Comparing Different Cost Allocation Policies for Large-scale RES-E Grid Integration in Europe

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Abstract

The EC Directive on liberalisation of electricity markets (EC (2004)) requires the electricity supply industry to be competitive, yet realises that many aspects of electricity supply are natural monopolies. Consequently, separation of the competitive segments of electricity generation and customer supply from the grid infrastructure is seen as a precondition for non-discriminatory grid access for third parties (e.g. RES-E generators) as well as for transparent procedures for cost allocation, grid regulation and grid tariff determination. But legislation and definition of RES-E policy goals on national as well as EU level still face a variety of lacks, e.g. (i) mixing up interfaces when demarcating the RES-E power plants from the grid infrastructure (grid connection, grid reinforcement) and system operation,

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(ii) neglecting disaggregated cost allocation of RES-E grid integration and, subsequently, (iii) mixing up different disaggregated cost elements (RES-E promotion instruments versus wholesale/balancing markets versus grid tariffs). The ongoing EC-Project **Green*Net*-EU27** models dynamic time paths for RES-E deployment in Europe up to the year 2020 for different degrees of unbundling, cost allocation schemes and RES-E policy instruments. In this paper a comparison of RES-E deployment (wind in particular) for different schemes of disaggregated cost allocation (and socialisation of corresponding cost) is conducted for selected countries (mainly Germany and UK) based on the software tool **Green*Net***. Moreover, sensitivity analyses are carried out to demonstrate the effects for different RES-E policy instruments. The modelling results show that the future pattern of large-scale RES-E deployment (wind in particular) significantly varies depending on the definition of the interface between the RES-E power plant, the grid infrastructure and overall system operation as well as on socialisation of corresponding disaggregated cost. Finally, recommendations are derived for large-scale least-cost RES-E integration against the background of correct unbundling.

JEL-Classification: Q20, D42, L43, L94

Keywords: Unbundling, Modelling, RES-Electricity, Electricity Grid Infrastructure, Cost Allocation

1. Introduction

The EC Directive on liberalisation of electricity markets (EC (2004)) requires the electricity supply industry to be competitive, yet realises that many aspects of electricity supply are natural monopolies. Consequently, separation of the competitive segments of electricity generation and customer supply from the grid infrastructure is seen as a precondition for non-discriminatory grid access for third parties (e.g. RES-E generators) as well as for transparent procedure for cost allocation, grid regulation and grid tariff determination.

But legislation and definition of RES-E policy goals on national as well as EU level still face a variety of lacks, e.g.

- mixing up interfaces when demarcating the RES-E power plants from the grid infrastructure (new grid connection lines, reinforcement of the existing grid) and system operation,
- neglecting disaggregated cost allocation of RES-E grid integration and, subsequently
- mixing up different instruments for socialising different disaggregated cost elements (RES-E promotion instruments versus wholesale/balancing markets versus grid tariffs).

The ongoing EC-Project **Green*Net*-EU27** (www.greennet-europe.org) models dynamic time paths for RES-E deployment in Europe up to the year 2020 for different degrees of unbundling, cost allocation schemes and RES-E policy instruments (both on country level as well as for the EU as a whole).

In this paper a comparison of RES-E deployment (wind in particular) for different disaggregated cost allocation schemes, socialisation of corresponding cost as well as for different RES-E promotion instruments is conducted for selected countries (mainly focusing on Germany and UK) based on the software tool **Green*Net***. Moreover, sensitivity analyses are carried out to demonstrate the effects of different RES-E policy instruments. The modelling results shall demonstrate that the future pattern of large-scale RES-E deployment (wind in particular) significantly varies depending on the definition of the interface between the RES-E power plant and the grid infrastructure as well as on socialisation of corresponding disaggregated cost and the RES-E promotion instrument itself.

The paper is organised as follows. Section 2 addresses the basic principles of unbundling in restructured electricity markets and the core role of the grid infrastructure in this context. In section 3 the simulation software **Green*Net*** is described briefly. In section 4 two country specific applications of **Green*Net*** for fundamental different RES-E policy tools (feed-in tariffs versus tradable green certificates) are conducted. Section 5 discusses the results and, finally, in section 6 conclusions for least cost RES-E integration are derived against the background of correct unbundling.

2. Unbundling and the role of the grid infrastructure

When talking about the EC-Directive 96/92/EC on liberalisation of electricity markets (and their implementation) unbundling is one of the cornerstones. More precisely, the separation of the transmission and distribution grid – due to their natural monopoly character – from the competitive segments of electricity generation and customer supply is seen as a precondition for non-discriminatory grid access of third parties (e.g. RES-E generators) as well as for transparent grid regulation procedures and grid tariff determination.

In the context of large-scale RES-E grid integration (e.g. wind) infrastructure related measures and cost (new grid connection lines, grid reinforcement) are frequently allocated directly to the RES-E generation plant. This is to some extent ambiguous having in mind the natural monopoly character of capital-intensive grid infrastructures (like e.g. offshore grid connections). Moreover, responsibilities for construction, operation and ownership of new grid connection lines for (offshore-) wind farms are still subject to very controversial discussions in different European countries:

- E.g. in the current German Renewable Energy Sources Act (EEG) it is still foreseen to allocate grid connection cost of (offshore-) wind farms to the wind farm and, subsequently, to socialise corresponding grid connection cost via feed-in tariffs. This practice (mixing up cost of kWh's generated and grid infrastructure assets) ignores the basic principles of the economics of natural monopolies and, therefore, is at least questionable (see Figure 1a).[2]
- On contrary, in countries like Denmark grid connection cost of (offshore-) wind farms are already allocated to the grid infrastructure and, subsequently, socialised via the grid tariffs (going in line with the basic unbundling principles). Moreover, the transmission system operator has the responsibility for construction, operation and ownership of the connection lines (see Figure 1b).

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[2] In general, grid infrastructure assets (natural monopolies) are depreciated differently compared to assets being subject to competition or feeding into competitive markets (like RES-E electricity generation).

From the economic point-of-view a necessary and sufficient condition for a natural monopoly – like electricity grids are – is the *subadditivity of cost.* In the particular case of offshore grid connection the following situation occurs: If $C_{Transmission,i}$ are the offshore transmission grid connection costs of an individual wind farm *i* in case of separate grid connection and $C_{Transmission,common}$ the common offshore transmission grid connection costs of all wind farms (c_i is the individual short distribution grid component) the following cost relation exists:

$$C_{Transmission,common} + \sum_{i=1}^{n} c_i < \sum_{i=1}^{n} C_{Transmission,i}$$

i.e., the sum of the transmission grid connection costs of the individual offshore wind farms (Figure 1a) is higher than the common transmission grid connection costs (plus individual short distribution grid components) of a collective of several wind farms (Figure 1b).

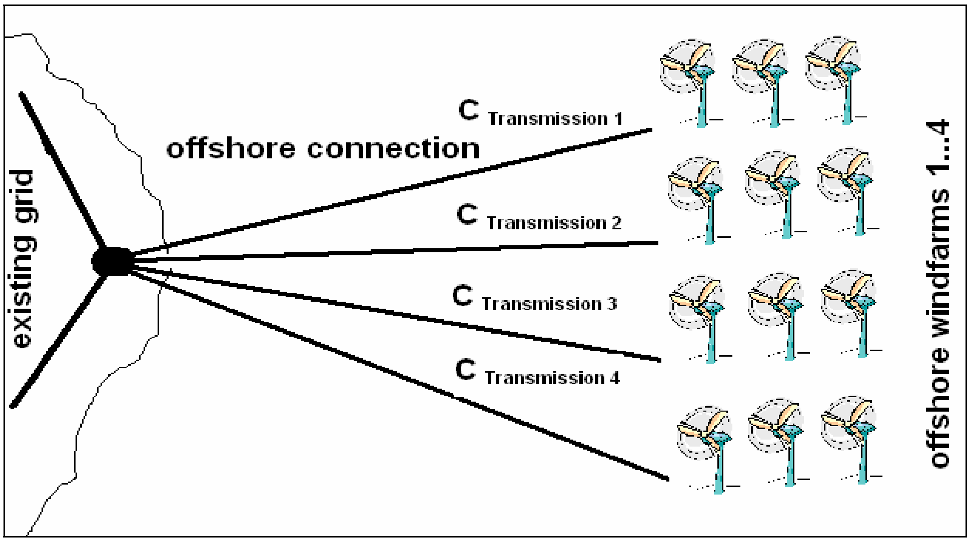

Fig. 1a. Separate offshore grid connection of each wind farm

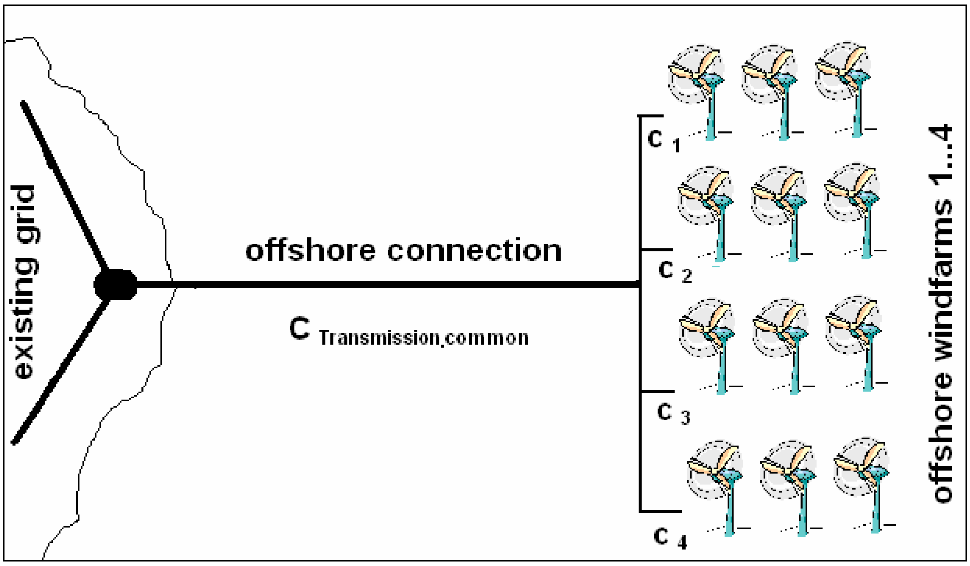

Fig. 1b. Common offshore grid connection of several wind farms

The separate treatment of new grid connection lines is not only relevant for wind, but also for other RES-E generation technologies being mainly determined by local availability of resources such as e.g. wind and small-hydro-power. In the case of allocation of grid connection costs to the long-run marginal costs of the RES-E power plant the investment decision is accompanied by a significant economic burden.[3] In this case, therefore, in practise often a compromise between best sites and proper grid conditions appears. If grid connection costs are socialised already by the grid tariff this burden has not to be handled by the RES-E generator.

Besides new grid connection lines (regardless of the distance and/or voltage level of connection) grid reinforcement measures may be necessary elsewhere in the existing network due to large-scale RES-E (wind) integration and, subsequently, changed load flows. The corresponding costs are also frequently allocated to a single RES-E generation technology (although changes in load flows have a variety of reasons, as there are e.g. changes in generation and load centres, power trading activities, etc.). Again, the allocation of grid reinforcement costs – regardless whether or not (or which share of) costs caused

[3] On contrary, grid connection of biomass – in general – is no crucial barrier as the location of the plant is even more independent from resource conditions.

by RES-E (wind) integration – to the corresponding grid infrastructure and socialisation by the grid tariffs has to be discussed in detail.

Moreover, considering the currently ongoing benchmarking and grid tariff regulation procedures in many European countries[4] guaranteeing the correct cost allocation of grid infrastructure costs is vital. Not least due to these ongoing grid regulation procedures, it is essential to start a fundamental discussion on the allocation of both RES-E related grid connection costs and grid reinforcement costs. In the past, for small scale RES-E integration, the share of grid related costs has been small compared to the long-run marginal costs of RES-E generation. Therefore, grid related costs have not been clarified, but often treated as part of the long-run marginal costs of the RES-E power plant and, subsequently, were socialised via the corresponding RES-E promotion instrument.

[4] I.e., the determination of eligible costs for building grids and grid operation and, subsequently, socialisation of corresponding costs via grid tariffs.

3. Description of the least-cost simulation software Green*Net*

The evaluation of strategies for an enhanced least-cost grid integration of RES-E generation technologies (with and without consideration of additional costs for grid connection, grid reinforcement and/or system operation) for different unbundled cases is conducted based on the simulation software **Green*Net***. Section 3.1 below briefly describes this software tool.

3.1 The GreenNet computer model

The **Green*Net*** model enables a comparative and quantitative analysis of least-cost RES-E grid integration strategies in the liberalised European electricity market (i.e. several 'old' EU15 countries and the new Member States Czech Republic, Hungary, Poland and Slovakia). The analysis can be conducted on aggregated (EU Member States') level as well as for individual Member States on an annual basis for the period 2005 to 2020 (2004 is the initial year). The major purpose of this software tool is to investigate the cost of RES-E deployment under different constraints and strategies on allocating the corresponding grid related and system related costs, see Figure 2.

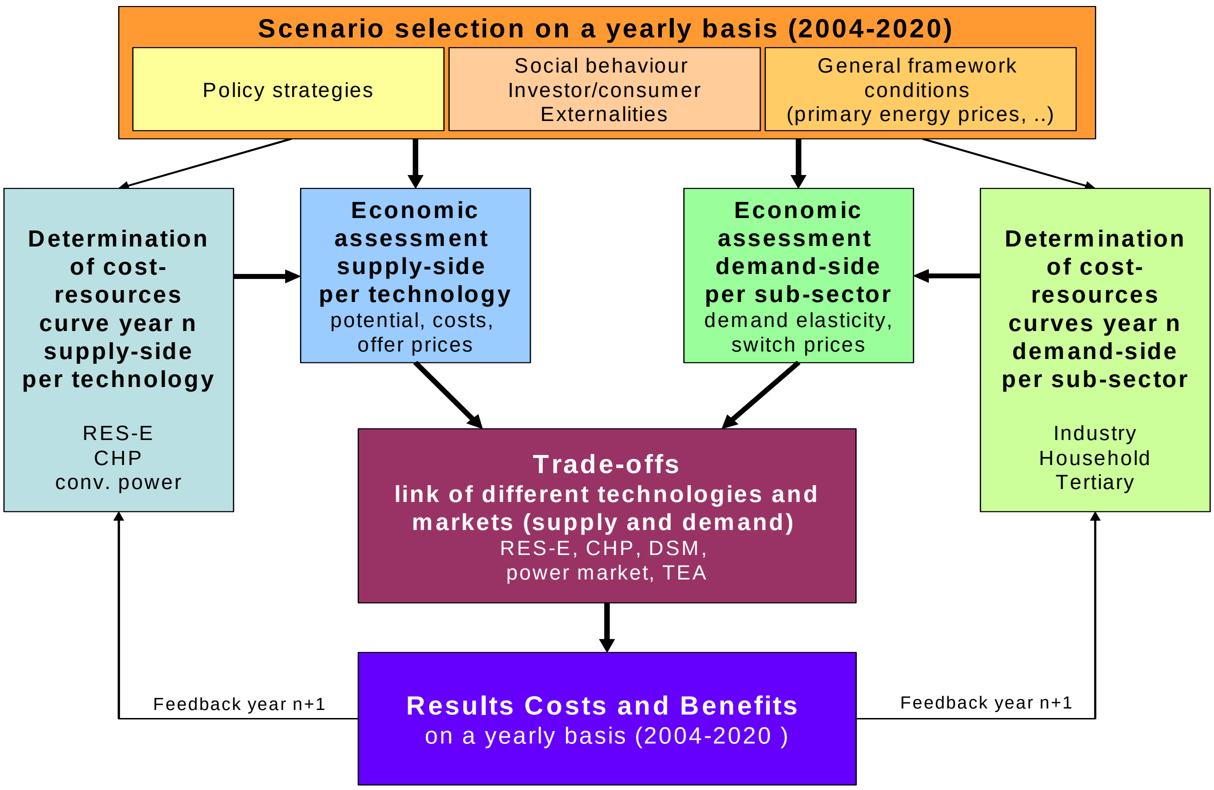

Fig. 2. Overview of the least-cost modelling approach in **Green*Net***

The general modelling approach in **Green*Net*** is to describe both electricity generation technologies (supply curve) and energy efficiency options (demand curve) by deriving corresponding dynamic cost-resource curves. The costs as well as the potentials of these dynamic cost-resource curves can change year by year. These changes are given endogenously in the model depending on the outcome of the previous year (n-1) and the policy framework conditions set for the simulation year (n).

Based on the derivation of the dynamic cost-resource curves an economic assessment takes place considering scenario specific settings like RES-E policy selection, socio-economic parameters (consumer and investor behaviour) as well as wholesale electricity price and demand forecasts. Wholesale electricity price projections on the conventional power market are implemented exogenously in **Green*Net***. Different wholesale price scenarios (e.g. for different fuel prices, CO_2-certificate prices, etc.) are calculated based on the optimisation tool $E2M2^s$. A comprehensive model description of $E2M2^s$ can be found in Swider et al (2005)[5].

Additionally costs for system operation (with versus without storage options) and grid reinforcement are modelled and – in case of selection – allocated to the marginal generation costs of the corresponding RES-E technology. The overall economic assessment includes a transition from generation and saving costs to bids, offers and switch prices.

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[5] The format of result presentation in $E2M2^s$ is compatible with the **Green*Net*** model. An iterative approach is used for modelling the interactions between the conventional power market ($E2M2^s$) and RES-E generation (**Green*Net***). In a first step, RES-E deployment up to 2020 is modelled based on **Green*Net*** assuming a wholesale electricity price forecast derived from a $E2M2^s$ model run (using estimates on RES-E deployment from literature). In a second step, RES-E projections and the residual request for conventional power generation determined in **Green*Net*** are used as input parameters for a new $E2M2^s$ model run. In a third step, an updated wholesale electricity price forecast again is used as an input for a new **Green*Net*** model run. This procedure is repeated iteratively until predefined deviations are acceptable (details see e.g. in Huber et al (2004c)).

Promotion instruments for RES-E technologies include the most important price-driven strategies (feed-in tariffs, tax incentives, investment subsidies, subsidies on fuel input) and demand-driven strategies (quota obligations based on tradable green certificates (including international trade), tendering schemes). In addition, electricity taxes and other direct promotion instruments supporting energy efficiency measures on the demand side can be chosen and investigated. As **Green*Net*** is a dynamic simulation tool, the user can change RES-E policies and parameter settings within a simulation run on a yearly basis. Furthermore, several instruments can be set for each country individually.

The results are derived on a yearly basis by determining the equilibrium level of supply and demand within each market segment considered. For a detailed description of the formal analytical framework of the modelling approach in **Green*Net*** it is referred to Huber et al (2004c). Moreover, a detailed description of the derivation of dynamic cost-resource curves as well as the comprehensive **Green*Net*** data base is conducted in Resch et al (2003).

3.2 Scenarios selection in GreenNet

Several simulation runs in **Green*Net*** are based on the assumption that currently implemented RES-E policy instruments remain without any adaptation up to 2020 (Business as Usual (BAU) RES-E policy). Sensitivity analyses consider the spread of options to allocate grid related and system related costs. This means that either the RES-E developer or society as a whole pay the additional costs of RES-E grid integration. Wind power, onshore and offshore, is considered especially because of its dominant position for new RES-E technologies, now and in the future. Wind power also relates to (i) high costs for connection to the nearest point of the existing grid compared to other RES-E and conventional technologies as sites are determined by local wind conditions, (ii) additional requirements for grid reinforcements of distribution as well as transmission grids as wind sites are mostly located in regions with low demand and weak existing grids and (iii) the requirement of additional system capacity for periods of weak wind as well as additional balancing requirements.

The scenario whereby 'society as a whole' pays additional costs requires further explanation for the liberalised electricity market, since the concepts derive from previously vertically integrated power systems. Previous to liberalisation, society can be said to have owned the grid infrastructure, since it was initially funded by governments through taxation. In the liberalised electricity market now it is unclear, however, where to allocate the costs of new equipment for grid connection and/or grid reinforcement. Either these costs have to be paid for by the owner of the new RES-E power plant, which may be a company with investors, or by the grid company, which is always a licensed monopoly. In the former case, expenditures initially come from investors and then have to be recovered from future generation income. In the latter case, expenditures come from internal reserves of the established grid company and are later recovered from the 'use of system' per unit tariff levied on the eventual electricity suppliers, who pass on the expenses to their consumers, i.e. to 'society'.

As additional grid and system related costs vary on country level (depending on the utilisation of existing grids, the spatial distribution of wind sites, the particular generation mix, etc.) a low, average and high cost scenario is implemented.

In particular, in the next section the following scenarios are investigated using the **Green*Net*** model:

Partial unbundling: grid connection costs allocated to the RES-E generator; grid reinforcement costs and system operation costs allocated to the end-user (i.e. shallow connection charging): Due to the fact that in many European countries (e.g. Germany, UK) this approach is implemented in practise this is also the default case in the existing version of the **Green*Net*** model (although this is supposed to be imperfect unbundling).

Full unbundling: grid connection costs, grid reinforcement costs and system operation costs allocated to the end-user (best case from the RES-E generators point of view): The end-user covers several grid-related and system-related cost elements. RES-E generators can neglect several cost elements in their investment decisions. This approach is already implemented e.g. in Denmark for offshore wind.

No unbundling: grid connection costs, grid reinforcement costs and system operation costs allocated to the RES-E generator (i.e. deep connection charging, worst case from the RES-E generators point of view): Several grid and system related cost elements are allocated to RES-E generators.

The bandwidth of possible scenario settings in the model **Green*Net*** is summarised in Figure 3.

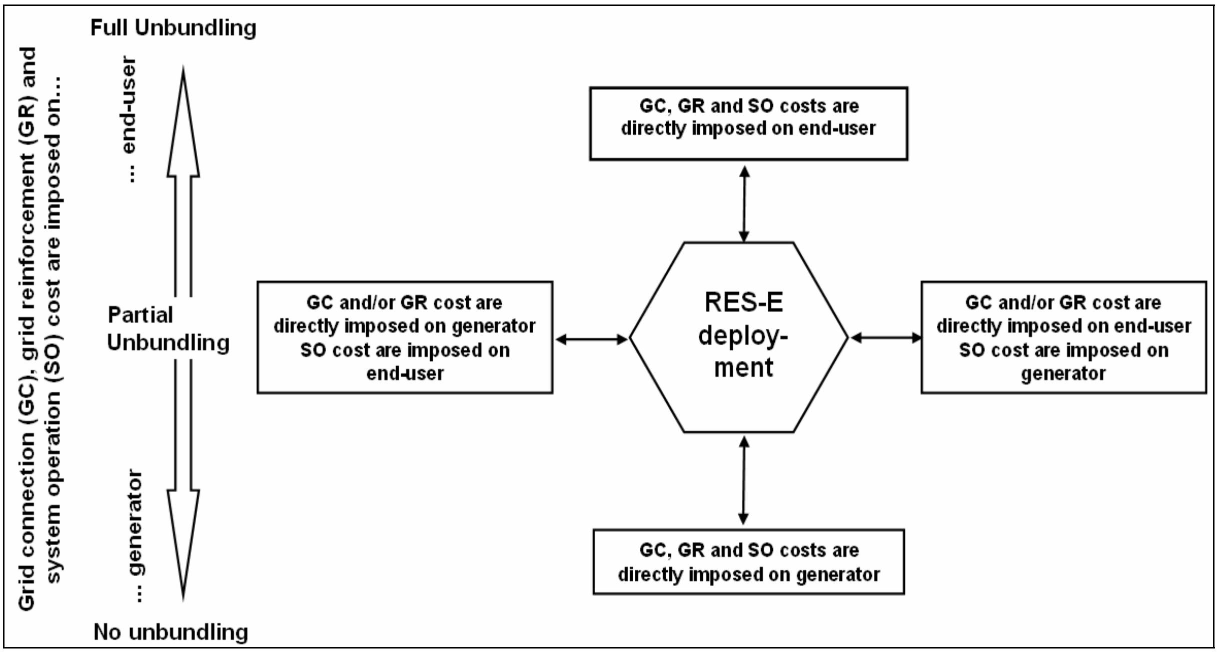

Fig. 3. Overview of the bandwidth of possible scenario settings in the model **Green*Net***

4. Case Studies: Germany and UK

In this section the impact of different cost allocation schemes on the future RES-E deployment is analysed for Germany and UK. In these countries two fundamental different RES-E promotion schemes are implemented at present. While in Germany RES-E technologies are supported by feed-in tariffs (i.e a price-driven instrument) in UK a tradable green certificate system is implemented (i.e. a demand-driven instrument). The particular design of those two RES-E promotion instruments is briefly summarized in the following paragraphs.

4.1 Design of RES-E promotion scheme

4.1.1 Germany

In Germany grid integration of RES-E generation technologies is supported by feed-in tariffs *(FITs)* being defined in the *Renewable Energy Sources Act (REA)*.[6] For onshore as well as offshore wind a stepped *FIT* is foreseen, i.e. the absolute level of the tariff depends on the quality of the site. Furthermore, the *FITs* are reduced by 2% annually. Hence, for RES-E generators the tariff is fixed at a defined level according to the year of contract signature. For offshore sites the *FIT* depends, furthermore, on the distance to shore and the water depth of a particular site. Table 1 summarizes the fixed feed-in tariffs in Germany according to the actual version of the *REA* for both onshore and offshore wind.

Tab. 1. *FITs* for onshore wind and offshore wind in Germany, according to the actual version of *Renewable Energy Act (REA)*

	Guaranteed duration	**Remarks**
Onshore	20 years	*Stepped FIT:* 87 €/MWh for the first 5 years and then between 55 and 87 €/MWh

[6] *Renewable Energy Sources Act (REA)* from 21st of July 2004, published in the Federal Law Gazette 2004 I No.40 on 31st of July 2004, Bonn.

		depending on the quality of site. *FITs* are reduced by 2% annually, no adjustment for inflation.
Offshore	20 years	<u>*Stepped FIT:*</u> 91 €/MWh for the first 12 years and then between 61.9 and 91 €/MWh depending on the distance to the shoreline and water depth. *FITs* are reduced by 2% annually from 2008 on, no adjustment for inflation.

<u>4.1.2 United Kingdom</u>

Electricity suppliers have to meet the commitments of the *Renewables Obligation (RO)*[7] by tradable green certificates, the so called *Renewables Obligation Certificates (ROCs)*. Thereby, each *ROC* represents 1 MWh of renewable electricity from eligible RES-E generators. For the periode 2005/2006 suppliers have to meet an obligation of 5.5% of each supplier's total delivered electricity. The quota obligation runs on a yearly basis and the obliged target will increase to 10.4% in 2010/2011. To meet the *RO* commitments electricity suppliers have three possibilities:

(i) to pay for the *ROCs* in association with physical supply of renewable electricity (purchased from eligible RES-E generators);

(ii) to buy *ROCs* from other suppliers or from the Non Fossil Purchasing Agency (NFPA) putting periodically *ROCs* on auction (acquired under existing Non Fossil Fuel Obligation (NFFO) contracts);

(iii) to pay the penalty or *Buy-Out Price* set by the regulator *(OFGEM)* for non-compliance of the quota.

The *Buy-Out Price* was set at £30 per MWh for the first obligation period (April 2002 to March 2003) and is adapted on a yearly basis. All penalty payments – representing the shortfall between the obliged and actual presented *ROCs* – are collected in a central fund. This fund is redistributed to electricity suppliers having met the obligation in relation to the number of *ROCs* each supplier has presented. If a tradable green certificate market works effectively, the price of a certificate reflects the difference between the wholesale electricity market price and the generation costs of new renewable generation

[7] *Renewables Obligation Order 2002*: in force since April 1, 2002.

capacities. The value of a certificate thus represents the additional cost of generating renewable electricity compared to conventional sources. Note, that wind offshore in the UK is additionally supported by capital grants (for details see Voogt et al (2004)).

4.2 Results of Green*Net* simulation runs

For several RES-E generation technologies the deployment of installed capacity and annual generation is simulated up to the year 2020 using the simulation software **Green*Net***. The following default settings are used:

- Development of wholesale prices according to E2M2^s BAU-scenario.
- RES-E policies are implemented according to the existing design in Germany and UK as described in the previous section.
- For grid reinforcement (GR) as well as system operation cost (SO) an average cost scenario is selected.
- System operation costs (SO) are determined considering average values for the capacity credit of wind.
- Grid connection costs (GC) are assumed to be 5% of the total investment cost of onshore wind and 10-25% of offshore wind (depending on the distance to shore).

4.2.1 Germany

In Germany the way of allocating additional grid related and system related costs has a considerable impact on the deployment of both onshore and offshore wind (see Figure 4). While for onshore wind deviations from the default scenario can be observed within the first years of the simulation period, for offshore wind allocation of additional costs doesn’t influences its deployment before 2015. Onshore wind currently is one of the most mature RES-E technologies and, therefore, its development is mainly determined by financial barriers, i.e. the design of the particular promotion scheme. Wind offshore technology, on contrary, is still a new technology and, therefore, non-financial barriers (like social acceptance, administration barriers, etc.) have a significant impact on its development. These non financial barriers are implemented within the **Green*Net*** model using the S-curve approach. Actually, access to the grid is also a non-financial barrier and, therefore, the separate allocation of grid connection costs and grid reinforcement costs in not just influencing the resulting costs of the RES-E technology itself but also the non financial barrier. Note, that non-financial barriers are not adapted according to the cost allocation scheme. They remain the same in several cost allocation scenarios. Therefore results derived in this paper can be interpreted to determine the lower bandwidth of wind onshore and offshore deployment. Another reason, why offshore scenarios do not differ for the first simulated years, is that specific grid reinforcement costs (GR) and system operation costs (SO) are increasing with higher wind penetrations in the system. Hence, the corresponding effects become significant with rising capacities installed.

For onshore wind the cumulated installed capacity increases from 17,560 MW in 2004 to 18,750 MW in 2020 in the case of partial unbundling (being currently implemented in Germany; i.e. the default scenario). Full unbundling (i.e. grid connection costs are socialised via grid tariffs) leads to an additionally installed capacity of 1,000 MW in 2020 while allocation of several grid related and system related cost components to the wind power producers results in 550 MW less installed capacity (compared to the default case of partial unbundling).

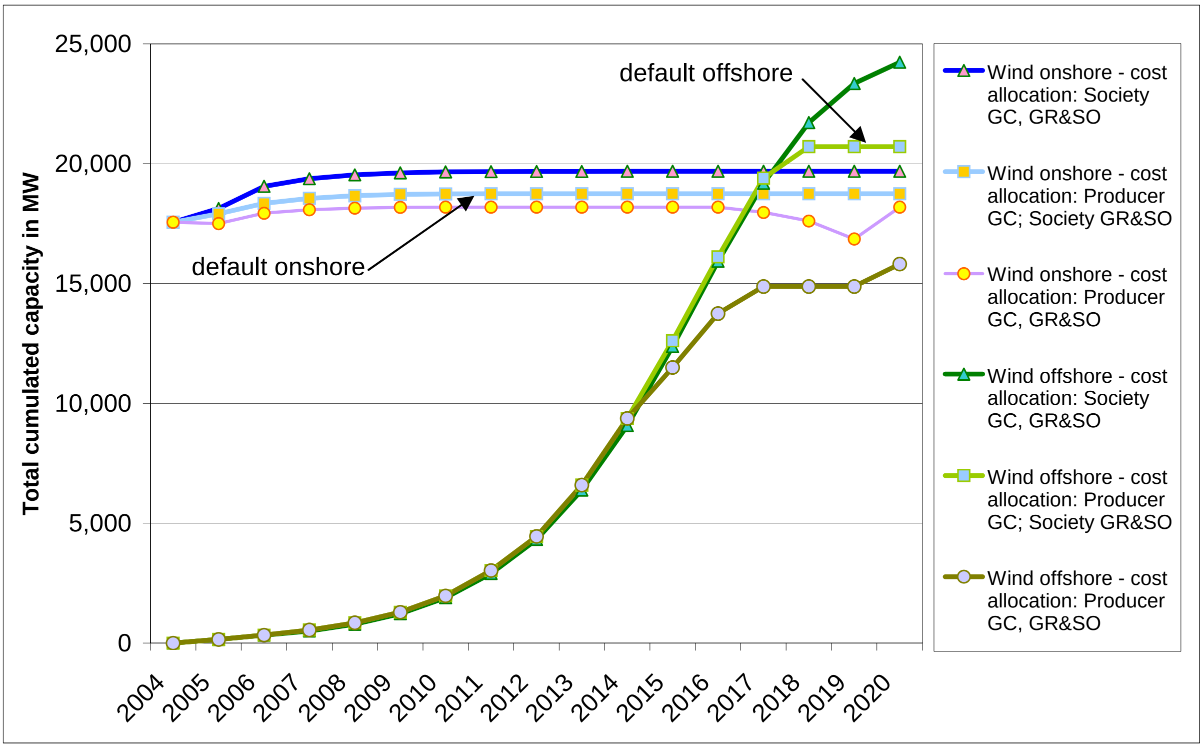

Fig. 4. Germany - Development of the total cumulated capacity of wind onshore and offshore for different cost allocation scenarios in Germany. Source: **Green*Net*** model runs. Legend: GC…grid connection, GR…grid reinforcement, SO…system operation.

For 2020 the cumulative wind offshore capacity varies considerable for the three different cost allocation scenarios. In the reference case the cumulated installed wind offshore capacity reaches 20,700 MW in 2020. Implementing full unbundling ("best case from the wind generator's point-of-view") results in a higher installed capacity of 24,200 MW in 2020. No unbundling ("worst case from the wind generator's point-of-view") results in 15,800 MW wind offshore installed.

To reach the same wind penetration for full unbundling like for the default case in 2020, *FITs* for onshore as well as offshore wind have to be adjusted. The necessary adjustment is determined within an iterative process using the **Green*Net*** software. For onshore wind the *FIT* has to be reduced by 3% to achieve the default penetration in 2020 and for offshore wind a reduction of 16% would be necessary.

A detailed analysis of onshore wind indicates that – although new capacity is installed continuously – the total wind onshore capacity remains constant after the year 2010 (see Figure 5). This is due to the fact that existing wind farms will be shut down due to end of lifetime.

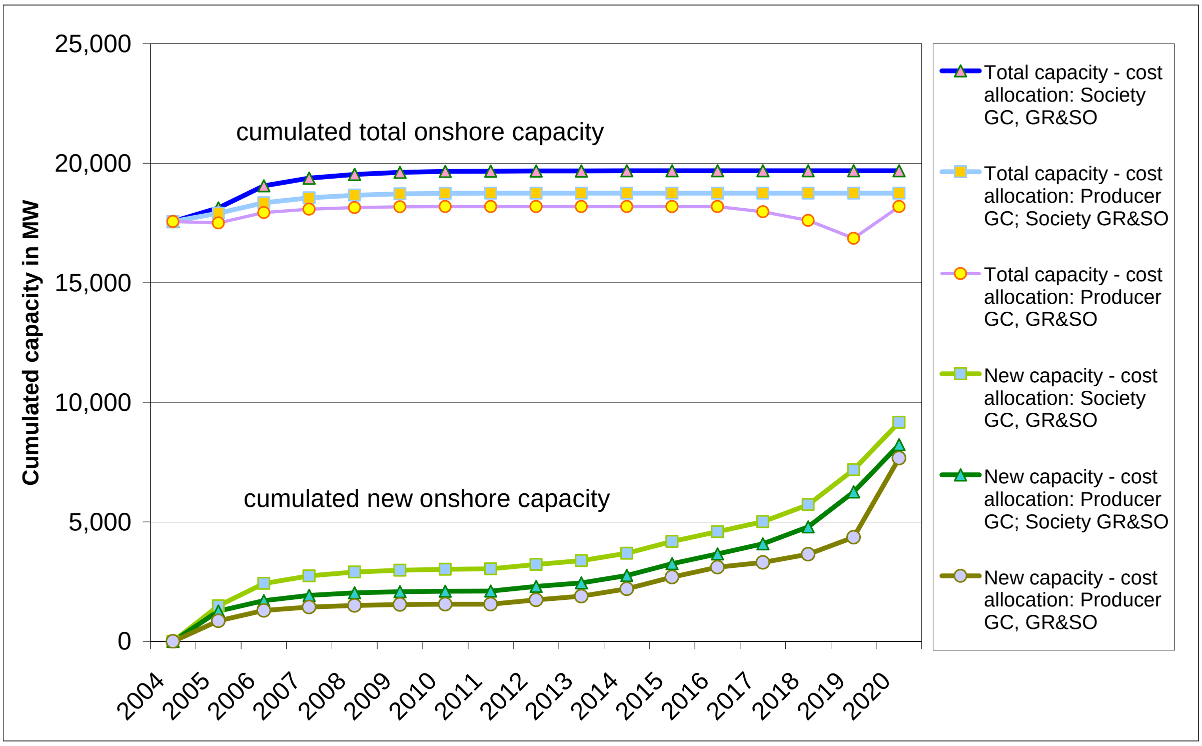

Fig. 5. Germany – Development of the cumulated wind onshore capacity installed after 2004 versus total wind onshore capacity for different cost allocation scenarios in Germany. Source: **Green*Net*** model runs. Legend: GC…grid connection, GR…grid reinforcement, SO…system operation.

In Figure 5 finally RES-E generation from new capacities only (installed after 2004) is analysed for the year 2020 for the three investigated scenarios. Whereas there is a considerable impact on generation of onshore and offshore wind, remaining RES-E generation technologies are not affected. This is due to the fact that a *FIT* like in Germany is a technology driven supporting mechanism being able to address each RES-E generation technology separately. In the case of no unbundling generation from new power plants is 7% less for wind onshore and nearly 25% less for wind offshore compared to the reference scenario. For the full unbundling scenario generation from new power plants rises by about 10% and 17% for onshore and offshore wind, respectively.

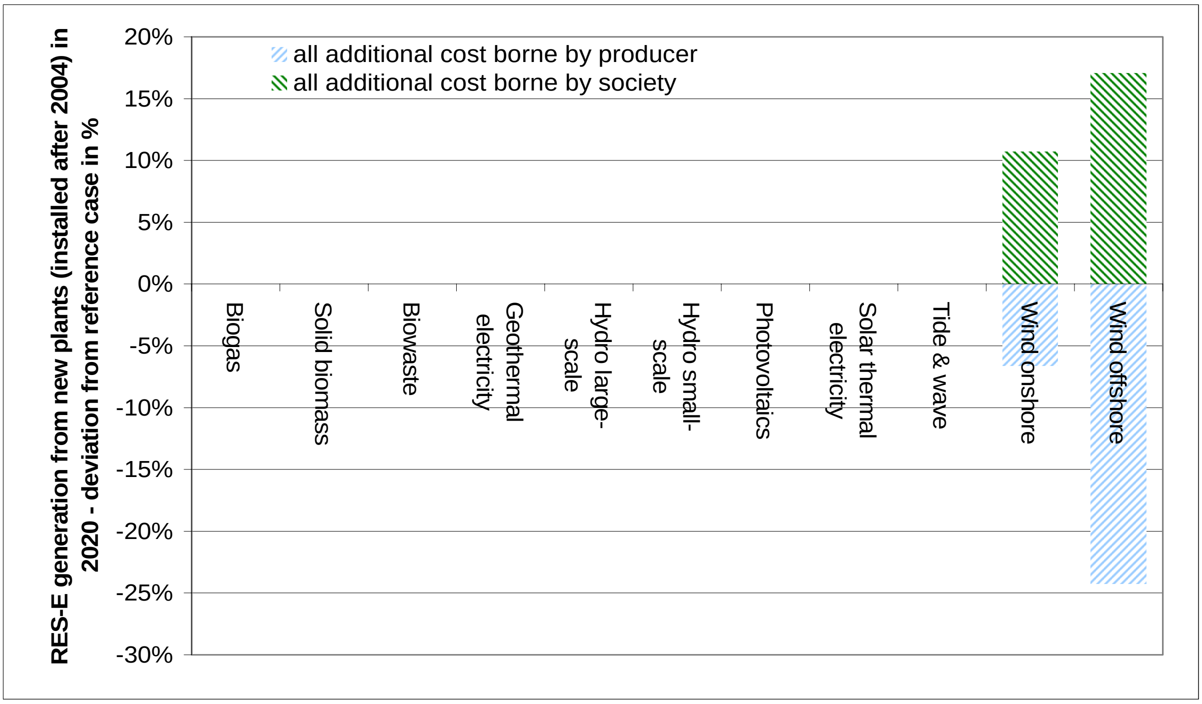

Fig. 6. Germany - Deviation (full unbundling versus no unbundling) of RES-E generation from new plants installed after 2004 from the reference case (partial unbundling) in 2020. Source: **Green*Net*** model runs.

4.2.2 United Kingdom

On contrary to the German feed-in tariff system, in the UK's tradable green certificates scheme wind deployment changes significantly less depending on the cost allocation policies. Compared to the reference case (partial unbundling) onshore wind generation from new power plants in 2020 is about 3% less in the case of no unbundling whereas there is a slightly increase in the case of full unbundling (see Figure 7). For offshore wind there is no change in generation at all for the different cost allocation policies for the year 2020. This indicates that long-run marginal costs of onshore as well as offshore wind are low compared to other RES-E technologies and, therefore, even when allocating additional costs they are not displaced by other technologies. For the case of full unbundling there is no considerable additional wind generation as the deployment is limited by non-financial barriers.

Figure 7 illustrates, that for capacity driven instruments (like the *RO System* in the UK) a decrease in the share of a particular technology normally results in an increase of one or more remaining technologies of the entire technology portfolio so that finally the total RES-E quota will be reached.

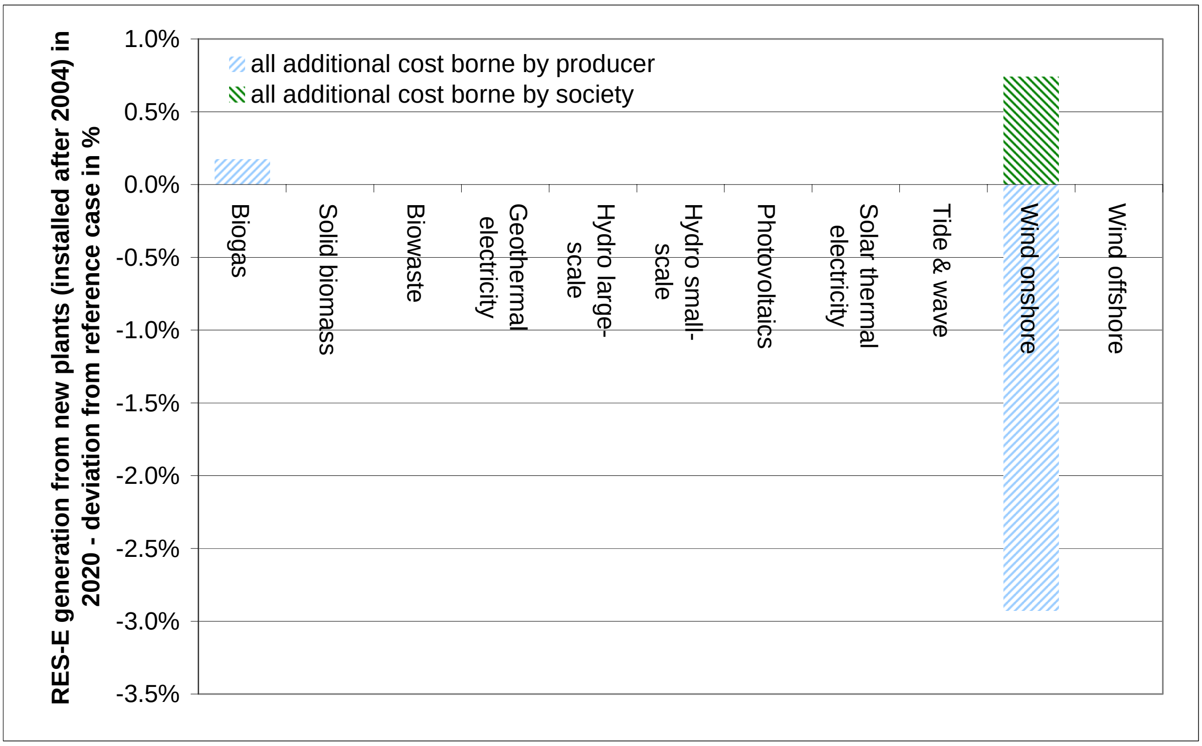

Fig. 7. United Kingdom - Deviation (full unbundling versus no unbundling) of RES-E generation from new plants installed after 2004 from the reference case (partial unbundling) in 2020.

Figure 8 discusses wind offshore generation in UK in detail. The results shown in Figure 8 are based on the assumption that additional offshore capital grants (currently implemented in practise) are neglected. Compared to the default settings in Figure 7 the difference is significant. Offshore generation (from wind power plants installed after 2004) is 17% less compared to the default case in 2020 while generation from biogas, tide & wave as well as wind onshore is substantially higher in relative terms. Hence without capital grants offshore wind becomes the RES-E technology that determines the price for *TGC*.

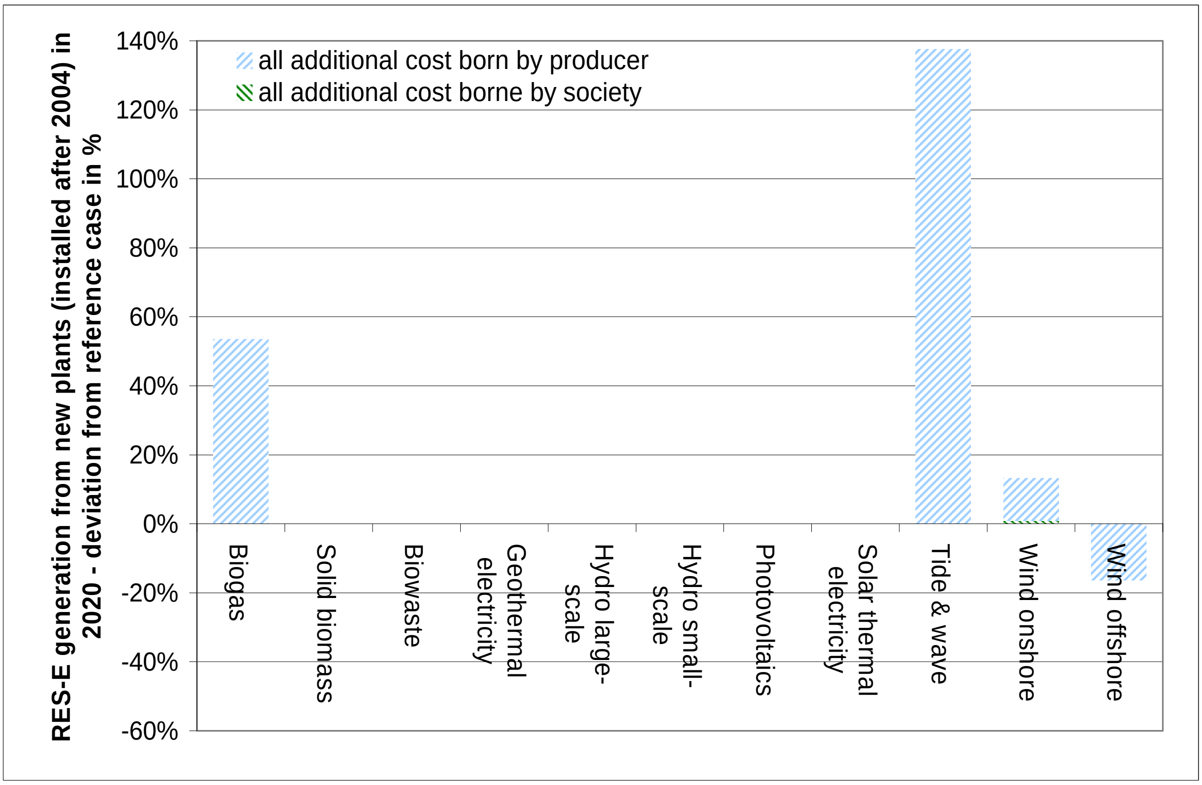

Fig. 8. United Kingdom - Deviation of RES-E generation from new plants installed after 2004 from the reference case in 2020 (without offshore capital grant).

Finally, an interesting parameter to be studied is the corresponding *TGC* price. Its development is illustrated in Figure 9 for the different cost allocation policies investigated. Until 2012 the price is equal to the penalty (43.6 €/MWh) for each scenario which indicates than in this period the RES-E quota is not fulfilled. Whereas for the partial unbundling and full unbundling scenario the *TGC* price decreases towards zero for the following years up to 2020, it remains at a higher price level in case of no unbundling.

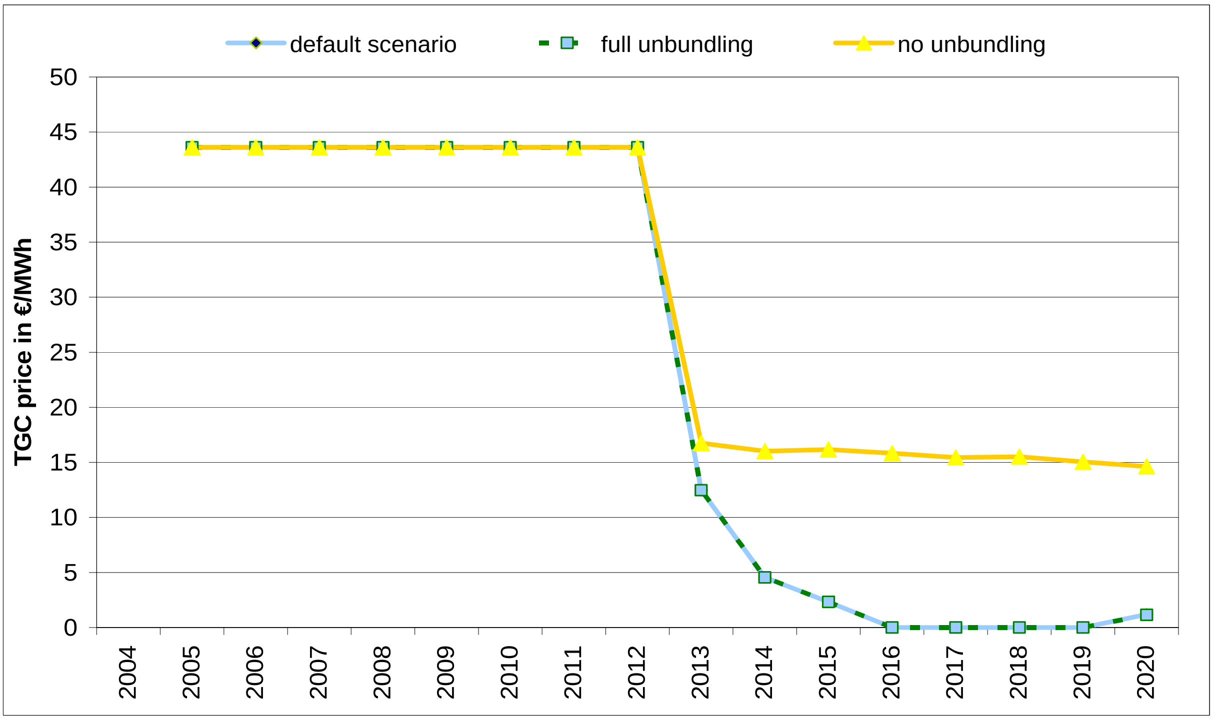

Fig. 9. United Kingdom – Development of the ROC price for different scenarios of cost allocation (without offshore capital grant).

5. Conclusions

Large-scale RES-E grid integration expects a clear definition of the interfaces between the RES-E power plant itself, the grid infrastructure and overall system operation. Due to small amounts of RES-E generation in the past the share of grid related and system related costs has been small compared to the long-run marginal RES-E generation costs. Therefore, these costs have not been clarified in detail, but often treated as part of the long-run marginal costs of the RES-E power plant and, subsequently, were socialised via the corresponding RES-E promotion instruments.

But this practice clearly violates the unbundling principles of the EC Directive as well as economic theory of network industries in general. E.g., in the current German renewable legislation it is still foreseen to allocate connection costs of several RES-E generation technologies (i.e. also offshore wind farms) to the project itself and, subsequently, to socialise corresponding connection costs via feed-in tariffs. On contrary, e.g. in Denmark grid connection costs of (offshore) wind farms are already allocated to the grid infrastructure and, subsequently, socialised via the grid tariffs (going in line with the basic unbundling principles).

The modelling results derived from the simulation software **Green*Net*** clearly demonstrate that the future pattern of large-scale RES-E deployment (wind in particular) significantly varies depending on both

- the definition of the interfaces between the RES-E power plant, the grid infrastructure and the overall system (incl. the allocation policy of the corresponding disaggregated cost elements) as well as on
- the type (price-driven versus capacity-driven) and design (absolute level) of the RES-E promotion instrument.

Moreover, the bandwidth of deployment of individual RES-E generation technologies is even greater for price-driven instruments (like feed-in tariffs in Germany) depending on the degree of unbundling than for capacity-driven instruments (like TGC systems in the UK). This result can be generalised if long run marginal costs of wind generation are considerably lower than for other RES-E technologies. This is somehow evident for onshore wind but might not be the case for offshore wind as shown in the scenario without capital grants for offshore wind. For price-driven instruments the quantitative effects of different allocation policies is primarily determined by the particular design of the promotion scheme and for new technologies like offshore wind by non-financial barriers, too.

As in the European Union currently there is still a lack of common understanding on both implementing the unbundling principles into the national electricity markets and deriving least-cost strategies of large-scale RES-E (mainly wind) grid integration, it is recommended to establish a strategic EU-wide policy for large-scale RES-E grid integration. In this context, a fundamental unbundling discussion is indispensable. This means in particular, that a definition of the interfaces between the RES-E power plant itself (incl. the “internal grid” and the corresponding electrical equipment) and the “external” grid infrastructure (i.e. new grid connection lines and reinforcement of the existing grid) as well as overall system operation (e.g. structure and design of balancing markets and corresponding procedures) has to be discussed comprehensively. Currently also a great variety of approaches is implemented throughput Europe to cover and socialise the corresponding cost elements (RES-E promotion instruments versus grid tariffs versus balancing markets). This mosaic clearly indicates that there exist further potentials to maximise RES-E grid integration in Europe with minimal cost for society.

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References

Auer H., M. Stadler, G. Resch, C. Huber, T. Schuster, H. Taus, L. H. Nielsen, J. Twidell, D. J. Swider: "Cost and Technical Constraints of RES-E Grid Integration", Project Report, WP2, August 2004, available on www.greennet.at

Auer H., C. Huber, G. Resch, T. Faber, C. Obersteiner: "Action plan for an enhanced least-cost integration of RES-E into the European grid", Project Report, WP10, February 2005, available on www.greennet.at

Bach P.F.: „Costs of Wind Power Integration into the Electricity Grids in Denmark", Proceedings, IEA Workshop on Integration of Wind Power into Electricity Grids, Paris, 25 May 2004.

DEWI: „Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020", Studie im Auftrag der Deutschen Energie-Agentur GmbH (dena), Konsortium: DEWI, E.ON Netz, EWI, RWE Net, VE Transmission, February 2005.

Dowling P., B. Hurley: „A strategy for locating the least-cost wind energy sites within the EU electrical load and grid infrastructure perspective", Proceedings, 5th International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, Glasgow, 7-8 April 2005.

EEG-Gesetz: Gesetz für den Vorrang Erneuerbarer Energien (Eneuerbaren-Energien-Gesetz – EEG), BGBL. Nr. 40/Teil I ausgegeben zu Bonn, 31. Juli 2004.

European Commission (2000): Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

European Commission (2001): Directive 2001/77 of September 27th 2001 on the Promotion of Electricity produced from Renewable Energy Sources in the internal electricity market.

European Commission (2004): Directive 2003/54/EC of June 26th 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC.

Ford R.:" Grid Integration of Offshore Wind in the UK", Proceedings, 5th International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind Farms, Glasgow, 7-8 April 2005.

Giebel G.: “On the Benefits of Distributed Generation of Wind Energy in Europe”, Phd thesis from the Carl von Ossietzky Universität Oldenburg, VDI Reihe 6, Nr. 444, Düsseldorf, VDI Verlag, ISBN 3-18-344406-2, 2001.

Groenhuijse L.: “Minimising the costs of integrating wind power into the grid: the Dutch situation”, Proceedings, IEA Workshop on Integration of Wind Power into Electricity Grids, Paris, 25 May 2004.

Gül T., T. Stenzel: “Variability of Wind Power an other Renewables: Management Options and Strategies, Report by the International Energy Agency, Paris, June 2005, available on www.iea.org

Hirst E., J. Hild: “The Value of Wind Energy as a Function of Wind Capacity”, The Electricity Journal 17 (6), 11-20. 2004.

Hooft, Jaap ‘t: “Survey of integration of 6000 MW offshore wind power in the Netherlands electricity grid in 2020”, Proceedings, European Wind Energy Conference (EWEC), Madrid, 16-19 June 2003.

Huber C., T. Faber, G. Resch, R. Haas: „Deriving Optimal Promotion Strategies for Increasing the Share of RES-E in a Dynamic European Electricity Market“, Action Plan of the Project Green-X, October 2004(a), available on www.green-x.at

Huber C., T. Faber, R. Haas, G. resch, J. Green, S. Ölz, S. White, H. Cleijne, W. Ruijgrok, P.E. Morthhorst, K. Skytte, M. Gual, P. Del Rio, F. Hernandez, A. Tacsir, M. Ragwitz, J. Schleich, W. Orasch, M. Bokemann, C. Lins: “Final report of the project Green-X” Green-X report, November 2004(b), available on www.green-x.at

Huber C., T. Faber, G. Resch, H. Auer: “The Integrated Dynamic Formal Framework of GreenNet”, Project Report, WP8, December 2004(c), available on www.greennet.at

ILEX Energy Consulting: “Quantifying the system costs of additional renewables in 2020“, A report of ILEX Energy Consulting in association with Manchester Centre for Electrical Energy (UMIST) for the Department of Trade and Industry (DTI), October 2002.

Milborrow D.J.: “The Real Cost of Integrating Wind”, Windpower Monthly, February 2004, p.35-38, 2004.

Morthorst P.E., K. Skytte, C. Huber, G. Resch, P. Del Rio, M. Gual, M. Ragwitz, J. Schleich, S. White: "Analyses of trade-offs between different support mechanisms", Green-X WP4-report, March 2004, available on www.green-x.at

Pantaleo A., A. Pellerano, M. Trovato: "Technical issues on wind energy integration in power systems: projections in Italy", Proceedings, European Wind Energy Conference 2003, Madrid, 16-19 June 2003.

Ragwitz M., C. Huber, G. Resch, T. Faber, M. Voogt, W. Ruijgrok, P. Bodo: "FORRES 2020 – Analyses of the renewable energy's evolution up to 2020", Final report of the project FORRES 2020 – on behalf of DGTREN, Fraunhofer IRB Verlag: ISBN 3-8167-6893-8, Karlsruhe, November 2005.

Resch G., H. Auer, M. Stadler, C. Huber, L.H. Nielsen, J. Twidell, D.J. Swider: „Dynamics and basic interactions of RES-E with the grid, switchable loads and storage", Project Report, WP1, October 2003, available on www.greennet.at

Smith P.: "A simulation of integration of wind generation into the Irish grid: impacts and remedies, Proceedings, IEA Workshop on Integration of Wind Power into Electricity Grids, Paris, 25 May 2004.

Soeder L.: "The Value of Wind Power", Proceedings, IEA Workshop on Integration of Wind Power into Electricity Grids, Paris, 25 May 2004.

Swider D.J., C.: "Scenarios on the conventional European electricity market", Project Report, WP6, February 2005(a), available for download from the project website www.greennet.at

Swider D.J., C. Weber: "The Effects of Stochastic Electricity Market Modelling on Estimating Additional Costs of Intermittent RES-E Integration", Proceedings, 7th IAEE European Energy Conference 2005, Bergen 28-30 August 2005(b).

Tembleque L.J.S.: "Costs of wind power integration into electricity grids in Spain", Proceedings, IEA Workshop on Integration of Wind Power into Electricity Grids, Paris, 25 May 2004.

Uyterlinde M.A., B.W. Daniels, M. de Noord, C. de Zoeten-Dartenset, K. Skytte, P. Meibom, D. Lescot, T. Hoffman, M. Stronzik, M. Gual, P. del Rio, P. Hernandez: "ADMIRE-REBUS:

Assessment and Dissemination of Major Investment Opportunities for Renewable Electricity in Europe using the REBUS tool", Internal Report, ECN, Petten, The Netherlands, 2003.

Van Werven, M.J.N., L.W.M. Beurskens, J.T.P. Pierik: "Integrating Wind Power in EU Electricity Systems: Economics and Technical Issues", Project Report, WP4, February 2005, available on www.greennet.at

Voogt M., R. Coenraads: "Analysis of the renewable energy's evolution up to 2020", Country Report – United Kingdom, Project FORRES 2020, December 2004.

Winter W.: "Windpower integration into the transmission system in Germany", Proceedings, IEA Workshop on Integration of Wind Power into Electricity Grids, Paris, 25 May 2004.

Wirl F.: "Die Theorie der Öffentlichen Firmen: Rahmenbedingungen für effiziente Versorgungs-unternehmen", Schriften zur Öffentlichen Verwaltung und Öffentlichen Wirtschaft, Band 126, NOMOS Verlag, Baden-Baden, 1991.