EU-15			16487,1	14687,9
		QUOTA_EU		
Austria	44,5	-	824,7	855,6
France	44,5	-	1639,7	2577,3
Greece	44,5	-	154,1	253,2
Italy	44,5	-	1931,0	2638,7
Nordic Market*	44,5	-	3050,7	2702,3
UK and Ireland	44,5	-	1233,1	497,7
Germany	44,5	-	1949,5	1830,0
BeNeLux**	44,5	-	400,7	298,3
Spain and Portugal	44,5	-	2873,7	2163,1
Total EU-15			14057,0	13816,3

* Finland, Sweden and Denmark

** Belgium, The Netherlands and Luxemburg relatively low in regions like BeNeLux or UK and Ireland (targets 7.6 % and 10.2 %, taxes of 2.8 % and 4.8 % respectively). In consideration of the adjustment effects on the electricity markets the technology-specific feed-in tariff finally leads to excess (or efficiency) costs of approximately 17.9 bn.€ vis-à-vis BaU.

When we switch to uniform feed-in tariffs in scenario *FEED_H* green values decrease - in some regions significantly - compared to *FEED_D*. The feed-in tariff now provides a premium that is oriented at the marginal costs of the RES-E supply options in each region. Countries like France (-21.8 €/MWh) and Germany (-19.1 €/MWh) exceedingly profit from a harmonization of green premiums. Accordingly, the total (EU-wide) magnitude of support decreases by approximately 2.6 bn.€ to 16.9 bn.€ caused by a more efficient distribution of support across technologies. In terms of loss in economic surplus *FEED_H* saves roughly 2.8 bn.€ compared to *FFED_D*.

A regional quota obligation as simulated in scenario *QUOTA_R* leads to similar results as uniform regional feed-in tariff systems. Regional quota obligations further marginally lower the magnitude of support on the EU-15 level by approximately 500 mio.€. Differences to *FEED_H* arise from interactions with the electricity markets such as changes in inter-regional electricity trade. Especially Spain and Portugal would profit from the regional quota system. Their total support level would decrease by roughly 400 mio.€ to approximately 5.7 bn.€.

Trade in TGC's - facilitated under *QUOTA_EU* - further reduces EU-wide costs significantly. The overall support level can be decreased to 14.0 bn.€. The uniform green value amounts to 44.5 €/MWh. As mentioned before, the equalization of marginal costs across regions leads to the exploitation of the most profitable RES-E potentials which direcly affects EU-wide adjusment costs for meeting the overall RES-E target. Under *QUOTA_EU* losses in economic surplus amount to 13.8 bn.€ and are, thus, approximately 23% lower than under *FEED_D*. Re-addressing our theoretical considerations in section 4 our quantitative analysis confirms the potentially huge excess costs of differentiated support schemes versus harmonized systems.

6 Conclusions

The political support for electricity produced from renewable energy sources has a long history within the European Union. At present, Member States employ a relatively wide range of support schemes. The most common are feed-in tariff systems, i.e. direct subsidies to electricity production from renewable energy, and quota obligations with tradable green certificates. In this paper, we have investigated the economic consequences of these two alternative policy instruments.

Our theoretical considerations and numerical simulations based on a large-scale partial equilibrium model of the EU electricity market, suggest that differentiated feed-in tariff schemes may incur substantial excess cost compared to regionally and EU-wide harmonized systems. If the “greening” of electricity was the only political objective an EU-wide tradable green quota would reach the European RES-E target at 23% lower costs than independent national feed-in tariff systems with technology-specific premiums. The higher costs can be interpreted as the additional premium to serve other objectives than the pure greening of electricity.

As a consequence, policy makers must clearly lay out the multiple objectives and the respective weights that can justify discriminatory pricing across renewable energies. In order to evaluate the efficiency of renewable promotion strategies, policy has to be more concrete on the weights attached to the different policy objectives otherwise, it is not possible to appraise and trade off renewable promotion policies with a combination of direct single-targeted instruments. A major concern in this context must be the potentially large inefficiencies due to co-existing overlapping policy strategies. One example on the field of climate policy is the parallel regulation of electricity industries within the EU via an EU emission quota system and multiple renewable policy initiatives at the Member State level. Given a certain ceiling of emissions (e.g. implied by the EU burden sharing agreement) a comprehensive market-based system of tradable emission quotas will endogenously determine the cost-efficient level of green energy within the EU and each Member State. Under pure emissions regulation there is no need for complementary green energy policies which at best have no effect but often may involve excess costs due to a deviation from cost-efficient allocation patterns.

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Appendix

Algebraic Model Description

Sets:	
R	Set of all regions (with index $r \in R$ where $rs \in R$ is an electricity exporting and $rd \in R$ an importing region)
F	Set of all firms (with index $f \in F$)
I	Set of all generation technologies (with index $i \in I$ where $ir \in I$ is a renewables technology)
P	Set of all power plants of technology type i in region r controlled by firm r (with index $p \in P$)
Parameters:	
$p0^{Ind}_{r,l}$	Initial electricity price in region r on the industrial market for electricity demand in load segmet l,
$p0^{Res}_{r}$	Initial electricity price in region r on the residential market
$D0^{Ind}_{r,l}$	Initial electricity demand of industrial customers in region r and load segment l
$D0^{Res}_{r}$	Initial electricity demand of residential customers in region r
$\sigma^{Ind}_{r,l}$	Elasticity of industrial demand in region r and load segment l
σ^{Res}_{r}	Elasticity of residential demand in region r
$c_{i,r,l}$	Variable production costs of plant of technology type i in region r and load area l
$\sigma^{Ind}_{r,l}$	Price elasticitiy of industrial demand in region r and load segment l
σ^{Res}_{r}	Price elasticitiy of residential demand in region r
K_p:	Generation capacity limit of plant p
$\bar{T}_{rs,rd}$:	Capacity limit of all inter-regional exchange points between region rs and region rd
$rm_{r,l}$:	Regional reserve requirements in region r and load segment l
gc_r:	Regional charges for distribution of electricity in region r
$tf_{rs,rd}$	Charges for inter-regional electricity transmission from region rs to region rd
$dl_{rs,rd}$:	Fraction of distribution losses of electricity exchange from region rs to region rd
cc_i:	Specific carbon coefficient for electricity generation from technology i
$\bar{C}L_r$:	Upper bound on carbon emissions in region r
rq_r:	Minimum shares of renewable electricity in the total supply to region r
Price variables:	
$p^{Ind}_{r,l}$	Price for electricity in region r on the industrial market in load segmet l,

p_r^{Res}	Price for electricity on the residential market in load segmet l,
$w_{f,r,l}$:	Marginal value of electricity supply by firm f in region r and load area l,
$\zeta_{r,l}$:	Shadow value on reserve capacity constraint in region r and load area l,
μ_p:	Shadow price on capacity constraint of plant p in load area l,
λ_r:	Shadow value on the renewables quota in region r,
ρ:	Price of tradable green certificates
$\tau_{rs,rd,l}$	Shadow price on transmission capacity between adjacent regions rs and rd,
$\omega_{ir,r}$:	Subsidy paid ro RES-E technology ir in region m,
ψ_r:	Electricity tax in region r
Activity levels:	
$S_{f,r,l}^{Ind}$:	Supply of firm f in load segment l to industrial customers in region r
$S_{f,r}^{Res}$:	Supply of firm f in load segment l to residential customers in region r
$D_{r,l}^{Ind}$:	Electricity demand of industrial customers in region r and load segment l
D_r^{Res}:	Electricity demand of residential customers in region r
$X_{p,l}$:	Electricity production of plant p in load segment l
$Z_{p,l}$:	Set-aside capactiy provision of plant $p$in load segment l
$E_{f,rs,rd,l}$:	Electricity trade by firm f from region rs to region rd
G_r^{EX}:	Green certificates exports of region r to the international market
G_r^{IM}:	Green certificates imports of region r from the international market

Zero-profit conditions:

Zero-profit condition for industrial supply ($\perp s_{f,r,l}^{Ind}$):

$$w_{f,r,l} + gc_r + rm_{r,l} \cdot \pi_{r,l} \geq p_{r,l}^{Ind} \cdot \left(1 - \frac{\theta_{f,r,l}^{Ind}}{\sigma_{r,l}^{Ind}}\right)$$

Zero-profit condition for residential supply ($\perp s_{f,r}^{Res}$):

$$\sum_l \theta_l^L \cdot (w_{f,r,l} + gc_r + rm_{r,l} \cdot \pi_{r,l}) \geq p_r \cdot \left(1 - \frac{\sum_l \theta_l^L \cdot \theta_{f,r}^{Res}}{\sigma_r^{Res}}\right)$$

Zero-profit condition for electricity production ($\perp x_{p,l}$):

$$c_{i,r,l} + \mu_{p,l} + cc_i\gamma_r + \lambda_r \cdot rq_r - \omega_{ir,r} \geq w_{f,r,l} + \lambda_r$$

Zero-profit condition for reserve capacity provision ($\perp Z_{p,l}$):

$$\mu_p \geq \zeta_{r,l}$$

Zero-profit condition for green certificates imports ($\perp G_r^{IM}$):

$$\rho \geq \lambda_r$$

Zero-profit condition for green certificates exports ($\perp G_r^{EX}$):

$$\lambda_r \geq \rho$$

Zero-profit condition for inter-regional electricity trade ($\perp E_{rs,rd,l}$):

$$w_{f,rs,l} + tf_{rs,rd,l} + \sum_{rs,rd} \left(\tau_{rs,rd,l} - \tau_{rd,rs,l}\right) \geq w_{f,rd,l} \left(1 - tl_{r,rr}\right)$$

Market-clearance conditions:
Market-clearance condition for industrial supply ($\perp p_{r,l}^{Ind}$):

$$\sum_f s_{f,r,l}^{Ind} = D0_{r,l}^{Ind} \cdot \left(\frac{p_{r,l}^{Ind}}{p0_{r,l}^{Ind}}\right)^{\sigma_{r,l}^{Ind}}$$

Market-clearance condition for residential supply ($\perp p_r^{Res}$):

$$\sum_f s_{f,r}^{Res} = D0_r^{Res} \cdot \left(\frac{p_r^{Res}}{p0_r^{Res}}\right)^{\sigma_{r,l}^{Ind}}$$

Market-clearance condition for electricity trade ($\tau_{rs,rd,l}$):

$$\bar{T}_{rs,rd} \geq \sum_{f,rs} E_{f,rs,rd,l} - \sum_{f,rd} E_{f,rs,rd,l}$$

Market-clearance condition for reserve capacity ($\perp \zeta_{r,l}$):

$$\sum_{f,i} Z_{f,r,i,l} \geq rm_{r,l} \cdot \sum_f \left(s_{f,r,l}^{Ind} + \theta_l^L \cdot s_{f,r}^{Res}\right)$$

Market-clearance condition for electricity production ($\perp w_{f,r,l}$):

$$\sum_p x_{p,l} + \sum_{rs,rd,i,l} \left[(1 - dl_{rs,r}) \cdot E_{f,rs,r,l} - E_{f,r,rd,l}\right] \geq s_{f,r,l}^{Ind} + \theta_l^L \cdot s_{f,r}^{Res}$$

Market-clearance condition for electricity production capacity ($\perp \mu_p$):

$$K_p \geq \sum_{l} (X_{p,l} + Z_{p,l})$$

Market-clearance condition for emission constraint ($\perp\gamma_r$):

$$\bar{C}L_r \geq \sum_{p,l} cc_i \cdot X_{p,l}$$

Market-clearance condition for renewable quota ($\perp\lambda_r$):

$$\sum_{f,ir,l} X_{f,r,ir,,l} \geq rq_r \cdot \sum_{f,l} \left(s^{Ind}_{f,r,l} + \theta^L_l \cdot s^{Res}_{f,r}\right)$$

Market-clearance condition for ad-valorem electricity tax ($\perp\psi_r$):

$$\sum_{l} \left(p^{Ind}_{r,l} \cdot \psi_r \cdot \sum_{f} s^{Ind}_{f,r,l}\right) + p^{Res}_r \cdot \psi_r \cdot \sum_{f} s^{Res}_{f,r} \geq \sum_{f,ir,l} X_{f,r,ir,,l} \cdot \lambda_r$$

Technology Mix

Table 6: Technology mix for electricity production under *FEED_D*, *FEED_H*, *QUOTA_R* and *QUOTA_EU*

	Technology	BaU	FEED_D	FEED_H	QUOTA_R	QUOTA_EU
		[in % of total generation]				
EEA	Nuclear	41,37	41,71	41,68	40,75	40,92
	Soft Coal and Lignite	13,90	14,00	14,01	13,56	13,51
	Hard coal	17,60	17,72	17,73	17,17	17,10
	Natural gas	18,75	18,13	18,15	19,49	19,83
	Fuel Oil				0,85	0,49
	Hydro	8,38	8,44	8,44	8,17	8,14
AUT	Soft Coal and Lignite	7,73	8,19	8,39	5,04	3,80
	Hard coal	22,65	17,45	17,30	17,78	17,23
	Natural gas	21,42	18,13	17,79	13,71	11,64
	Fuel Oil	5,63				
	Hydro	35,94	40,26	40,19	45,57	47,84
	Biomass	0,59	3,99	4,35	4,32	5,36
	Wind	3,94	8,64	8,87	10,08	10,51
	Other RES	2,11	3,34	3,12	3,50	3,61
CZE	Nuclear	26,24	25,84	25,76	27,52	27,74
	Soft Coal and Lignite	46,65	46,90	46,96	45,85	45,71
	Hard coal	2,75	2,76	2,77	2,70	2,69
	Natural gas	10,00	10,06	10,07	9,83	9,80
FRA	Hydro	14,36	14,43	14,45	14,11	14,07
	Nuclear	62,23	60,09	61,77	61,95	58,32
	Natural gas	1,10	1,25	1,23	1,14	1,20
	Fuel Oil	20,94	18,82	17,03	18,73	7,00
	Hydro	15,74	17,91	19,78	18,00	29,85
	Wind					3,42
	Solar		0,37			
	Other RES		1,56	0,20	0,18	0,19
GRE	Soft Coal and Lignite	60,70	60,50	60,50	61,15	10,05
	Natural gas	15,47	15,61	15,61	14,89	
	Hydro	23,83	23,89	23,89	23,96	70,13
	Biomass					0,55
	Wind					17,36
	Other RES					1,91

	Technology	BaU	FEED_D	FEED_H	QUOTA_R	QUOTA_EU
		[in % of total generation]				
Ita	Soft Coal and Lignite	1,16	1,22	1,21	1,40	1,29
	Hard coal	61,72	31,85	32,12	26,98	42,96
	Natural gas	36,10	35,62	35,59	35,84	35,70
	Hydro	1,01	8,59	9,17	10,60	9,05
	Biomass		8,52	8,04	9,16	4,74
	Wind		0,52	0,52	0,60	0,55
	Solar		0,23			
	Other RES		13,45	13,34	15,42	5,71
POL	Soft Coal and Lignite	64,78	65,56	66,58	64,89	64,89
	Natural gas	27,48	27,84	28,14	27,39	27,39
	Fuel oil	5,64	4,47	3,11	5,62	5,62
	Hydro	2,11	2,14	2,16	2,10	2,10
Nordic	Nuclear	42,77	39,04	40,55	38,17	32,61
	Hard coal	24,22	16,39	14,81	16,60	10,22
	Natural gas	1,44				
	Hydro	27,31	35,26	34,00	35,01	37,58
	Biomass		0,22			2,23
	Wind		1,88	5,23	4,66	9,55
	Other RES	4,26	7,21	5,41	5,57	7,81
Baltic	Nuclear	27,61	27,61	27,61	27,61	27,61
	Natural gas	32,01	32,01	32,01	32,01	32,01
	Hydro	40,38	40,38	40,38	40,38	40,38
GBR	Nuclear	25,12	26,31	26,55	26,24	26,10
	Hard coal	36,84	30,52	30,34	30,33	28,27
	Natural gas	37,06	33,03	32,97	33,30	31,37
	Hydro	0,22	0,23	0,23	0,23	0,23
	Biomass		2,37	0,44	0,44	2,18
	Wind		2,40	5,07	5,08	6,73
	Other RES	0,76	5,13	4,40	4,39	5,11
DEU	Nuclear	41,11	39,49	40,05	40,13	42,21
	Soft Coal and Lignite	7,34	3,39	4,87	4,78	5,85
	Hard coal	17,52	14,96	14,67	14,74	15,27
	Natural gas	23,40	19,09	17,56	17,48	20,23
	Fuel oil	9,75	10,29	10,09	10,14	10,01
	Hydro	0,59	1,90	4,42	4,36	0,61
	Biomass		5,73	3,83	3,84	1,61
	Wind		1,38	1,35	1,36	1,23
	Solar		0,47			
	Other RES	0,29	3,31	3,15	3,17	2,98
BLX	Nuclear	26,40	24,33	24,07	24,09	23,61
	Hard coal	37,09	33,91	34,32	34,19	31,58

	Technology	BaU	FEED_D	FEED_H	QUOTA_R	QUOTA_EU
		[in % of total generation]				
	Natural gas	35,09	34,39	34,23	34,34	34,39
	Hydro			0,07	0,07	0,23
	Biomass		2,07	1,30	1,30	2,10
	Wind		3,12	4,26	4,25	5,91
	Other RES	1,42	2,19	1,76	1,76	2,18
SPAP	Nuclear	22,34	26,70	26,73	27,26	24,39
	Soft Coal and Lignite	0,23	0,27	0,27	0,28	0,25
	Hard coal	40,67	19,41	19,02	17,70	31,85
	Natural gas	32,26	22,93	23,29	24,07	30,17
	Hydro	3,04	10,09	14,48	14,77	6,58
	Biomass	0,01	9,24	7,83	7,40	1,88
	Wind	0,03	2,99	3,89	3,97	1,52
	Solar		3,87			
	Other RES	1,42	4,49	4,50	4,55	3,37

Regional RES-E production

Figure 5: RES-E deployment in scenarios *FEED_ D* and *FEED_ R*

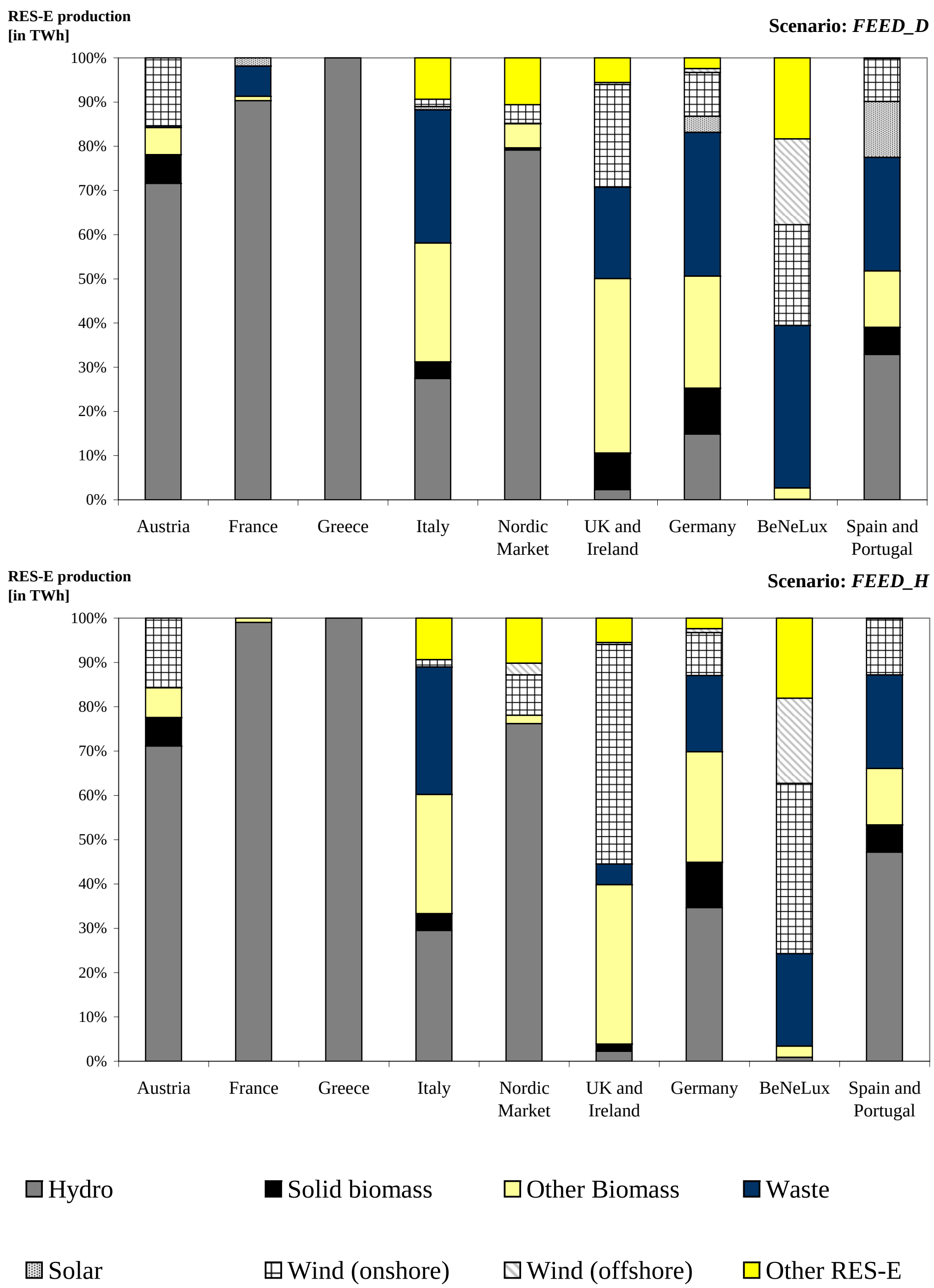

Figure 6: RES-E deployment in scenarios $QUOTA\_R$ and $QUOTA\_EU$