EUROPEAN RES-E POLICY ANALYSIS

A model based analysis of RES-E deployment and its impact on the conventional power market

Final Report, April 2010

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Institute of Energy Economics
at the University of Cologne

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Abbreviations

a.g.l.	Above ground level
BAU	Business-as-usual
Bill.	Billion (German: Milliarde)
BMU	Bundesumweltsministerium (department for environment, Germany)
BoS	Balance of System
CO_2	Carbon dioxide
CHP	Combined Heat and Power
CSP	Concentrating Solar Power
DIME	Dispatch and Investment Model for Europe
DNI	Direct Normal Irradiation
DSM	Demand Side Management
EC	European Commission
EEG	Erneuerbare Energien Gesetz (Renewables Energy Law in Germany)
EU	European Union
EU27	All 27 EU Member States
EU27 ++	All 27 EU Member States plus Norway and Switzerland
FIT	Feed-in Tariff
GDP	Gross domestic product
GO	Guarantees of Origin
GW	Gigawatt
GWh	Gigawatt hour
HDR	Hot Dry Rock
HQS	Harmonized Quota System
IDEA	Instituto para la Diversificación y Ahorro de la Energía
kW	Kilowatt
kW_p	Kilowatt peak
LORELEI	Linear Optimization Model for Renewable Electricity Integration in Europe
Mill.	Million
MS	Member State
MW	Megawatt
MWh	Megawatt hour
NFFO	Non Fossil Fuels Obligation (UK)
NI-NFFO	Northern Ireland Non Fossil Fuels Obligation
NPV	Net Present Value
NQS	National Quota System
NTC	Net Transfer Capacity
OFGEM	Office of Gas and Electricity Markets (UK)
O&M	Operation and Maintenance
PFER	Plan for the Promotion of Renewable Energies (Spain)
PV	Photovoltaics
RD	Royal Degree (Spain)
RES	Renewable Energy Sources
RES-E	Electricity from Renewable Energy Sources
RES-H&C	Heating and Cooling from Renewable Energy Sources
RES-T	Transport from Renewable Energy Sources
RO	Renewable Obligation Order (UK)
ROC	Renewable Obligation Certificate (UK)

RPR	Registro de Preasignación de Retribución (Register on the in-advance-allocation of the compensation)
SEK	Swedish krona
SRO	Scottish Renewables Obligation
TGC	Tradable Green Certificates
TSO	Transmission System Operator
TWh	Terawatt hour
UK	United Kingdom

Executive Summary

Motivation and Methodology

The 2009 EU Directive on the promotion of renewable energy sources (RES) establishes national targets for RES shares of total energy consumption. The overall European target is 20% RES in 2020, covering heating and cooling, transportation, and electricity generation. Against the background of these ambitious policy targets, the present study investigates possible developments of renewable energies in the European electricity sector (RES-E).

This study analyses regional RES-E deployment induced by different support schemes and the interaction between the renewable and the conventional power markets under growing RES-E shares until 2020, with a further outlook until 2030. Since Norway and Switzerland are part of the European power market, these countries are also included in this study (EU27++). In a first step, the renewable resource potentials and deployment costs of the following RES-E technologies have been assessed: wind onshore and offshore, biomass, photovoltaics, geothermal power, concentrating solar power, small hydro power, tidal and wave power. In order to analyze their deployment in more detail, subtechnologies and subregions have been included, resulting in a total of 2,222 modelled deployment options per year. In order to create a Business-as-usual scenario (BAU), all European RES-E support schemes have been implemented in a newly developed optimization model for renewable energy deployment (LORELEI[1]). The LORELEI model was linked to the competitive power market model DIME[2] in order to analyze interdependent effects in both markets.

The different possible attributes of RES-E support are price-based versus quantity-based, technology-specific versus technology-neutral, and national versus EU-wide harmonized support. Three scenarios of support schemes are analyzed in detail to take into account a certain bandwidth of design options. The first scenario models a harmonized quota system (HQS). Here, all national targets are aggregated to form a single European technology-neutral quota for RES-E generation. The RES-E

[1] “Linear Optimization Model for Renewable Electricity Integration in Europe”
[2] “Dispatch and Investment Model for Europe”

deployment develops according to a cost-minimizing calculus, modelling EU-wide competition between technologies and plant locations. The BAU scenario models all European support schemes according to their actual designs. Feed-in tariff systems (FIT), premium systems, and quota systems have been implemented with their current designs and pricing definitions (e.g. tariff reductions over time have been implemented as defined in the national laws). Since the BAU scenario is dominated by national FIT systems, the deployment is mainly price-based and technology-specific. The “Cluster scenario” takes into account the possibility for Member States (MS) to design shared RES-E support schemes, which is given by the EU directive.
Since a shared quota system is easier politically implementable than a shared FIT system, we defined the cluster by aggregating the quotas of those MS, which have national quota systems in the BAU scenario.

Conclusion – Lessons Learned and Implications for Future Developments

According to the assessment of regional RES-E potentials, the EU-wide RES-E target is feasible – however posing significant challenges for the development of the conventional power system.

Since the HQS is the only scenario which reaches the European RES-E targets due to the quantity-based setting, and since it does so at minimal RES-E generation cost, this normative scenario is at the center of our discussion. We summarize the main findings of HQS and compare it with the scenarios BAU and Cluster. This order emphasizes that this study includes comparative scenario analyses and no forecast. Scenarios are extrapolations under given sets of assumptions. They do not reflect most likely developments. Especially, our BAU scenario freezes current national RES-E promotion laws. It does not include likely, but in detail unforeseeable adaptations of these laws.

RES-E support in HQS Scenario

1. RES-E Generation Mix

In HQS RES-E are promoted in a Europe-wide and technology-neutral manner. Optimization of RES-E deployment takes into account regional RES-E generation costs and national power prices.

In HQS, intermitting wind power deployment plays a dominant role. Especially the currently still uncertain deployment of offshore wind increases significantly in HQS. Still expensive technologies like photovoltaics or geothermal power are hardly deployed under technology-neutral support.

2. RES-E costs

The **investment costs** in the HQS scenario are bill. 313 €$_{2007}$ accumulated net-present value between 2008 and 2020. The dominant technologies are wind onshore with 42%, wind offshore with 21% and biomass with 24%. The remaining 13 % are spent for less mature technologies, with a 6% share of concentrating solar as the largest share of the minor technologies.

3. Regional Distribution and TGC Trade Streams

Since the harmonized quota scenario calculates one single Europe-wide RES-E quota, the individual national targets are reached through an ex-post TGC trade. It is important to note that national RES-E targets have not been defined by all MS yet. Therefore in this study these targets needed to be assumed.

Some MS with low or expensive resource potentials gain from buying certificates to reach their targets, while MS with larger potentials and relatively low targets gain from deploying additional RES-E above their targets and selling TGCs on the market. Mainly countries with a high wind power potential deploy RES-E above their national target. Within the target setting, the wealth of the individual MS has been taken into account. Eastern European countries received lower targets according to their GDP. Therefore, it can be seen that altogether the 12 Eastern European countries are net-exporters of TGCs due to their comparatively low RES-E targets. However, since some Eastern European MS have still considerable demand growth rates, the target fulfillment can also require these countries to become net importers. Altogether, the 15 Western European MS import TGC with a value of 3.9 bill €$_{2007}$ in 2020 when a

GDP weighted target setting is assumed, and 4.6 bill $€_{2007}$ when a GDP per capita target-setting is assumed.

4. Harmonization Gains

In this study harmonization gains are defined as cost savings in RES-E generation (investment, O&M, fuel costs and heat remuneration), solely through a switch from national to harmonized support. In order to calculate these savings, the harmonized quota scenario is compared with an auxiliary scenario which differs only in this respect. Therefore, the auxiliary scenario simulates national technology-neutral quota systems. The potential RES-E cost reduction between these two technology-neutral scenarios is bill. 118 $€_{2007}$ accumulated net present value 2008-2020. It is important to note that this harmonization gain in RES-E generation may be counteracted by additional costs of e.g. grid enhancements due to higher concentration of intermitting RES-E in certain regions resulting from harmonized support. Grid costs and additional costs in the conventional power systems are not considered in this study, but would need to be assessed to find an overall efficient solution.

Conventional Power Market in HQS Scenario

5. Total Generation Mix

The RES-E share in the EU27 rises to a significant degree of roughly 34 % in 2020 and 45 % in 2030, due to the quantity-based target setting.

Power generation from lignite remains approximately constant, due to relatively low costs of providing lignite from indigenous mines. Nuclear power generation remains an important energy source in the European generation mix. The share of hard coal shrinks in the generation mix, also due to the relevance of the CO_2 price and the lower demand for conventional generation. Due to its lower CO_2 intensity, higher flexibility, and relatively low investment costs natural gas will play a relatively larger role in the power generation mix.

6. Capacity Effects and Shift in Power Plant Utilization

Since RES-E cover an increasing share of demand, the utilization of the installed conventional power capacities is reduced. In the longer run, this results in a shift towards a higher share of peak load capacity and a smaller share of base load capacity. In addition, sufficient backup capacity needs to be installed since only a small share of the RES-E capacity can be counted as securely available capacity. This results in a hardly reduced demand for conventional power capacity in order to fulfill the required security of supply. Altogether the total installed (renewable and conventional) generating capacity rises significantly to fulfill both the RES-E targets and the system adequacy criterion.

7. Required Flexibilities in the Power Market

The intermittent wind power and to a lesser extent photovoltaics infeed changes the patterns of the power market in most regions significantly. In addition to demand structures, especially wind situations become increasingly important for the power plant dispatch. Especially hours with low demand and high wind power infeed challenge the power system.

- The model results show that in hours with low load and high wind power infeed, notable shares of wind infeed are turned down. The absolute amount of turned-down wind infeed rises over the years, which shows increasing integration challenges. This indicates that the possibility of wind power reduction is important to guarantee system stability at all times.
- Additionally, the model requires a backstop technology, which is utilized if generation from other RES-E exceeds load. This indicates demand for additional flexibilities in the power system, which could be provided by various measures, such as additional power storages, demand-side management in industry or households, or more flexible RES-E infeed, e.g. through a more demand-oriented dispatch of biomass-fired plants.
- The model results also show that electricity exports increase in countries with high shares of wind power. This indicates additional demand of both cross border transmission capacities and national grid enhancements. The reason is that wind power generation is relatively concentrated regionally compared to other RES-E technologies and that the transport of electricity to demand regions becomes increasingly challenging. Endogenous extensions of the electricity grid were however not considered in this study.

Comparison with BAU Scenario

While in the HQS scenario, RES-E is supported by a Europe-wide technology-neutral quota, in the BAU scenario promotion policies of every EU27++ country are modeled in accordance with current policies. For the majority of countries this implies RES-E support by a technology-specific feed-in tariff system. Differences in the outcomes of both scenarios are thus influenced by a RES-E support which differs with regard to the issues of price versus quantity-based support and technology-specific versus technology-neutral support.

8. RES-E generation in BAU

The mainly price-based support in BAU leads to a lower RES-E deployment than HQS throughout the considered period. (In reality, of course tariffs are likely to be adjusted, if failure of target achievement is anticipated.) Also in BAU the RES-E share increases significantly to 32% in 2020. As in HQS the increase is largely driven by the deployment of wind power, especially offshore-wind power. In addition, again similar to HQS, biomass generation contributes significantly. In contrast to HQS, rather expensive technologies like geothermal and especially photovoltaics play a more important role.

9. RES-E costs in BAU

In the BAU scenario the investment costs of bill. 412 $€_{2007}$ (accumulated NPV 2008-2020) are dominated by photovoltaics (44%) and sizeable shares of wind onshore (19%) and offshore (15%) as well as biomass (13%).

When it comes to the comparison of the generation mix, RES-E capacities and investment costs in BAU and HQS indicate that HQS contains potential efficiency gains within the RES-E sector. A direct comparison of costs between BAU and HQS is however problematic, due to the different quantity deployment paths. Thus, it has been necessary to build an auxiliary scenario in which the harmonized quota scenario reaches exactly the same RES-E amount as in the BAU scenario with the same timely deployment path. Total RES-E cost savings of a switch from BAU to the auxiliary HQS is 174 bill. $€_{2007}$ net present value accumulated 2008-2020. These cost savings arise from two effects, first due to the change from a national to a EU-harmonized support, and secondly due to the change from a mainly technology-specific to a technology-neutral support of RES-E in Europe.

Comparison with the Cluster Scenario

The cluster scenario is a scenario between BAU and HQS, in which the countries which currently have a quota system (Belgium, United Kingdom, Poland, Romania, Sweden) form a cluster and can thus benefit from harmonization effects within this trade-cluster. Countries which currently support RES-E by feed-in tariffs, bonus systems or tax incentives, are modeled as in BAU.

10. RES-E generation in Cluster

On a EU27++ level the generation mix in the Cluster scenario does not change much from the mix in BAU, as generation in the majority of countries in BAU have a FIT system and are consequently not influenced by the quota cluster.

Within the cluster countries, it can be noticed that in 2020 Belgium, Romania and Sweden generate less RES-E than in BAU. The three countries thus benefit from the possibility to not fulfill their quota on their own but rather import TGC from UK and Poland. As a consequence of the use of better RES-E locations, cost savings of 35 bill. $€_{2007}$ accumulated NPV 2008-2020 compared to BAU can be realized.

11. Outlook

Currently, many different promotion schemes for electricity generation from renewable energy sources (RES-E) are in effect in Europe. A more harmonized approach would enable to utilize considerable cost-savings in RES-E generation, as a result of competition between plant locations. In addition, the introduction of competition between technologies would lead to substantial cost-savings. Such efficiency gains however have to be balanced with additional integration costs, especially grid costs due to a regionally more concentrated deployment of some RES-E technologies under a more harmonized and technology-neutral promotion scheme. A detailed balancing of such costs and benefits of harmonization has not been considered in this study.

Utilizing cost-efficient RES-E potentials throughout Europe is essential. Therefore, an integrated geographical and intertemporal optimization is crucial to balance the different lead times, lifetimes and deployment times between the grid infrastructure as well as conventional and renewable generating capacities. One can conclude that while a more EU-harmonized approach to RES-E promotion than in place today is certainly recommendable, a strategy for optimum integration of RES-E calls for further research, encompassing aspects of both generation and transport of electricity in Europe.

1 Introduction

The aim of this study is to analyze scenarios of an increasing share of electricity from renewable energy sources (RES-E) in Europe. Thereby the focus is twofold. First, power market developments are analyzed depending on the applied RES-E promotion policy. To promote RES-E this study includes the issues of price-based vs. quantity-based support, technology-neutral vs. technology-specific support, and national vs. EU-harmonized support. Second, this study focuses on the repercussions of a deeper RES-E penetration on the conventional power market. This includes issues like system adequacy and the increasing requirement for flexibility of the power system in Europe until 2030.

Three working packages were necessary to analyze these two main goals. In a first step a database of RES-E potentials, costs and support schemes has been built up, covering the EU-27 (plus Norway and Switzerland – EU27++). Secondly, the "Linear Optimization Model for Renewable Electricity Integration in Europe" (LORELEI) has been developed. It deploys RES-E according to the underlying support schemes, potentials and cost parameters. Finally, LORELEI has been linked to the Dispatch and Investment Model for Europe (DIME), which models the conventional power market by meeting the residual demand in an efficient manner. By means of this model coupling, three different support scheme scenarios for electricity market evolution in Europe until 2030 have been analyzed: A scenario applying an EU-wide harmonized technology-neutral RES-E-quota (HQS), a Business-As-Usual (BAU) scenario, extrapolating the current schemes in the Member States, and a hybrid scenario in-between these two.

The report is structured in three Parts: The first part provides an overview on RES-E support according to the current political landscape and discusses evaluation criteria for RES-E promotion systems. The second part discusses the definition of the considered scenarios, the employed models and their conventional and renewable input parameters. And finally in the third part, the results of the computed market scenarios will be discussed, and conclusions drawn to address implications for future developments and research needs.

PART I: RES-E Promotion Systems

This first part of the report deals with RES-E promotion systems. First, in chapter 2, a motivation for the research project is provided by a discussion of the status quo of RES-E promotion in EU27++. This chapter includes a brief overview of the legislative background of RES-E support and describes the status quo of RES-E shares, of the RES-E generation mix and of the employed RES-E promotion systems in EU27++. Chapter 3 focuses on the attributes of RES-E Promotion Systems. After a brief definition of evaluation criteria for RES-E Promotion Systems, chapter 3 evaluates attributes of RES-E promotion systems with regard to the afore defined criteria.

2 Motivation and Status Quo of RES-E Promotion

The European Parliament adopted the "Climate Package" on December 17th, 2008. Within this package, a new directive for the RES-E support has been defined. The preceding renewables directive was adopted in 2001 (2001/77/EC). This directive defined RES-E targets for the EU-15 and later for the EU-25. Since then, Bulgaria and Romania joined the EU and received targets as well (see Table 2-1).

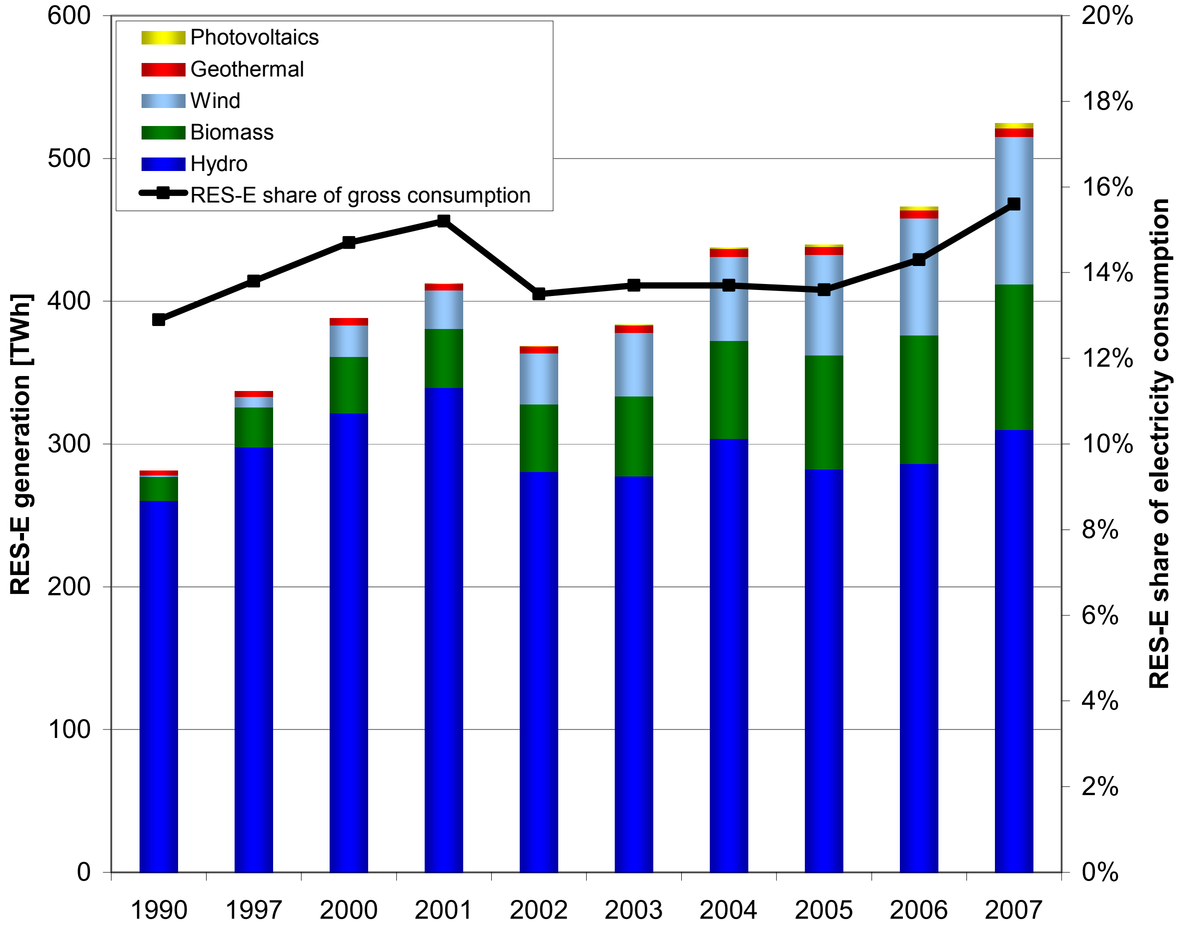
Table 2-1: RES-E share 1997, 2006; RES-E targets in 2010

	1997 RES-E Actual	2007 RES-E Actual	2010 RES-E Target
Austria	65.5%	59.8%	78.1%
Belgium	1.0%	4.2%	6.0%
Bulgaria	7.0%	7.5%	11.0%
Cyprus	0.0%	0.0%	6.0%
Czech Republic	3.5%	4.7%	8.0%
Denmark	8.8%	29.0%	29.0%
Estonia	0.1%	1.5%	5.1%
Finland	25.3%	26.0%	31.5%
France	15.2%	13.3%	21.0%
Germany	4.3%	15.1%	12.5%
Greece	8.6%	6.8%	20.1%
Hungary	0.6%	4.6%	3.6%
Ireland	3.8%	9.3%	13.2%
Italy	16.0%	13.7%	25.0%
Latvia	46.7%	36.4%	49.3%
Lithuania	2.6%	4.6%	7.0%
Luxembourg	2.0%	3.7%	5.7%
Malta	0.0%	0.0%	5.0%
Netherlands	3.5%	7.6%	9.0%
Poland	1.8%	3.5%	7.5%
Portugal	38.3%	30.1%	39.0%
Romania	30.5%	26.9%	33.0%
Slovakia	14.5%	16.6%	31.0%
Slovenia	26.9%	22.1%	33.6%
Spain	19.7%	20.0%	29.4%
Sweden	49.1%	52.1%	60.0%
United Kingdom	1.9%	5.1%	10.0%
EU-27	**13.1%**	**15.6%**	**21.0%**

Source: BMU, 2009.

Although the EU published the first RES-E directive in 2001, some countries started already in the 1980s and 1990s with RES-E support (e.g. Denmark, Germany, Spain). By now, the amount of RES-E generation has been growing constantly, as can be seen in Figure 2-1.

Figure 2-1: RES-E generation and shares in the EU-27, 1990-2007



Source: EWI, based on BMU (2009).

The main share of RES-E generation is based on large hydropower plants, which show a considerable volatility over the years. However, although the amount of the new renewable technologies, such as wind power and biomass power show a significant increase, especially since 2000, it is striking that the RES-E share (black line) remains more or less at the same level. This is not surprising, considering the increasing electricity demand in some MS. This observation, amongst others, contributed to the establishment of the 20% energy efficiency improvement target of the EU until 2020, which is also considered in the climate package, however not yet defined as a binding target.

The new 2008 directive has changed the approach compared to the 2001 directive. Instead of RES-E targets, the directive defines RES targets for the final energy consumption. This includes heating and cooling, transportation and electricity (RES-

H&C, RES-T and RES-E). The Commissions distribution of the RES targets between the MS is based on the 2005 RES shares, a flatrate addition and a GDP per capita approach.[3] The resulting RES targets can be seen in Table 2-2.

Table 2-2: RES-Targets in 2020

	2020 RES Target
Austria	34%
Belgium	13%
Bulgaria	16%
Cyprus	13%
Czech Republic	13%
Denmark	30%
Estonia	25%
Finland	38%
France	23%
Germany	18%
Greece	18%
Hungary	13%
Ireland	16%
Italy	17%
Latvia	40%
Lithuania	23%
Luxembourg	11%
Malta	10%
Netherlands	14%
Poland	15%
Portugal	31%
Romania	24%
Slovakia	14%
Slovenia	25%
Spain	20%
Sweden	49%
United Kingdom	15%
EU-27	**20%**

It is up to the MS to define targets for the individual sectors. These targets need to be published in National Action Plans until June 30th, 2010 (Directive 2009/28/EG). While some countries have already defined RES-E targets for 2020 (e.g. Germany 30%), others still have no long term strategy. This study focuses on the RES-E promotion, which requires a separate calculation of the national RES-E target (see chapter 6.3).

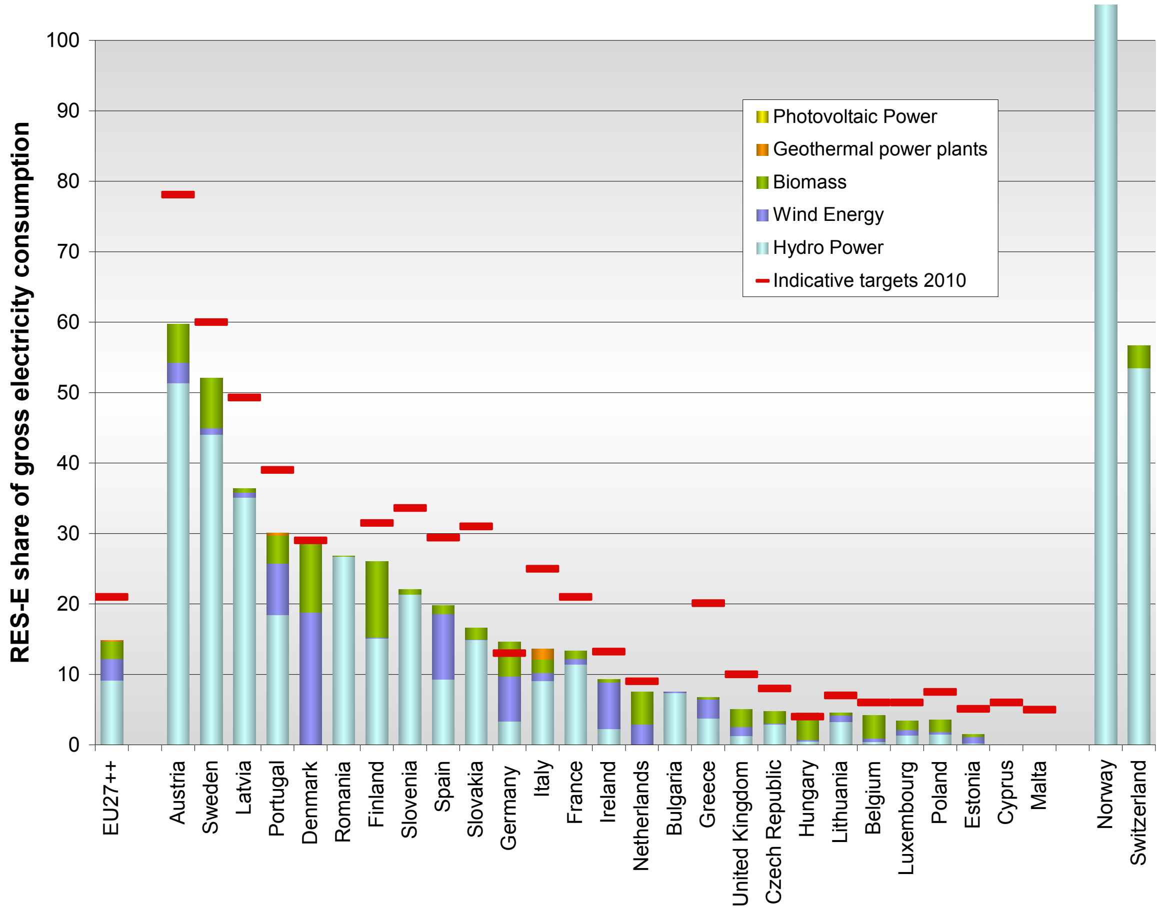
Source: Directive 2009/28/EG (2009).

Status Quo of RES-E promotion systems

As described above, the 2001 RES-E directive has defined targets for all MS. The overall target for the EU-27 is 21% (2010). Figure 2-2 provides an overview of the current (2006) RES-E shares of the MS. It can be seen, that some countries are on track to meet their target, while others need to strengthen their effort in order to increase their RES-E share.

[3] COM (2008).

Figure 2-2: RES-E share in 2007 of EU27++ and corresponding 2010 targets



Source: EWI, based on Eurostat data.

The recently published progress report of the European Commission[4] states, that it is likely that the EU will miss its 2010 target of 21%. In 2006, the RES-E share of the EU-27 has been 14.5%.

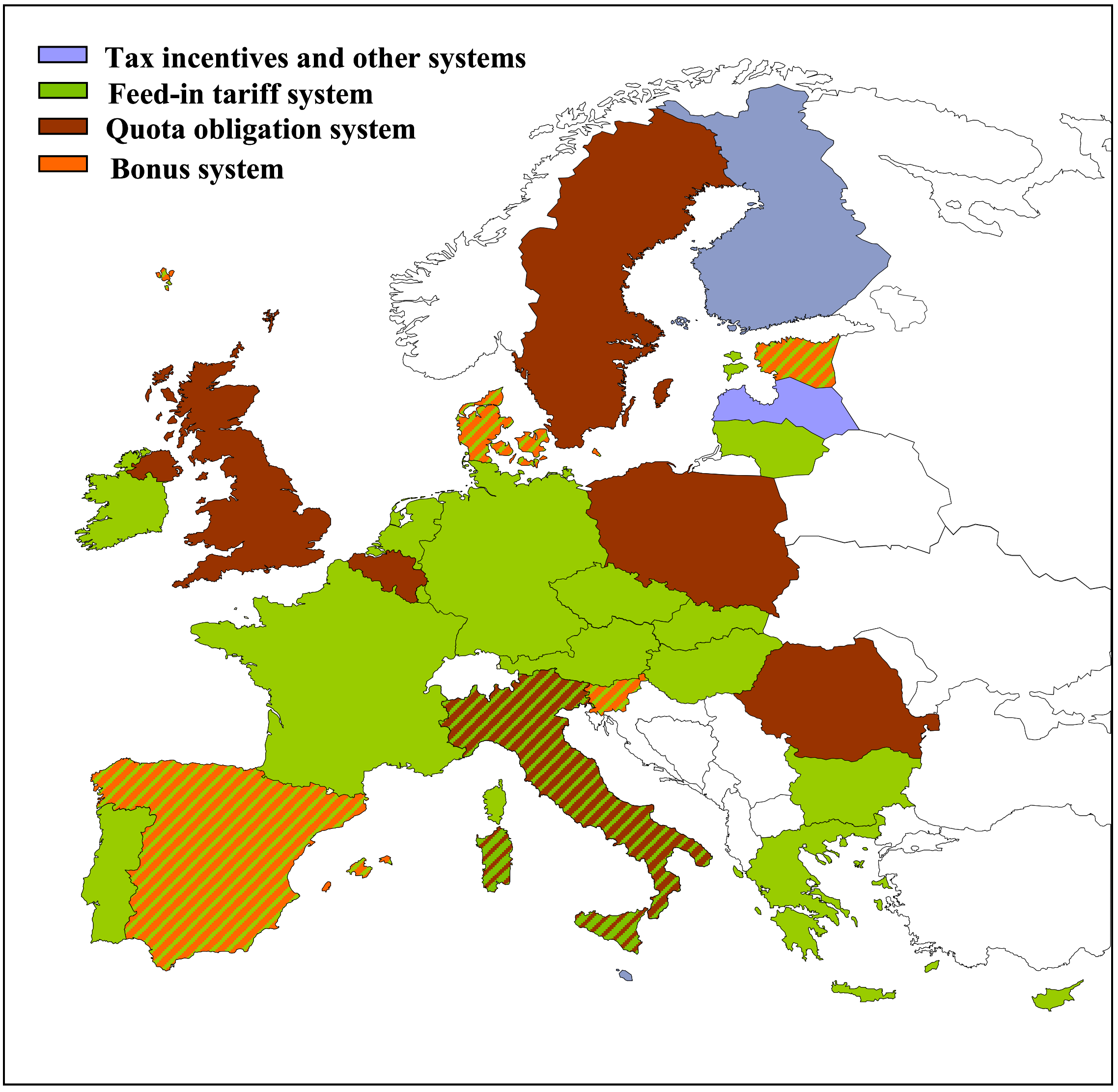
Currently, there is a variety of different RES-E support scheme designs installed in the EU member states, since policy decisions in this field are in the responsibility of the individual MS and the degree of coordination has not been decided yet. Chapter 3 provides an overview of the particular support schemes' attributes and discusses the main implications of the different designs.

For now, a differentiation between the main systems is sufficient. Currently 18 countries have chosen a price-based support, such as feed-in tariffs (FIT) or premium systems to support their RES-E deployment. Six countries use quantity-

[4] COM (2009) 192 final.

based support, i.e. quota systems, and three countries have implemented a tax-based support or other systems (see Figure 2-3). Also, some countries have hybrid systems, which allow the RES-E producers to choose for example between a FIT or a premium support or which are characterized by different support systems for different technologies.

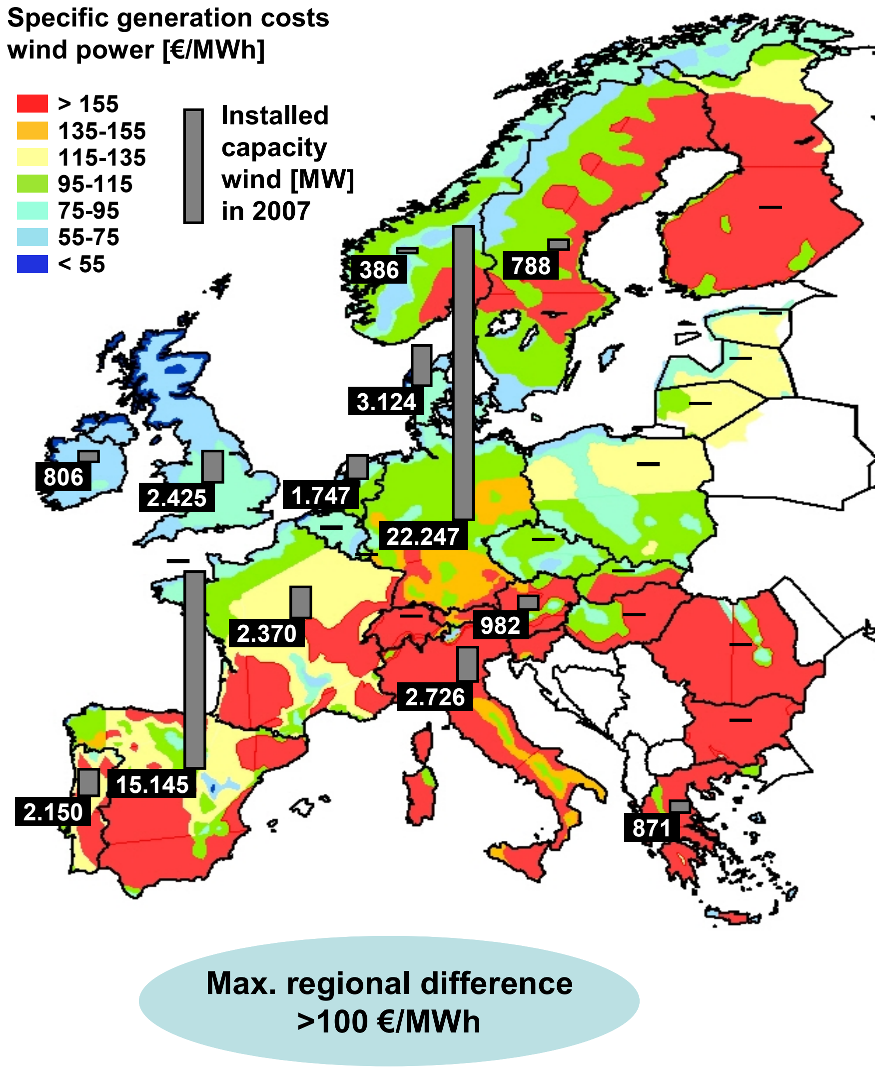
Figure 2-3: RES-E Support Schemes in the EU



Source: EWI.

These historically grown uncoordinated national actions have lead to a RES-E deployment, which in many cases is not based on the quality of the natural potentials of the regions, but mainly on the kind of support a certain technology receives in a particular region. Figure 2-4 and Figure 2-5 show the spread between the quality of the natural resources, measured by specific electricity generation costs for the cases of wind power and photovoltaics, and their respective deployment, measured by installed generation capacity.

Figure 2-4: Wind Power Qualities and Deployment in the EU27++ (2007)

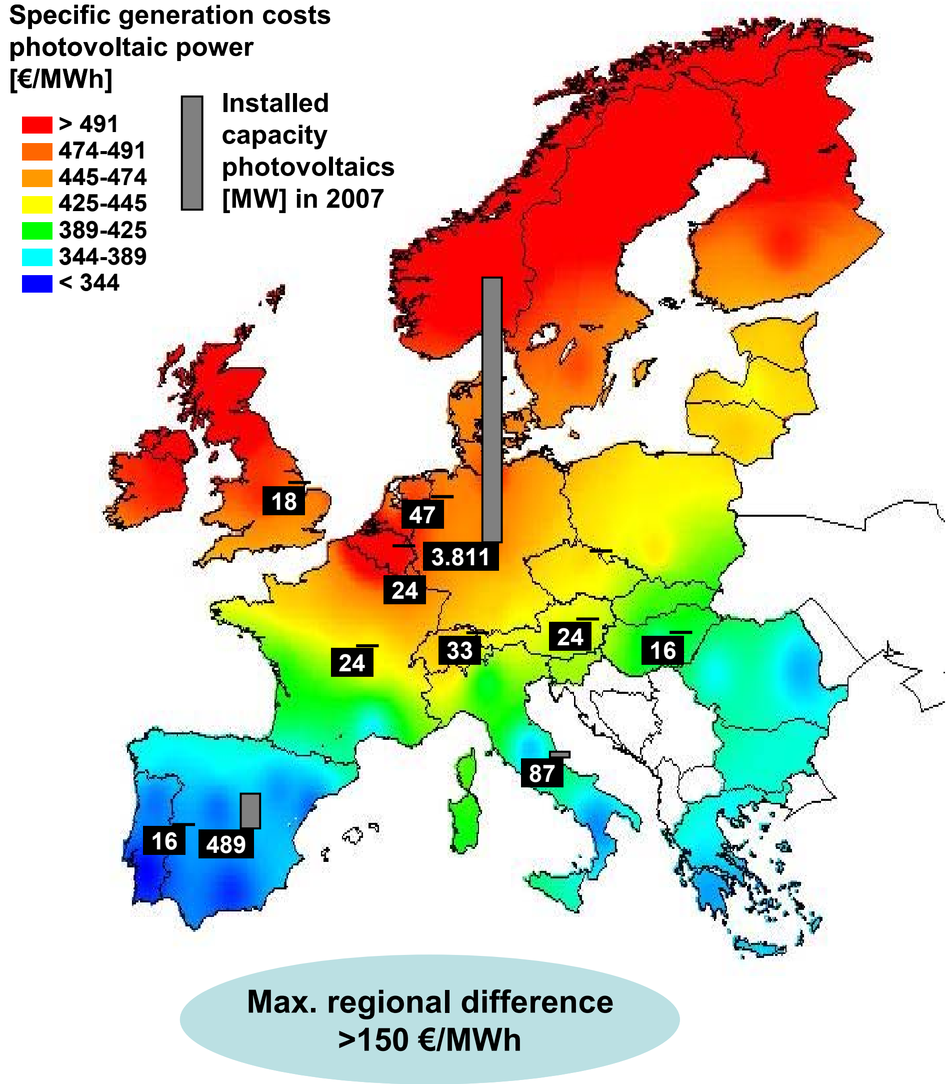


Source: EWI

The color coding shows the regional electricity generation costs of a 1.6 MW wind power plant. It can be seen, that wind power deployment mainly took place in Germany, Spain and Denmark. These countries have been early starters and chose FIT for their RES-E support. This picture becomes even more evident when it comes to photovoltaics support. As can be seen in Figure 2-5, the best resources are located in southern Europe. Although the generation costs between Spain and Germany differ by more than 100 €/MWh, the deployment in Germany exceeds the

Spanish one considerably. This as well can be attributed to the technology-specific FIT support in these countries.

Figure 2-5: PV Power Qualities and Deployment in the EU27++ (2007)[5]



Source: EWI.

A long discussion about the extent of harmonization has dominated the policy formulation process of the 2009 RES directive. Already the 2001 RES-E directive

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[5] The specific generation costs of photovoltaics decreased significantly from 2007 until today. The investment costs for photovoltaics of 2009 are about 40% lower than in the year 2007. Within the modeling in this study this cost development is taken into account (see chapter 6.2.2.5 on investment costs and learning curve assumptions). However the conclusion which can be drawn from Figure 2-5 is not affected by a decrease of investment costs which occurred in all European countries. The reason for the imprtant differences between specific generation costs of the southern and northern European countries is not an absolute level of investment costs but the important differences of fullload-hours of photovoltaics in Europe.

stated that a European support scheme harmonization is the long term goal, further observations of the support scheme performances are necessary to completely understand and evaluate the individual policy choices. Especially the possibility to trade Guarantees of Origin (GO) between the MS and count them towards their target has been heavily discussed during the latest process. While the first draft has stipulated the possibility of GO trade with some open design issues, the adopted directive clearly states in Article 15 that there will be no target counting of GO on country level. However, Article 6 of the 2008 directive states that a statistical transfer of RES amounts is possible on bilateral MS level. This possibility will not affect the deployment decision of private corporations – these will still be solely based on the national support scheme.
Some steps towards an actual harmonization are defined in Articles 7 – 10, which describe the possibility of joint projects between MS, third countries as well as the involvement of private corporations. Since the European Commission (EC) sees the pros and cons of a harmonization, it shifts the responsibility to the MS with Article 11. This Article opens the possibility of joint support schemes between MS. Therefore it enables the MS to harmonize subsequently through the principle of subsidiarity. If MS choose to support RES jointly, they can form a cluster, which could be open to other MS if they choose so. Thereby, the directive maintains the status quo, which is in the best interest of some countries and on the other hand enables other MS to cooperate and gain from a potential harmonization process.

This study is motivated by the question which deployment results from the different support scheme designs assumed in the scenarios. What could be the magnitude of potential harmonization gains and what overall costs are necessary to fulfill the 2020 RES-E targets. Finally, the response of the conventional power market is of particular interest.

3 RES-E promotion policies

As pointed out in the introduction, one aim of the study is to systematically analyze the effect of different support systems on the deployment of RES-E by technology and region within the EU and to quantify the associated costs. This has been done by computing three different main scenarios in which the promotion systems differ substantially. Differences in the promotion policies refer to the issues of (i) quantity-based versus price-based support, (ii) technology-neutral versus technology-specific support and (iii) national versus EU-harmonized support. In order to evaluate the results of the different scenarios, it is important to understand how these characteristics influence the extent to which the chosen evaluation criteria effectiveness and efficiency are met in the different scenarios. Therefore we proceed as follows: Section 3.1 gives a brief definition of the evaluation criteria. In section 3.2 the above listed characteristics of promotion systems are described and evaluated with regard to their ability to meet the chosen evaluation criteria.[6]

3.1 Evaluation criteria for RES-E promotion schemes

Many different evaluation criteria have been elaborated to assess the success of RES-E support schemes. The most prominent among them are effectiveness and efficiency. But many different definitions of these are used, according to different political or commercial interests. In this study, we use the *economic* definition of the different criteria, which will briefly be explained below.

3.1.1 Effectiveness

This criterion has two aspects: One is the *stimulation* of renewable energy expansion and the other one is the accuracy in terms of *target achievement*.

The aspect of stimulation is relevant if the objective of expansion does not include an upper limit; therefore this interpretation of effectiveness is useful as a valuation criterion when a *minimum* objective is set for a certain period of time. Accuracy

[6] To exemplify the design variations that are applied in reality, four case studies of different MS can be found in the attachment.

becomes relevant, when a *certain* quantity of renewable energy has to be reached at a certain point in time.

3.1.2 Efficiency

The term efficiency can be divided into two subsumable concepts:

Static efficiency means that, in a given period of time, a given output in terms of RES-E (TWh) is produced from a minimum input (€) and can also be described by the term *cost efficiency*. Another interpretation is the *output-sided efficiency* which is acquired when a maximum output is generated from a given input.

Dynamic efficiency is a generalization of static efficiency which in addition includes the concept of an optimal growth rate of renewable energy capacities. Thus it addresses optimality of a time-path, associated with path-dependent falling unit costs due to increasing maturity (usually the experience curve concept is applied in this context). Therefore, the concept of dynamic efficiency includes a number of complex issues. For instance, if the expansion of current RES-E technologies takes place too fast and leads to the utilization of a great part of the existing potentials, it may delay or prevent the expansion of future technologies with lower costs. Also, it can be very important to invest in an infant and more expensive technology in order to have lower RES-E costs in the long run. Among many other parameters, the evaluation of such intertemporal trade-offs depend on the applied discount rate, which is a controversial issue on its own. Thus, due to unsolved methodological issues and a high degree of uncertainty dynamic efficiency is difficult to measure. For this reason efficiency comparisons between the different scenarios concentrate on static efficiency.

3.2 Classification of RES-E promotion schemes

RES-E support systems can be classified with regard to three main criteria. First, in section 3.2.1 quantity-based and price-based instruments are compared. Second, in section 3.2.2 RES-E support systems the differences between technology-specific and technology-neutral instruments are discussed. Section 3.2.3 focuses on the difference between national and harmonized support systems.

3.2.1 Quantity-based versus Price-based instruments

Principally, there exist two different types of market-based promotion schemes for renewable energies: quantity-based instruments and price-based instruments. In economic theory, both types of instruments have the same economic effects, under the assumption that the regulator has perfect information. If he does not, extreme price reactions can result from "wrongly" set quantities and extreme quantity deviations from "wrongly" set prices. Under uncertainty about optimal quantities and prices, it is possible that mixed policies give better results than their unadulterated versions.[7] In reality, most of the countries which promote RES-E use variations of the original support mechanisms. Some countries even use mixed policies for different technologies; for example Denmark, which has a FIT system for most of the technologies, uses auctions for offshore wind farms.

3.2.1.1 Quantity-based instruments

Quantity-based instruments are implemented to reach a certain target for electricity produced by RES (usually a percentage of RES-E in the electricity mix) by fixing the amount of energy which needs to be provided by market participants. These instruments have an inherent uncertainty about the price. In practise, quantity-based instruments are mostly quota obligations.

Countries with quota systems place an obligation on the market participants (producers, suppliers or consumers of electricity) to fulfil a certain percentage of their produced, purchased or consumed energy with renewable energy. Usually, tradable green certificates (TGC) form a substantial part of the system, i.e. the promotion of RES-E takes place through a separate trading of TGCs which is working independently from the physical electricity market. In the original form, the general quota for one period is unalterable and it has to be fulfilled by every obligated party, so that the obligation level has to be chosen very carefully. The quota has to be sufficiently high to give the investors of RES-E technologies the necessary planning security and thus *stimulate* their expansion. The *target achievement*, however, is given in the quota obligation system per definition, otherwise penalties must be paid. On the other hand, if the quota is set too ambitiously the *dynamic efficiency* of the

[7] Weitzman, M. (1974).

system may decrease. The *static efficiency* depends on the issue of technology-neutral versus technology-specific support (see page 34).

While most quota systems have a technology neutral support, the **banded quota system** is an example for a technology-specific quota support system. In such a system, the number of certificates issued to an operator of a RES-E plant depends on the electricity generation technology. The number of certificates issued altogether depends on the technology of the different power stations. Hence, the government objective which prescribes a certain amount of certificates per MWh sold by a supplier cannot provide for a definite amount of RES-E but has to form an expectance of the future developments in order to determine the objective: How much capacity will be built additionally? Which technologies will be preferred by the investors given a certain banding? Only after having answered these questions, the authorities can conclude how many certificates they should budget per MWh.

Such an approach is afflicted with a lot of imponderabilities, especially in terms of the accuracy in achieving the RES-E target, which is supposed to be one of the strengths of a quota system. Notwithstanding, banding of technologies implies the advantages of a technology specific system, i.e. the promotion not just of technologies close to marketability, but also of promising technologies in the stage of development.[8]

Other modifications of the original quota system design which have been implemented in some countries, aim at reducing the investment risk which is higher in a quantity-based than in a price-based support system, as in the first one the certificate price and thus the producers' incomes are uncertain. One possibility to lower the investment risk is to restrict the amplitude of the TGC by the setting of **price limits.** An upper price limit can be set in order to avoid too great impacts of low quantities of certificates by imposing a penalty which has to be paid by committed market participants if they cannot present the requested TGCs at the end of a trading period. This penalty then simultaneously constitutes the upper limit for the TGC price. A lower price limit by contrast prevents the TGC price to drop under a certain level, however without approaching the underlying problem of too low a quota.

Banking and borrowing are further possibilities to increase planning security and reduce the volatility of TGC prices. Banking means that TGCs that are issued to

[8] For more details on the banding quota system, see the UK case study in the attachment, which also explains the buyout fund, which is a particular characteristic of the UK RES-E policy.

RES-E producers in one trading period can be carried forward to a later period and then be sold. If, for example, the quota set by a government or the respective penalty price is too low, so that producers of RES-E fall short of the necessary extra revenue from the TGCs because they are not able to sell them, banking gives the producers the opportunity to realize the revenue by selling the TGCs in a later period. If, in contrast, the quota is set too high to be fulfilled in one period, so that TGC prices increase to a high level, the possibility to trade TGCs from previous periods will alleviate the pressure on TGC prices.

Borrowing, by contrast, means that operators are allowed to sell TGCs that they have not generated yet but that they are up to generate in the subsequent period. However, borrowing currently does not appear in the existing European quota systems.

3.2.1.2 Price-based instruments

Price-based instruments set a fixed price or premium to stimulate the expansion of electricity produced from RES. The quantity of produced electricity is dependent on the (politically) set price or premium and therefore price-based instruments imply an uncertainty about the quantity-outcome.

Feed-in tariffs (FIT) are regulated tariffs granted by the government to the producers of domestic renewable electricity in form of a total price per energy unit (e.g. kWh) for a certain period of time. The motivation behind setting fixed prices for RES-E is ensuring a profitable operation to the producers. Usually, the system is combined with a priority access to the electricity grid and a guaranteed purchase of RES-E, which also gives additional security to investors.

If tariffs are high enough to provide investment certainty to producers, the FIT system has a very high *effectiveness* in terms of *stimulating* the RES-E expansion. But, on the other hand, if tariffs are set too high or too low, RES-E targets will be overfulfilled or missed. Too high tariffs for particular technologies may negatively affect the efficiency of RES-E deployment because relatively inefficient technologies overexpand. In reality, in many FIT systems tariffs are regularly amended, which may counteract an expected over- or underfulfillment of the targets. This **regular amendment** seems at first sight to be a factor that makes it more difficult for

investors to plan assuredly. However, governments might generate planning reliability by communicating their adjustment standards to the operators.
In general, the *static and dynamic efficiency* of the system depends on the particular design of the FIT system, in case of the static efficiency on the question whether support is technology-neutral or technology-specific.
Dynamic efficiency can be increased by the implementation of the regular **degression** which is subject to the date of commissioning and applies to all electricity generating installations put into operation after a certain point in time. Mostly, the degression in the initial tariffs applies on a yearly basis. The intention is to induce a technology development, thus under such a FIT system, the respective technology would not be profitable any more after several years without innovations and cost reductions.
On the other hand, some FIT systems include an **inflation adjustment of tariffs**. Obviously, adjusting also the tariffs for plants to be erected prospectively reduces the above mentioned pressure for the manufacturer to lower the costs of generation and therefore to innovate.
Another special design characteristic of some of the FIT systems linked to the issue of promotion costs is **the detailed tariff differentiation.** An instance of the differentiation in terms of location and generating conditions can be found in the German as well as in the French promotion system. In the latter, operator of wind turbines erected in 2007 receive the full tariff of 8.2 €ct/kWh only for the first ten years, whereas thereafter the remuneration is calculated subject to the full load hours realized in the first ten years. The distinction corresponding to generating conditions and technology details is a measure to reduce unnecessarily high payments to operators of “basic” plants on the one hand and to allow for the promotion of a variety of different technology mutations on the other hand. The distinction measures are therefore actually an attempt to implement perfect tariff discrimination in the FIT system by cutting down the producer surplus and, by doing so, to reduce the total funding volume.

Premiums, in contrast to feed-in tariffs, are paid to the producer on top of the conventional power market price. It is usually described as a variation of the FIT system but it implies a higher risk for investors because the produced electricity has to be merchandised on the conventional electricity market with the usual price risk.

The premium, which is paid on top of the market price, is meant to help to cover the production costs but in contrast to feed-in tariffs the overall income per unit is variable. The effectiveness of this instrument depends on the level of the premium. The static and dynamic efficiency are dependent on the specific design of the system. As in FIT systems, technology-specific premiums and a possible degression over time have effects on efficiency.
In order to limit the intrinsic uncertainties of a premium, some countries have implemented upper and lower limits of the total remuneration (sum of market price and premium) by designing a variable premium (for further details, see the case study of Spain in the attachment).

Fiscal incentives usually have the form of tax exemptions or tax reductions from certain taxes, e.g. carbon taxes. In countries where these taxes are very high the exemption can be sufficient to stimulate RES-E production. But in most cases the instrument is applied as a complement to other support schemes.

Beside the distinctions made until now, a further one is made between technology-specific and technology-neutral RES-E support. As already mentioned, this attribute can apply to both of the above mentioned types of instruments (quantity-based and price-based).

3.2.2 Technology-specific versus Technology-neutral instruments

Typically, **technology-specific instruments** are implemented to support infant technologies in order to generate experience effects, which lead to cost reductions On the other hand, technology-specific support is often justified by a value of a broader RES-E mix in the future. In reality, FIT systems usually have technology-specific tariffs, but they can be found in the other systems as well. Also, there are FIT systems that are technology-neutral (i.e. the Maltese one).

To have **technology-neutral instrument** means that every produced MWh RES-E has the same value. Therefore, systems which use this approach should lead to a *cost efficient* deployment, by deploying the cheapest and usually most mature technology at the best site. Quota systems often are technology-neutral but in many cases there have been implemented variations which allow a technology-specific support; they can have either bandings (sub-quota for individual technologies) or a different value for a MWh from a particular technology (e.g. one MWh from photovoltaics stations receives two certificates).

3.2.3 National versus harmonized support systems

RES-E support systems can further be distinguished with regard to their geographical scope. National support systems define feed-in-tariffs or quotas which are applied only within national borders. Generally, this implies that national targets have to be reached by using only the RES-E potential within national borders. In the case of harmonized RES-E support, a common quota or a common set of feed-in-tariffs is applied in the harmonized region. This leads to a RES-E deployment at locations where RES-E potential is most favorable.

PART II: Scenarios, Methodology and Input Parameters

The second part of the report deals with the methodological approach of the research project. In Chapter 4, the different scenarios of support schemes which were analyzed in the study, are described. Chapter 5 provides an overview of the two linear optimization models which were employed to analyze the effect of the different RES-E support schemes both on the RES-E deployment and on the conventional power market. Chapter 6 describes both conventional and renewable input parameters of the models.

4 Scenario definitions

In order to analyze the RES-E deployment under different promotion policies as well as the impact of a deeper RES-E penetration on the conventional power market, three main and two auxiliary scenarios have been modeled. In the Harmonized Quota system (HQS), a EU-wide, technology neutral RES-E quota is adopted. The Business-as-usual scenario (BAU) extrapolates current promotion policies until 2030. In the Cluster scenario, countries which currently have implemented a national quota system, form a quota cluster, while policies remains unchanged for countries which currently have implemented a feed-in-tariff system (respectively a tax incentive or bonus support system). In the following, the different scenarios are discussed in detail.

4.1 Main scenarios

This section is supposed to provide an overview on the main scenarios, which will be discussed in greater detail in the study results.

4.1.1 Harmonized Quota System (HQS)

In the HQS scenario, a EU-wide technology-neutral quota enables competition between the different RES-E technologies as well as competition between the different European regions. The technology-neutral support in HQS leads to a deployment of least cost technologies. The EU-wide quota ensures that RES-E capacities are built in countries with relatively high RES-E potentials and with hence relatively low generation costs, as national RES-E targets do not have to be fulfilled by each country on its own. The difference between national targets and the amount of RES-E generation within a country is ex-post aligned by importing or exporting TGC. These TGC streams are purely a matter of redistribution and do not have an influence on the deployment within the model.

4.1.2 Business-as-usual (BAU)

In BAU, the current promotion scheme of every modelled country is extrapolated. Figure 4-1 depicts how each of the 29 countries is modelled in BAU with regard to the support system. Especially, the technology-specific support has been integrated in great detail. For example the degression of the tariffs in a FIT system is calculated until 2030. The inflation adjustment has been integrated as well as the detailed tariff differentiation according to quality of sites and resources. In case a country implemented an option between a FIT and a premium system, the premium system has been implemented in the model, because its incentives usually are more beneficial than the fixed FIT option. Since electricity from PV can also be directly consumed without feeding into a grid e.g. in a household (grid parity), the endconsumer price (wholesale power price plus additional costs such as grid costs) can become the relevant remuneration in case the feed in tariff becomes smaller than the endconsumer price and of course if it is sufficient to cover PV RES-E generation costs.

The quota systems have been implemented mainly in their pure form. Upper price limits of the particular countries have been integrated. Since the optimization model receives the RES potential exogenous without annual fluctuations, it works basically as if banking and borrowing (which in reality provide a risk reduction against the natural volatility of some RES) were integrated. Due to the above explained uncertainty about the specific quota in the case of a banded quota system, the UK quota system is implemented without technology specific RES-E values but as a technology neutral quota system. Italy has been modelled as a premium system, since the quota is only applicable for a relatively small share of the overall RES-E target. In addition, through a conversion mechanism the TGC price is more or less fixed, which basically acts as a premium. Smaller installations in Italy are remunerated by a FIT system.

Figure 4-1: Modelling of country specific promotion policies in BAU scenario

Country	Promotion System			Characteristics of fixed-price-regulations				Comments
	FIT	Premium	Quota	Promotion Period in years	Compulsory annual changes in tariffs for new plants	Discretionary changes in tariffs for new plants	Compulsory adjustment of tariffs for existing plants to inflation	
Austria	x			12	x			Annual revision of tariffs. Year-by-year reduction for new plants regulated by law, but no instruction about size of cutback is given.
Belgium			x					
Bulgaria	x			12				
Cyprus	x			15				
Czech Republic	x			15		x	x	Regular revision of tariffs, but there is no special requirement.
Denmark		x		20; Exception: Offshore Wind (42,000 full load hours)				
Estonia		x		12				
Finland		x		no limit				The Finnish promote RES-E with excise duties. These work just like a premium.
France	x			20; Exception (15 years): biomass, onshore wind, geothermal	x		x	Both for new plants as for existing ones there is a legally fixed adjustment. Tariffs for new plants are fully adjusted to inflation (except for wind), tariffs for existing plants only partially.
Germany	x			20	x			Tariffs for new plants are reduced annually by the inflation index.
Greece	x			20			x	Annual revision of tariffs: either adjustment to the change of PPCs approved bills or adjustment to inflation index.
Hungary	x			no limit		x		
Ireland	x			15	x		x	Annual adjustment according to inflation. However, it is up to the individual suppliers and generators to transpose this adjustment and incorporate in into their Powert Purchase Agreements.
Italy		x		15 years for alle technologies except for photovoltaics; 20 years for photovoltaic installations				FIT is available only for all photovoltaic installations with a 20-year-price-guarantee and for all other technologies up to 200 kW for 15 years.
Latvia	x			10	x			Tariffs are adjusted according to a formula including the trade final tariff for natural gas.
Lithuania	x			20				

Country	Promotion System			Characteristics of fixed-price-regulations				Comments
	FIT	Premium	Quota	Promotion Period in years	Compulsory annual changes in tariffs for new plants	Discretionary changes in tariffs for new plants	Compulsory adjustment of tariffs for existing plants to inflation	
Luxemburg	x			15	x			Legally implemented annual degression of tariffs for new plants.
Malta	x			no limit				
Netherlands	x			15 years for wind and photovoltaics; 12 years for biomass				
Poland			x					
Portugal	x			12-25				
Romania			x					
Slovak Republic	x			12		x	x	Tariffs for existing plants are usually adjusted according to inflation index. Tariffs für new plants are revised annually.
Slovenia		x		10				
Spain		x		20 years for wind, geothermal and ocean energy; 25 years for hydro, photovoltaics and solarthermal energy; 15 years for biomass				
Sweden			x					
United Kingdom			x					
Norway								no promotion policy
Switzerland	x			20 years for biomass, wind onshore and geothermal; 25 years for hydro and photovoltaics	x			According to technology annual reduction of tariffs by 0,5% - 8%

4.1.3 Cluster

In the Cluster-scenario countries which currently have a quota system (namely Belgium, Poland, Romania, Sweden, United Kingdom) form a cluster. This implies – as in HQS – that these countries do not longer have to fulfil their national targets on their own. Instead, RES-E is generated in the cluster countries with lowest generation costs. Countries which currently support RES-E by feed-in-tariffs, bonus systems or tax incentives, are modelled as in BAU.

4.2 Auxiliary scenarios

The purpose of the following two scenarios is to ensure comparability of key figures between the different main scenarios.

4.2.1 National Quota System

This scenario was implemented in order to calculate harmonization gains, which arise when countries do not necessarily have to fulfill their targets on their own but are allowed to trade TGCs. In order to separate this effect, the HQS can be compared with the National Quota System, which has been designed by the requirement to fulfill the national targets within the national borders. Under both systems, promotion schemes in every country rely on technology-neutral quotas. Thus, differences observed between the two scenarios can be attributed to the possibility of TGC trade existing only in HQS.

4.2.2 Harmonized Quota System with RES-E-targets as resulting in BAU-scenario

This scenarios´ purpose is to ensure comparability of support and investment costs between BAU and an appropriately modified HQS scenario.

As under BAU scenario most countries have a price-based support system, the amount of RES-E capacities constructed is not the same as under HQS scenario where RES-E support is quantity based in all countries. For this reason, a modified HQS was computed, taking as quota obligation the amount of RES-E achieved in the BAU scenario.

5 Methodology

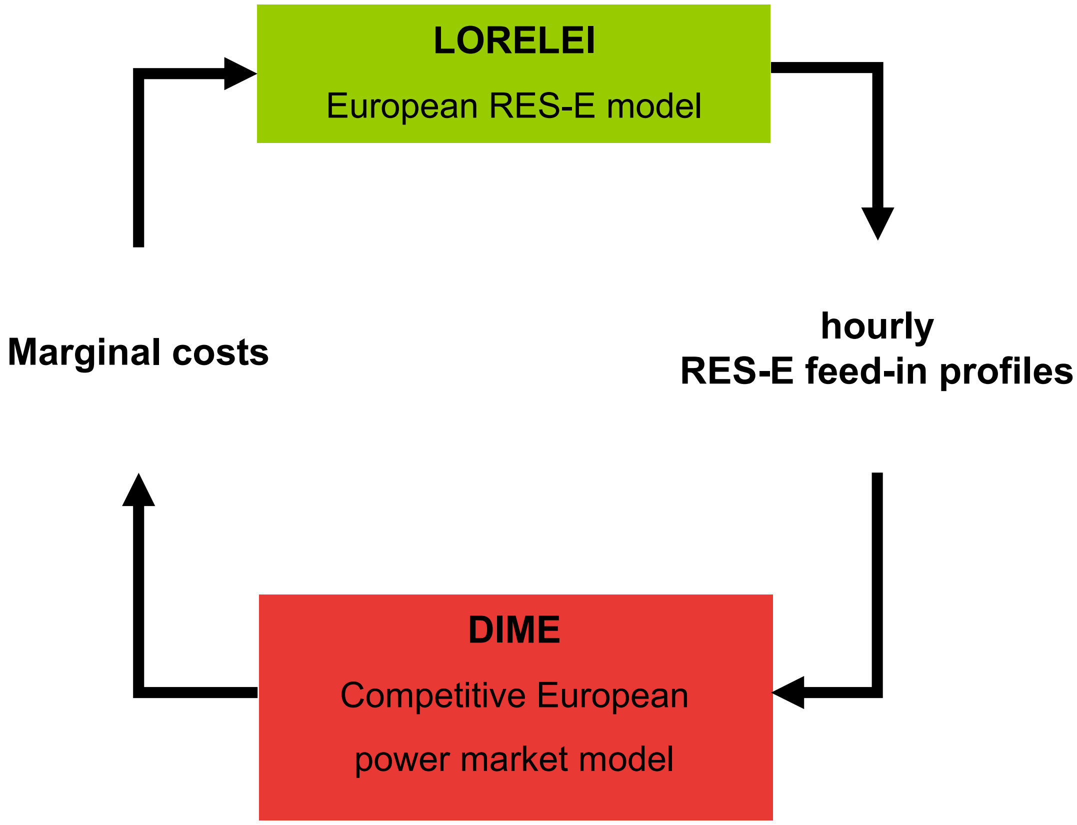
In order to optimize not only the RES-E deployment in all 29 countries (under the different scenarios), but to take also into account the interdependence with the conventional power system in every country, an iteration process of two models has been implemented.[9]

The "Linear Optimization Model for Renewable Electricity Integration in Europe" (LORELEI) calculates the optimal RES-E deployment in every country. Hourly RES-E feed-in profiles which result from LORELEI calculations are an exogenous parameter in the conventional "Dispatch and Investment Model for Europe" (DIME). This approach simulates the preferential infeed obligation which is generally applied in FIT systems. DIME calculates the cost-efficient deployment of the conventional power system, needed to meet the residual demand in every country. The cost-minimizing process includes the decision which amount of energy is imported or exported by a country. The national power prices which can be deduced from the DIME calculations are in turn important input parameters for the LORELEI model since the national price level influences deployment of RES-E capacity.

This interdependence between LORELEI and DIME is illustrated in Figure 5-1.

[9] For more details on the LORELEI-model see WISSEN (forthcoming). A more detailed description of the DIME-model can be found in the attachment.

Figure 5-1: Interdependence between LORELEI and DIME



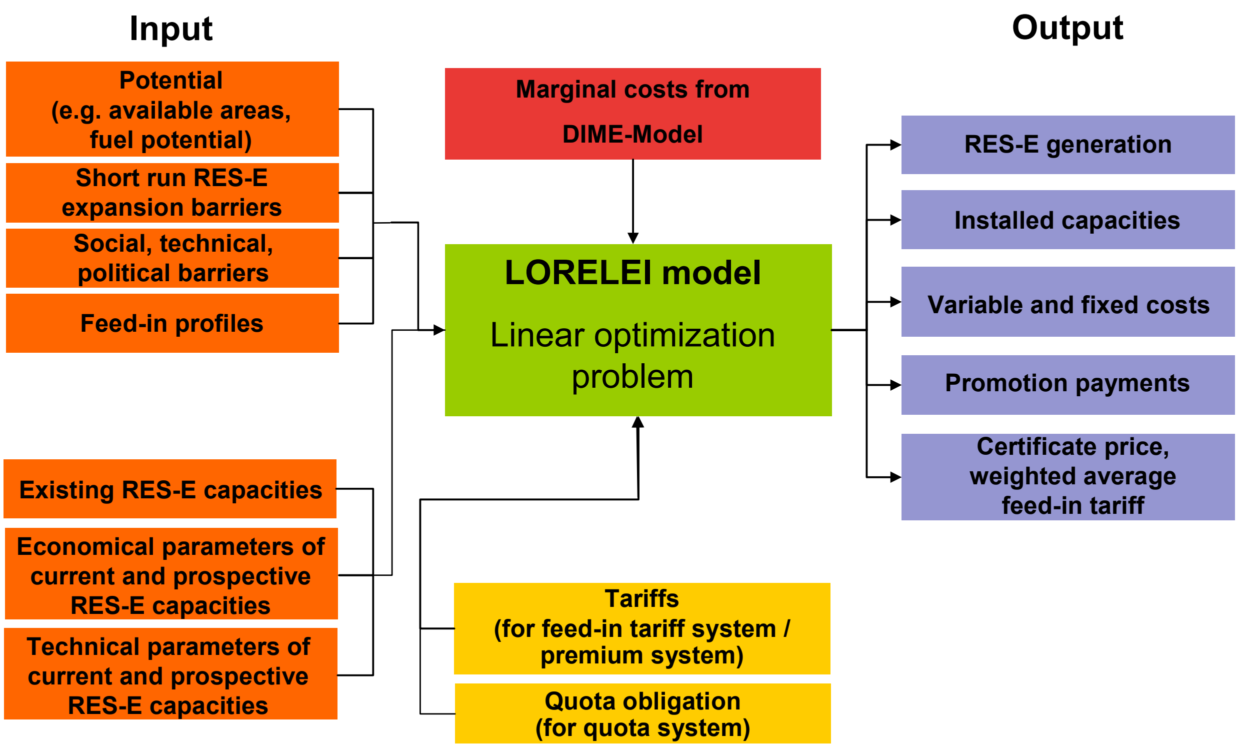
Source: EWI.

5.1 LORELEI

Figure 5-2 illustrates the optimization process within LORELEI. Important input parameters concern the RES-E potential in every country (see chapter 5), current and prospective RES-E generation costs and the amount and structure of already existing RES-E capacities within each country. In addition, current and prospective technical parameters of RES-E technologies (i.e. electric efficiencies) are input parameters for the optimization process. Furthermore the optimal RES-E deployment depends on the particular scenario (see Chapter 3). Under the quota system, capacities of a specific RES-E technology are constructed as long as the sum of marginal generation costs (calculated in DIME) and certificate price (determined within LORELEI as a result of the quota obligation and the marginal costs of the most expensive RES-E technology needed to fulfil the quota) exceed the generation costs of this specific RES-E technology.

Under the feed-in-tariff system, the investment decision for RES-E capacities is based on the difference between generation costs of a specific technology in a specific country and the feed-in-tariff for this technology within this country. In addition, spot prices can also be decisive for investments under a feed-in-tariff system in the case they exceed both, the generation costs and the feed-in-tariff. This is more likely to happen in the long run under feed-in-tariff systems with substantial degression rates, when in addition generation costs sink due to learning curve effects.

Figure 5-2: LORELEI Model



Source: EWI.

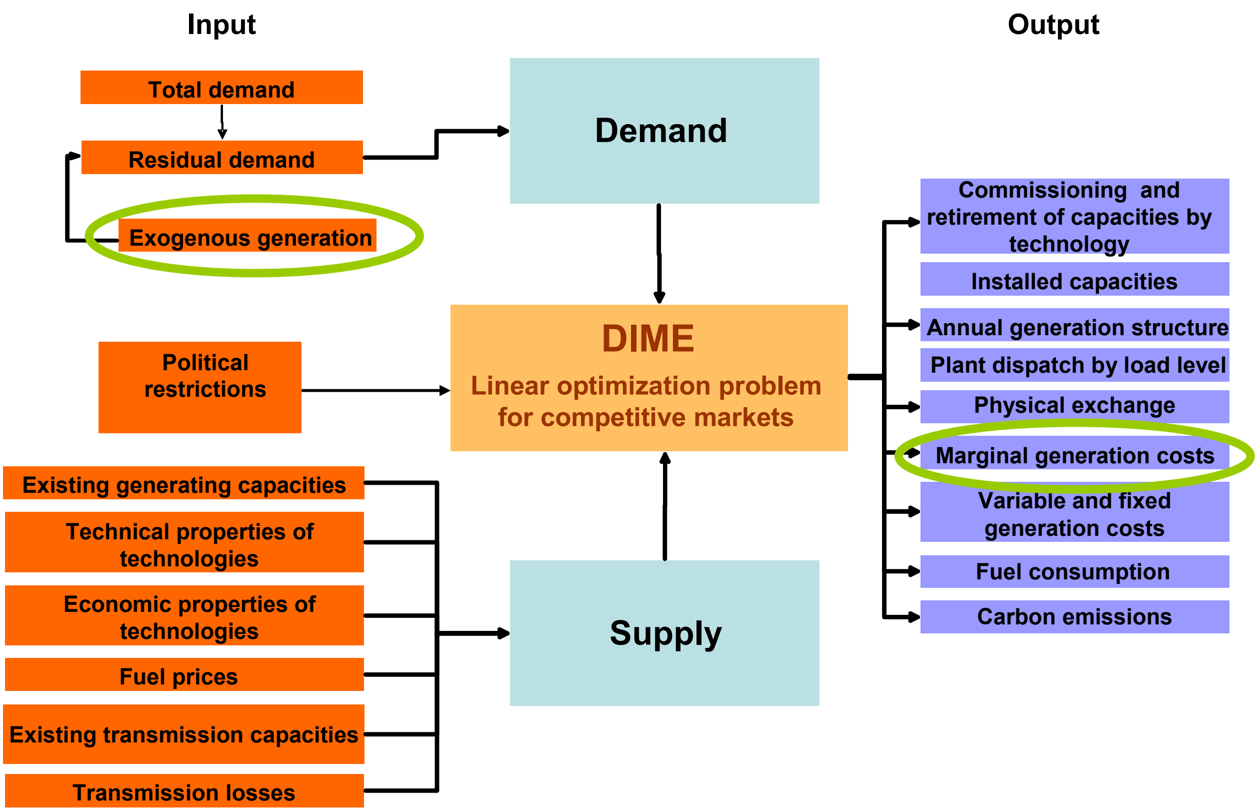
LORELEI outputs are the RES-E capacities built in every country, as well as the corresponding generation. Total variable and fixed costs of RES-E technologies also result from LORELEI calculations. Moreover, as already mentioned, the certificate price is computed in LORELEI. Consequently, the amount of promotion payments in every country under every scenario can also be derived from LORELEI outputs.

5.2 DIME

DIME is a linear optimization model for the conventional European electricity market. It is applied to simulate dispatch as well as investment decisions regarding the supply side of the electricity sector. The objective function minimizes total discounted costs based on the assumption of a competitive generation market.

Figure 5-3 depicts schematically the optimization process of DIME. Input parameters can be divided into three major groups: demand side parameters, supply side parameters and political parameters.
The demand which has to be met by conventional generation is the residual demand, which is determined by subducting the exogenous generation from total demand.

Figure 5-3: DIME Model



Source: EWI.

For this purpose first of all the RES-E generation computed in LORELEI is deducted. In addition, the generation from following other technologies is treated exogenously in DIME and thus deducted from total demand: large run-of-river, waste, large CHP technologies outside Germany and small-scale CHP technologies (see Table C-1 in the annex).

Regarding the supply side, important input parameters concern the costs of generation (investment costs, O&M costs, fuel prices – see Chapter 6 for the respective assumptions), technical parameters of conventional generation technologies and the amount of conventional capacities already existing within a country. The NTC values are another input parameter for the model, as they define the amount of domestic demand which has to be met by domestic conventional power generation respectively the amount of conventional power capacities which can be built in countries with relatively low generation costs and exported to countries with relatively high generation costs. Political input parameters include for example decisions on nuclear policy.

As an output of the cost-minimizing process, the structure of generation and capacities is identified for every country. Beside other outputs which are specified in Figure 5-3, the crucial output for the iteration process is the resulting level of marginal generation costs in every country.[10] These marginal generation costs are interpreted as spot prices and – as described above – are taken as input parameter for LORELEI calculations.

[10] Please note that here marginal generation costs also include capacity costs in peak hours and can therefore be interpreted as long-run marginal costs.

6 Input Parameters

The following chapter provides a description of assumptions concerning the costs of conventional power plants (fuel prices and investment costs) and the development of power demand. Furthermore it provides inputs concerning nuclear policy and NTC values. The second part of the chapter describes the RES-E input parameters in more detail.

6.1 Conventional Input Parameters

6.1.1 Fuel and CO_2 Prices

Fuel price assumptions are depicted in Table 6-1. Short term assumptions are based on futures, which are trades on exchanges. While world market prices have been on exceptionally high levels in 2008, prices are currently on a downtrend due to the current global economic situation and by assumption will rejoin their long term trend in the medium term.

6.1.1.1 Nuclear

Uranium prices increased during the last years as new nuclear plants were built world wide, mainly in Asia and Eastern Europe. Further nuclear plants are still under construction and will contribute to an ongoing rise in uranium demand. On the other hand, higher uranium prices motivate further investments in the exploration of new mines. Taken all effects into account, prices are assumed to decrease slightly from 2020 onwards.

6.1.1.2 Lignite

Since energy production from lignite is only profitable at plants situated next to the mines and since lignite is thus hardly traded, a world market price for lignite does not exist. Lignite prices are therefore assumed to remain at the current level.

6.1.1.3 Coal

Global coal consumption grew at a high pace since 2000. In 2008 world market prices for coal reached an exceptional high level due to a steep increase of demand, due to unforeseeable events as flooded mines in Australia and the export stop from China (caused by coal scarcity in the country itself) and finally due to a rise in supply costs (increase in the cost of materials, diesel, labour and shipping). Currently, prices are on a downtrend. The price assumption for 2010 is based on future contracts, plus a supplement for transportation costs. In the long term, coal prices are expected to rise only at a moderate pace. Global coal consumption will continue to grow, but at a slower pace. In addition, global coal supply is also expected to rise. IEA (2008) expects no capacity constraints until 2030. Known remaining reserves are assumed to be more than adequate to meet the demand growth until 2030. Still, coal prices are expected to follow a long term uptrend as the lowest-cost reserves are depleting (causing higher supply costs and/or higher transport costs due to longer transport distances), and as costs of materials, diesel, labour and shipping will also rise in the long term.

6.1.1.4 Gas

While the gas price is currently closely linked to the oil price, in the future gas prices will be less influenced by oil price movements as an increasing share of gas is going to be used in electricity generation, leading to a loosening in the close substitutional relationship of gas and oil. Furthermore, the gas market will become more competitive in the long term due to the ongoing liberalization of the gas market and due to an increase in supplies of liquefied gas.

6.1.1.5 Oil

In 2008, the oil market has been characterized by price levels largely exceeding long term price trends. As in the coal market, prices for oil are currently on a downtrend, assumed to rise again in the short term when worldwide economic situation will recover (for 2010 the oil price is assumed to be 71 $/barrel). In the long term oil prices are expected to increase at a pace according to a scenario in between IEA oil price projections of 2007 and of 2008 – taken into account, that the 2008 projection has been largely influenced by the temporarily sharply escalating prices in 2008.

Thus, a price-path slightly above the average between the two IEA projections is assumed: Input oil prices reach 87 $/barrel in 2020 and 104 $/barrel in 2030.

6.1.1.6 CO_2 Prices

EU Emission Allowances are currently traded at prices of about 10 Euros per tonne CO_2. Future prices are indicating that market prices will increase in the short and medium term. In the medium as well as in the long term, CO_2 prices are assumed to increase due to the reduced amount of CO_2 certificates which is expected to be allocated in future periods.

Table 6-1: Fuel and CO_2 – Price Assumptions

Year	Nuclear	Lignite (€2007/MWh_{th})	Coal	Gas	CO_2 [€/t]
2015	3.5	4.5	10.5	22.2	20
2020	3.3	4.5	11.1	24.2	25
2030	3.3	4.5	11.9	29.4	35

Source: EWI.

6.1.2 Power Plant Investment Costs

Power plant investment costs were determined by an analysis of investment costs of lately completed power plants, of power plants being in the process of construction and of planned power plants. EWI assumes that investment costs until 2015 remain at the current level. Afterwards, coal plant investment costs are expected to decrease, as current cost levels are strongly influenced by a temporary capacity shortage.[11]

[11] Carbon capture and storage (CCS) has not been considered in this study. Depending on cost assumptions, e.g. invest costs, coal and CO2 prices, as well as conversion efficiency losses, the share of coal-based generation could increase within the conventional power market. Usually, CCS deployment is assumed at higher CO2 prices than used in this study.

Table 6-2: Conventional Power Plant inputs

	Available Year	Investment Costs [€/kW]	Lifetime Years	Net Efficiency [%]
Nuclear	after 2010	2,200	40	33,0%
Lignite	before 2015	1,500	40	39,4%
Lignite	after 2015	1,350	40	43,0%
Coal	before 2015	1,350	40	46,0%
Coal	after 2015	1,200	40	50,0%
CCGT	before 2015	550	30	58,0%
CCGT	after 2015	550	30	61,0%
OCGT	before 2015	350	25	35,0%
OCGT	after 2015	350	25	40,0%
Oil	after 2010	450	25	40,0%

Source: EWI.

6.1.3 Electricity Demand

The underlying demand assumption of this study is based on a study from DG-Env (2008), which models the EU Policy Package and also takes the energy efficiency targets into account. Table 6-3 depicts the demand levels resulting in the DG-Env study until 2020 under consideration of the EU climate targets. Since these targets are only defined until 2020 and thus not taken into account into the calculations for the period beyond 2020, the DG-Env demand levels increase dramatically after 2020. Therefore, for this study it is assumed that demand stays at the DG-Env 2020-level until 2030. Even though targets beyond 2020 are not yet defined, it is unlikely that there will be no target setting in the long-term. In addition, especially in the long-term, electricity demand is influenced by opposing effects which in sum justify the assumption of a stagnating power demand: While in the past, economic growth was coupled to increasing power demand, energy efficiency due to technical development has lead to a partial decoupling of power demand and productivity growth. In addition, the catch-up effects of Eastern European countries which cause high growth rates in the short-term, will have a smaller influence in the longer run. On the other hand, additional demand on the electricity sector could be placed by energy demand from other sectors (e.g. heat and transport).

Table 6-3: Gross Electricity Consumption of all EU Member States (TWh)

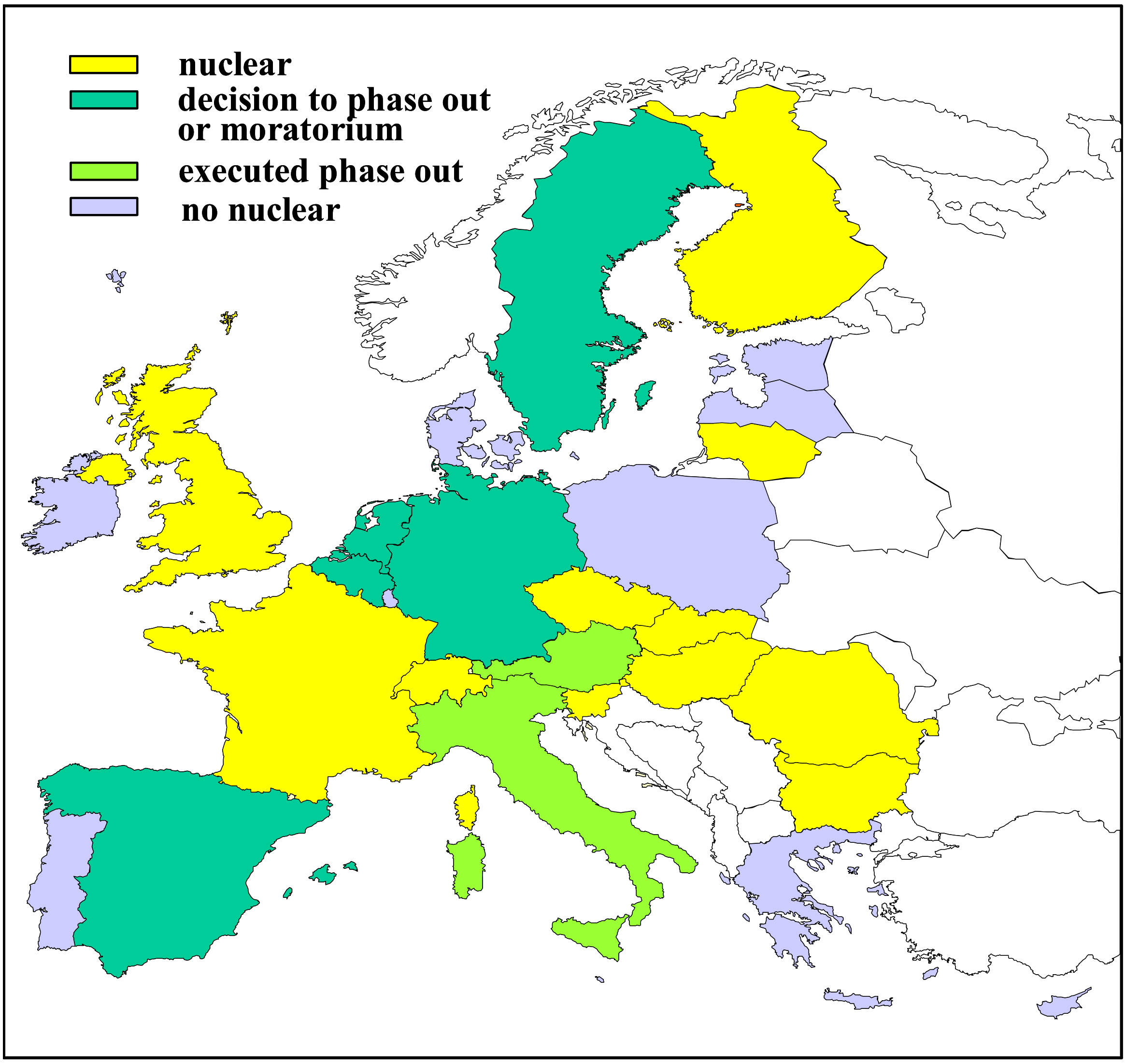
Country	2005	2015	2020	2030
Austria	66	71	77	77
Belgium	92	101	110	110
Bulgaria	36	34	38	38
Cyprus	4	5	5	5
Czech Republic	69	73	105	105
Denmark	38	34	35	35
Estonia	9	11	12	12
Finland	88	98	106	106
France	510	541	573	573
Germany	608	609	632	632
United Kingdom	406	391	410	410
Greece	63	67	70	70
Hungary	42	47	49	49
Ireland	27	31	34	34
Italy	346	389	420	420
Latvia	7	10	12	12
Lithuania	11	14	16	16
Luxembourg	7	7	8	8
Malta	2	2	2	2
Netherlands	118	130	129	129
Norway	124	131	133	133
Poland	144	161	176	176
Portugal	53	66	71	71
Romania	56	68	77	77
Slovakia	28	34	39	39
Slovenia	15	17	19	19
Spain	289	339	362	362
Sweden	151	163	162	162
Switzerland	62	64	65	65
EU27	3,287	3,512	3,745	3,745
EU27++	3,472	3,707	3,944	3,944

Source: EWI, based on DG-Env (2008).

6.1.4 Nuclear Policy

The nuclear policy of the EU is under the responsibility of the individual MS. Due to the different risk perception of nuclear accidents or the ultimate waste disposal, MS decided differently about their nuclear policy. While some MS value the advantage of relatively cheap base load electricity generation, others took consequences from e.g. the Chernobyl incident and decided to phase-out of the nuclear based electricity generation. Figure 6-1 provides an overview of the individual MS nuclear policy.

Figure 6-1: EU Nuclear Policy



Source: EWI.

A group of countries communicated a possible shift towards a nuclear renaissance. Within this group, some have not enacted these plans yet and therefore are not implemented in this study.[12] However, since the nuclear policy in these countries prohibit new constructions, some MS decided on a lifetime extension of existing plants. Therefore, nuclear power plants in Spain and Sweden receive a lifetime

[12] The recently elected German Government announced to step back from the phase out decision under consideration of safety standards and special arrangements regarding the absorption of producer rents.

extension to 50 years and in the Netherlands to 60 years. The extension requires investments of 500 €/kW according to EWI/Prognos (2007) in order to fulfill the required safety standards. Other MS, such as Italy and Poland announced plans to erect new nuclear power plants and have laid the legal basis for this step. Therefore, these countries have no nuclear policy constraints in this study.

6.1.5 Cross border transmission capacities

As the focus of this study is not a grid analysis including endogenous grid constructions, existing and planned cross border transmission capacities have been taken into account corresponding to their net transfer capacities (NTC). The NTC used in this study are mainly based on the ETSOVista data platform[13] and on UCTE[14] publications for future grid development. Table 6-4 provides an overview of the development of cumulated net import and export capacities. In case of future projects, which are published without a corresponding NTC value but a flux voltage, the capacity cannot be assessed since the intermeshing of the grid leads to loop-flows.

[13] See etsovista.org.
[14] See ucte.org, e.g. UCTE Transmission Development Plan 2008.

Table 6-4: Overview of Import and Export NTC in MW (Summer)

Country	Direction	2008	2010	2020	2030
Austria	import	5,620	6,220	6,391	6,391
	export	4,900	5,500	5,696	5,696
Belgium	import	5,100	5,400	5,659	6,659
	export	3,600	4,050	4,272	5,272
Bulgaria	import	1,300	1,300	1,300	1,300
	export	1,550	1,550	1,550	1,550
Cyprus	import	0	0	0	0
	export	0	0	0	0
Czech Republic	import	4,350	4,350	4,506	4,506
	export	6,550	6,550	6,738	6,738
Denmark-East	import	1,900	2,500	2,500	2,500
	export	2,300	2,900	2,900	2,900
Denmark-West	import	2,630	3,230	3,273	3,273
	export	3,190	3,790	4,539	4,539
Estonia	import	2,100	2,100	2,800	2,800
	export	2,100	2,100	2,800	2,800
Finland	import	3,650	3,650	5,150	5,150
	export	1,950	1,950	2,650	2,650
France	import	8,270	10,420	12,641	15,331
	export	13,800	15,300	17,511	19,911
Germany	import	18,960	19,300	22,276	22,276
	export	13,710	14,050	16,852	16,852
United Kingdom	import	2,080	3,400	3,502	5,502
	export	2,410	3,730	3,832	5,832
Greece	import	1,450	1,450	1,450	1,450
	export	1,550	1,550	1,550	1,550
Hungary	import	5,400	5,400	5,420	5,420
	export	3,200	3,200	3,200	3,200
Ireland	import	410	410	410	410
	export	80	80	80	80
Italy	import	6,590	7,440	9,679	9,679
	export	2,700	3,700	5,954	5,954
Latvia	import	2,250	2,250	2,250	2,250
	export	2,200	2,200	2,200	2,200
Lithuania	import	2,980	2,980	4,730	4,730
	export	3,980	3,980	5,730	5,730
Luxembourg	import	860	860	860	860
	export	860	860	860	860
Malta	import	0	0	0	0
	export	0	0	0	0
Netherlands	import	6,700	8,020	9,829	9,829
	export	6,500	7,820	9,604	9,604
Norway	import	3,350	3,350	4,650	4,650
	export	3,900	3,900	4,600	4,600
Poland	import	2,700	3,040	4,132	4,132
	export	3,300	3,640	4,807	4,807
Portugal	import	1,100	1,200	2,800	2,800
	export	1,200	1,300	3,000	3,000
Romania	import	2,250	2,250	2,410	2,410
	export	1,950	1,950	2,110	2,110
Slovakia	import	3,450	3,450	3,539	3,539
	export	4,050	4,050	4,050	4,050
Slovenia	import	1,670	1,670	1,730	1,730
	export	2,430	2,430	2,430	2,430
Spain	import	2,400	3,700	5,466	6,866
	export	1,600	3,400	5,110	6,800
Sweden	import	6,940	6,940	7,770	7,770
	export	6,880	6,880	8,430	8,430
Switzerland	import	6,840	7,240	7,589	7,589
	export	9,960	10,210	10,755	10,755

Source: EtsoVista, UCTE, EWI.

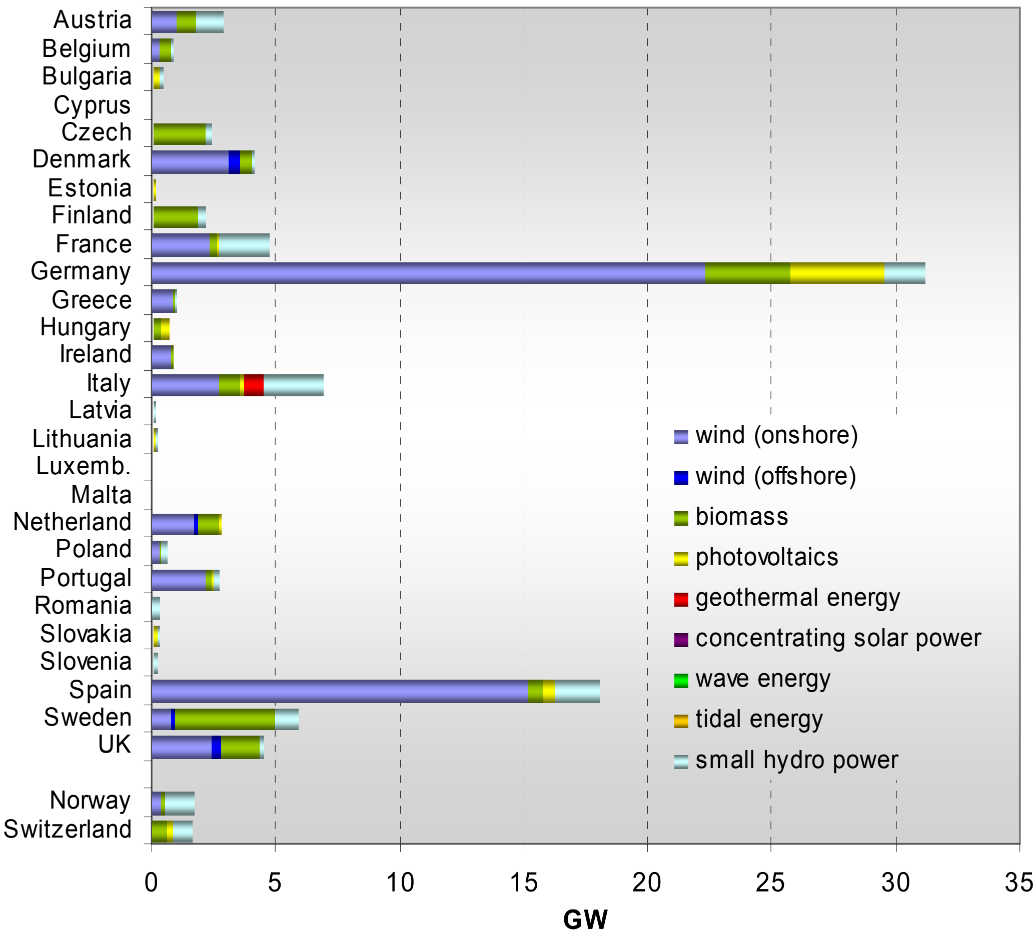
6.2 Renewable Energy Input Parameters

The research of RES-E potentials and costs has been an important part of the study. In this chapter, the determination of RES-E input parameters is described for each technology (wind on- & offshore, biomass, photovoltaics, concentrating solar power, geothermal energy, tidal and wave energy, small hydro power). In Section 6.2.1, the Status Quo with regard to installed RES-E capacities and their technical lifetimes is presented. Section 6.2.2 provides a description of the potential and cost analysis of each RES-E technology. Section 6.2.3 gives an overview of the RES-E potential for each technology in each of the EU27++ countries and of the RES-E generation costs for all technologies in 2010, 2020 and 2030, which result from the analysis.

6.2.1 Status Quo of RES-E Capacities

In Figure 6-2 the installed capacities in the EU27++ countries in 2007 can be seen. It is striking that in Germany and Spain the most capacities have been built especially in terms of wind onshore and photovoltaics capacities.

Figure 6-2: Installed RES-E capacities in EU27++ countries in 2007

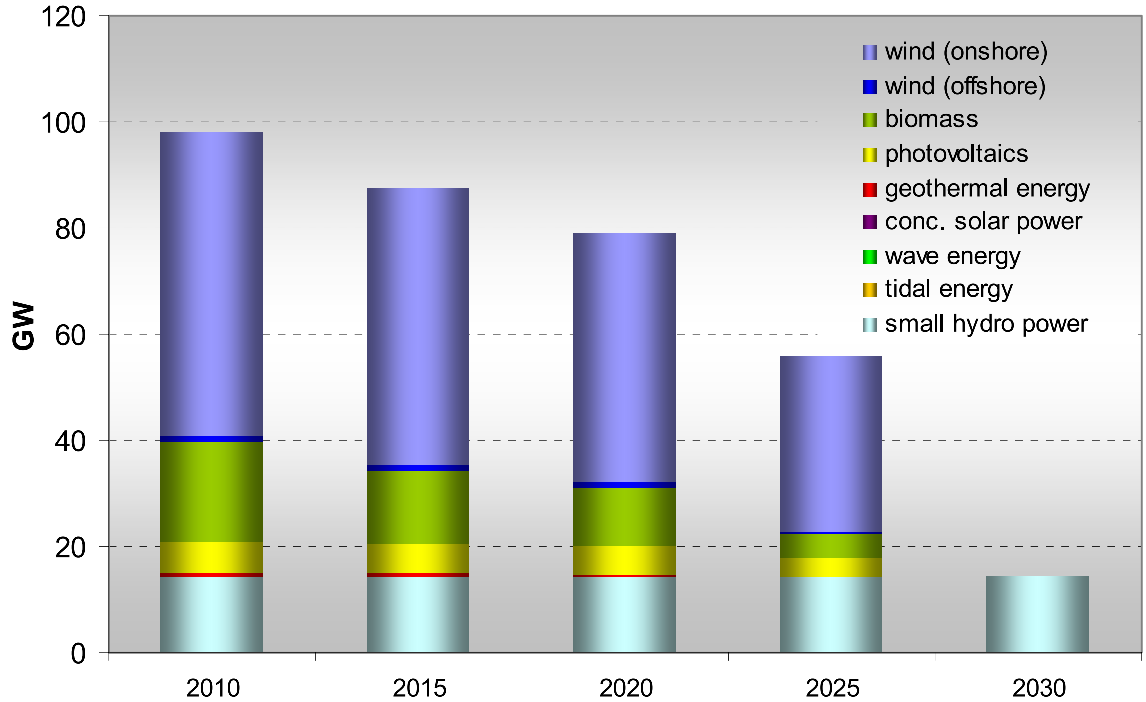


Source: EWI based on statistics.

While in some countries a significant amount of renewable capacities has been installed in others the expansion has been marginal. Apart from some exceptions such as Belgium or the Czech Republic this applies especially to the new member countries.

When adding the technical lifetime of each technology the development in technical terms of current installed capacities in EU27++ can be deducted. Except for small hydro energy and concentrating solar energy which have technical lifetimes of 35 and 25 years respectively, the technical lifetime of renewable energy technologies is fixed at 20 years. In Figure 6-3 it can be observed that current installed capacities will be reduced modestly until 2020 and nearly completely until 2030. Only small hydro power will not be depleted. Existing small hydro power plants can be repowered at comparably beneficial costs, so that additional support is not necessary.

Figure 6-3: Development of current renewable capacities in EU27++ countries



Source: EWI based on statistics.

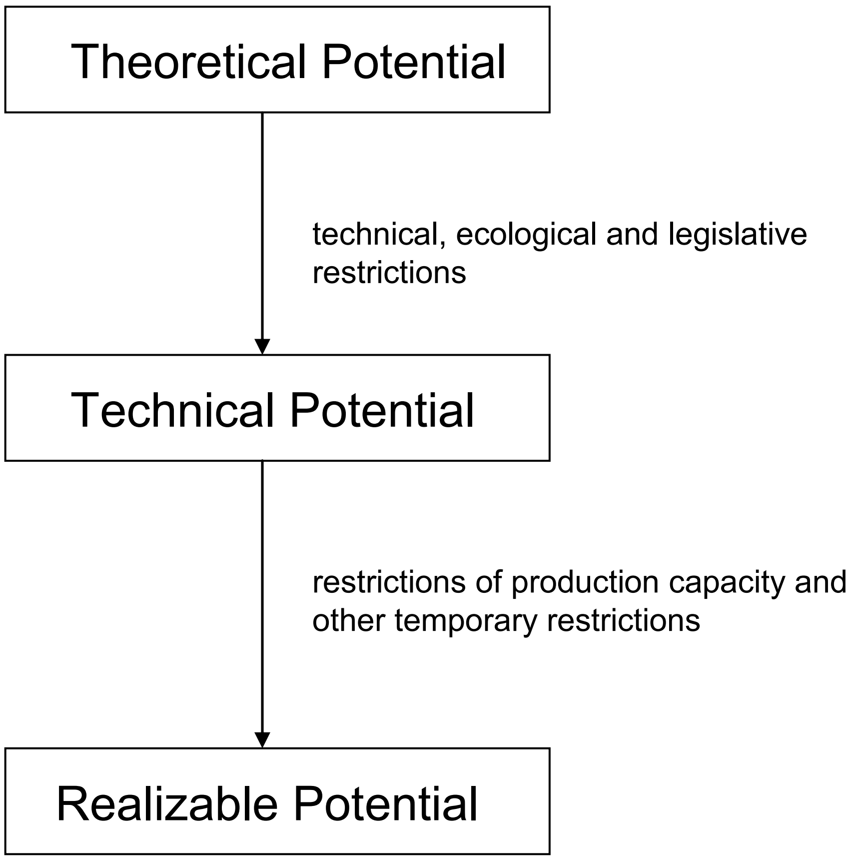
6.2.2 Technology specific analysis of potential and costs of RES-E

In this section, the specific input parameters of each RES-E technology are explained. These parameters include the potential, investment costs and operating and maintenance (O&M) costs and the full load hours of each technology. Before discussing the parameters for each technology, steps in the assessment approach which are common to all technologies will be explained.

Potential

The concept of potential applied in this study, corresponds to the realizable potential which differs considerably from other existing notions of potential, i.e. from the theoretical and technical potential shown in Figure 6-4.

Figure 6-4: Different concept of RES-E potential



Source: EWI, based on Kaltschmitt/Streicher/Wiese (2006).

The theoretical potential corresponds to the *physically* useable amount of energy supply at a given point or period of time and for a given region (i.e. the sun irradiation on the earth within one year). Due to technical, ecological, structural and administrative barriers, only a small part of the theoretical potential can actually be used for electricity generation. The technical potential characterizes the part of the theoretical potential, which is usable under the consideration of technical, ecological and legislative restrictions while the realizable potential takes further into account restrictions of production capacity and other restrictions which form short to medium-term barriers to RES-E deployment.

Investment and O&M costs

For every technology current (2007) investment costs[15] as well as operating and maintenance (O&M) costs are identified. While investment costs are allocated over the whole depreciation period, O&M costs fall due every year. The cost fraction of unskilled labor is adjusted across countries according to a wage index[16]. Thereby wage dissimilarities are supposed to decline over time. However, a complete alignment will not be achieved as labor is not completely mobile. In contrast, the non-labor intensive cost share is assumed to be equal across countries. Hence, apart of wage dissimilarities differences in electricity generation costs across countries are primarily caused by different full load hours and varying site qualities respectively. In case of biomass electricity generation costs are further influenced by fuel prices and heat bonuses.

Future cost developments are for the most part calculated by using the experience curve concept.[17] In this model the experience curve of type 1 has been used which means that cost reductions are attributed only to investment cost reductions and thus are expressed in €/kW. With increasing cumulative installed capacity investment costs are reduced by learning effects. It is assumed that the learning process takes place essentially at a global level, i.e. future global expansion has to be considered. Nevertheless, increases in technological efficiency have been taken into account either by including separate technology types or by allowing directly for increases in efficiency.

The cost reduction of less mature technologies such as photovoltaics, concentrating solar power,[18] tidal and wave power plants is significantly higher than for already experienced technologies.

[15] Note that costs in this study are prices for the particular technology. Real costs would eliminate the margins within the value chain. These margins could be lower if companies order very high volumes of a particular technology. Therefore, it is possible that the prices assumed in this study differ from the prices some companies can realize at the market. Eliminating the margins of the value chain is unfortunately not possible due to the lack of information.

[16] Eurostat (2008).

[17] IEA (2000).

[18] In case of concentrating solar power the cost reduction is largely caused by economies of scale effects due to a bigger plant size.

Amortization

The discount rate is set at 8.5% p.a. The deprecation period for the renewable energy technology classes but small hydro power amounts to 15 years. Due to its higher technical lifetime small hydropower is depreciated over a longer period of 25 years.

Specific parameters of the renewable energy technologies

In the following, parameters specific to each technology are explained. To this belong amongst others the differentiation of the technology classes in several subtechnologies, the differentiation of different subregions as well as the way potential and costs have been determined.

6.2.2.1 Wind Onshore

First of all, 57 subregions are distinguished to allow for a very detailed examination taking into account the different local conditions for wind energy in these regions (see Figure 6-5). The subdivision of the different European countries into subregions is done by ensuring that within one subregion wind conditions are approximately the same.

Figure 6-5: Subregions for Wind Onshore in Europe

Source: Eurowind.

For onshore wind turbines, there is made a distinction between seven subtechnologies differing in capacity size, hub height, rotor circular surface and area required by a single wind turbine.

Table 6-5: Subtechnologies of wind onshore

Subtechnology	Feasibility	Capacitiy [MW]	Hub Height [m]	Rotor Circular Surface [m^2]	Area required by a single Wind Turbine [km^2]
windtech_1	2007	0.3	42	804	0.026
windtech_2	2007	0.85	66	2,042	0.065
windtech_3	2007	1.60	84	4,299	0.137
windtech_4	2007	3.05	88	6,359	0.203
windtech_5	2007	4.50	111	9,847	0.314
windtech_6	2011	6.00	124	10,202	0.325
windtech_7	2016	8.00	140	13,267	0.423

Source: EuroWind, EWI.

As shown in Table 6-5 the wind turbine technologies have different time horizons for their feasibility. The smaller five categories (windtech_1 to windtech_5) already exist and represent typical classes of wind turbines installed in Europe.[19] The last two categories (windtech_6 and windtech_7) are expected to be developed until 2015 and 2020 respectively.

Wind onshore potential

To calculate the potential of onshore wind energy within the subregions as applied in this study the following steps are made: The suitable areas for the wind power generation are calculated by EuroWind. Areas which have a mean wind speed of less than 5 m/s in a height of 100 m a.g.l. (above ground level) are omitted. Furthermore, forest, sea, rivers and urban or industrial areas are excluded.

Wind onshore costs

The investment costs of onshore wind turbines depend on capacity and on national labor costs. For example in Germany costs are the following:

[19] EuroWind.

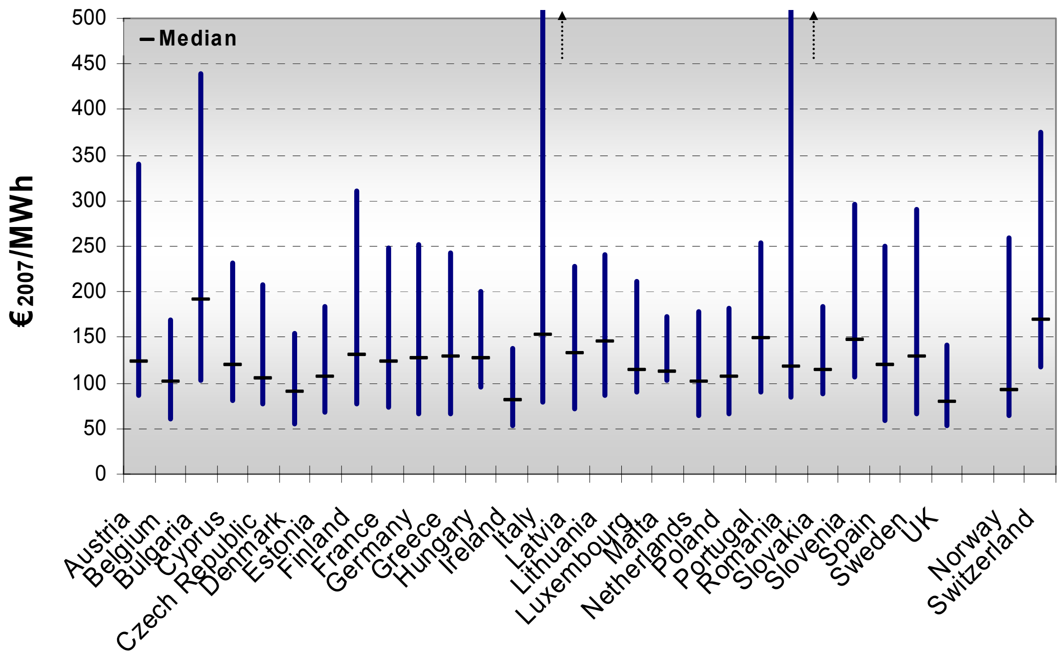
Table 6-6: Investment and O&M costs for wind onshore in Germany in 2007

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
windtech_4	1,261	50
windtech_5	1,647	50
windtech_6	1,647	50
windtech_7	1,647	50

Source: EuroWind.

A literature review on global experience curves for wind turbines[20] reveals that on average the so-called progress ratio is about 0.93. This means that with each doubling of the installed capacity costs decline by 7%. As mentioned before this cost reduction is only related to installation costs. The development of O&M costs is included by the assumption that the O&M costs constitute a constant share of the investment costs across the whole operating period of each turbine. In Figure 6-6 the electricity generation costs of wind onshore in 2007 can be seen.

Figure 6-6: Electricity generation costs of wind onshore in 2007



Source: EWI.

[20] IEA (2000), Neij et al. (2003), Junginger et al. (2005).

Wind Onshore Full Load Hours

As mentioned above, wind data are provided by EuroWind. Measurements of more than 350 stations are examined over 10 years, from 1997 to 2006, with a high time resolution from one to three hours. Out of these data a typical wind year for Europe is identified (2002). Based on the wind data from this year 57 subregions are created as described above. National borders are also considered while creating the subregions. For each of them, a load curve for wind is generated. Then the energy output for each subtechnology in each subregion is calculated out of the corresponding load curve. Factors included in this calculation are: air temperature, air density, roughness length, and typical ground elevation, the power curve of the subtechnology, hub height, and rotor diameter.

The result from this is a number of energy outputs for each subtechnology in each subregion. A matrix of wind onshore full load hours is calculated from these energy outputs and flows in the LORELEI model.

6.2.2.2 Wind Offshore

The subtechnologies of offshore wind turbines differ in capacity size, hub height and rotor circular surface. Three subtechnologies have been defined (see Table 6-7). As shown in Table 6-7 the wind turbine technologies have a different time horizon for their feasibility. The smallest category (*windtech_1*) exists already and represents the current state of the technology in European offshore windfarm projects. The last two categories (*windtech_2 and windtech_3*) are expected to be developed from 2016 and 2021 onwards respectively. The capacity of each subtechnology is given in MW. The last column contains the required space for each wind turbine in km².

Table 6-7: Subtechnologies of wind offshore

Subtechnology	Feasibility	Capacity [MW]	Hub Height [m]	Rotor Cirular Surface [m^2]	Area required by a single Wind Turbine [km^2]
windtech_1	2007	5	90	11,310	0.706
windtech_2	2016	8	110	18,869	1.177
windtech_3	2021	10	130	24,053	1.501

Source: EWI.

Wind offshore potential

The potential of offshore wind energy in the subregions is calculated in the following way: First, the marine surface area of each country is detected and then divided in such a way that the areas match with the offshore subregions that have been defined before. The offshore subregions represent the spatial distribution of different marine areas and different water depths. The distinction is made between shallow waters and high water depths. This corresponds to a water depth of up to 20 m and from 20 m to 40 m, respectively. All areas with a water depth higher than 40 m are omitted in order to attain only the suitable areas for the installation of offshore wind turbines. Moreover, competing usages such as routes of transports, military areas or protected areas are taken into account.

Wind offshore costs

The investment costs of offshore wind turbines depend on the water depth at the installation field. In the case of Germany costs have the following values:

Table 6-8: Investment and O&M costs for wind offshore in Germany

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
SWD (up to 20m)	3,200	121
HWD (20 to 40m)	3,560	121

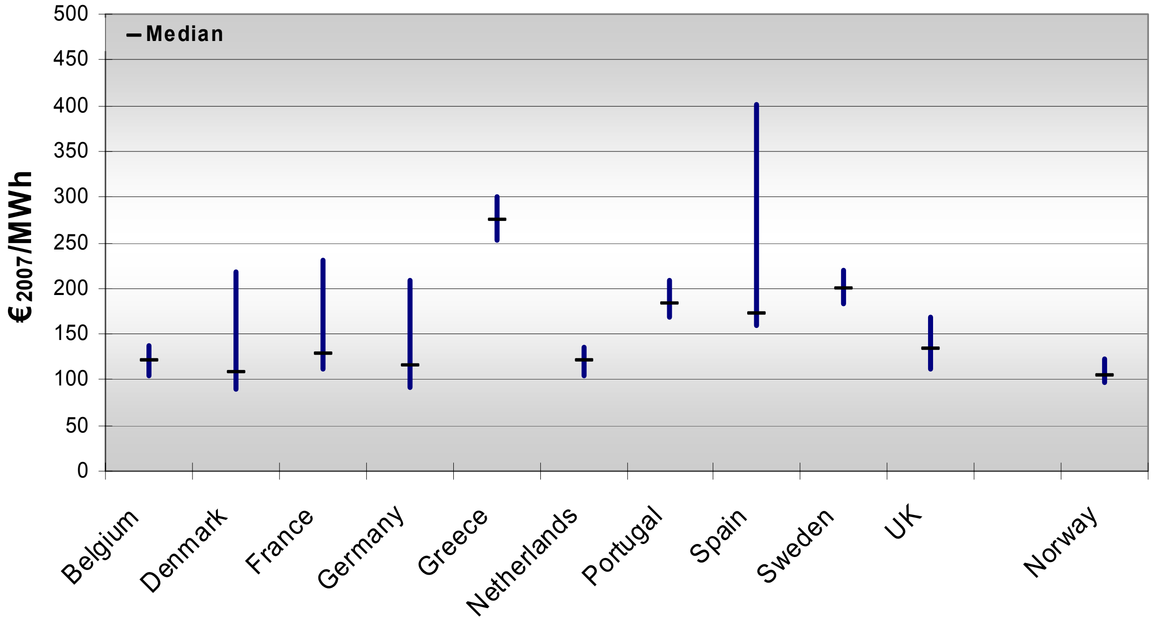
Source: EuroWind; EWI.

In Figure 6-7 the electricity generation costs of wind offshore in 2007 can be seen.

The progress ratio for offshore wind turbines has been defined at 0.91. This means that with each doubling of the installed capacity, costs decline by 9%.[21]

[21] Jamasb (2007).

Figure 6-7: Electricity generation costs of wind offshore in 2007



Source: EWI.

Wind Offshore Full Load Hours

The calculation of the full load hours for the different wind offshore subtechnologies in the 18 offshore subregions follows the same methodology as in wind onshore. The only difference is the time resolution of wind speed data which is six hours.

6.2.2.3 Biomass

In case of biomass data have been provided by IE Leipzig. As shown in Table 6-9 biomass is distinguished in three different categories. The categories are: solid biomass, biogas, and liquid biomass. Solid biomass, contains energy crops such as wood from short rotation plantation, corn, agricultural residues, like straw, logging residues, used wood, and dry sewage sludge. Due to many different applied technologies in practice three different plant sizes have been chosen as reference plants. Biogas plants form the second category. Mainly silo maize silage, liquid manure, dung, grass silage and biogenic settlement waste are gasified. This category consists of two plant sizes. Oily plants like rape and sunflowers are used for extracting liquid biofuel. Internal-combustion engines convert the liquid biofuel to power. Because of the comparatively small quantity only one plant size is taken into consideration. Other biofuels like bioethanol are used primarily in the traffic sector. For the calculations it was assumed that the future use of biomass occurs for the energy sector only in combined heat and power plants.

Table 6-9: Subtechnologies of biomass

Category	Subtechnology	Capacity [MW]	Fuel
biosolid	biosolid_1	0.5	energy crops, agricultural residues, forestry, used wood, sewage sludge
	biosolid_2	5.0	
	biosolid_3	20.0	
biogas	biogas_1	0.5	silo maize, grass, manure
	biogas_2	5.0	
bioliquid	bioliquid	0.2	rape, sunflowers

Source: IE Leipzig.

Biomass Potential

Biomass potentials are derived taking into account natural resources and ecological conditions. The biomass potential of a country refers to the potential it has by its own resources – biomass imports are therefore not considered. The highest potential is located in France, Germany, Spain and Hungary. Only a small part of available potential is currently used. Restrictions such as competing land use are included in the analysis.

In general the highest potential has solid biomass, in particular forestry, used wood and energy crops. In case of energy plants an expansion of the cultivation areas and increases of the yield per acre is presumed. In 2030 they have the highest potential. For biogas a moderate expansion of the potentials exists. Liquid biomass in general plays a rather subordinated role.

Biomass Cost

With increasing power plant size investment and O&M costs decrease (see Table 6-10). Liquid biomass power plants have the lowest investment costs, however also high fuel costs. According to IE Leipzig investment and O&M costs decrease until 2030 by about 10%.

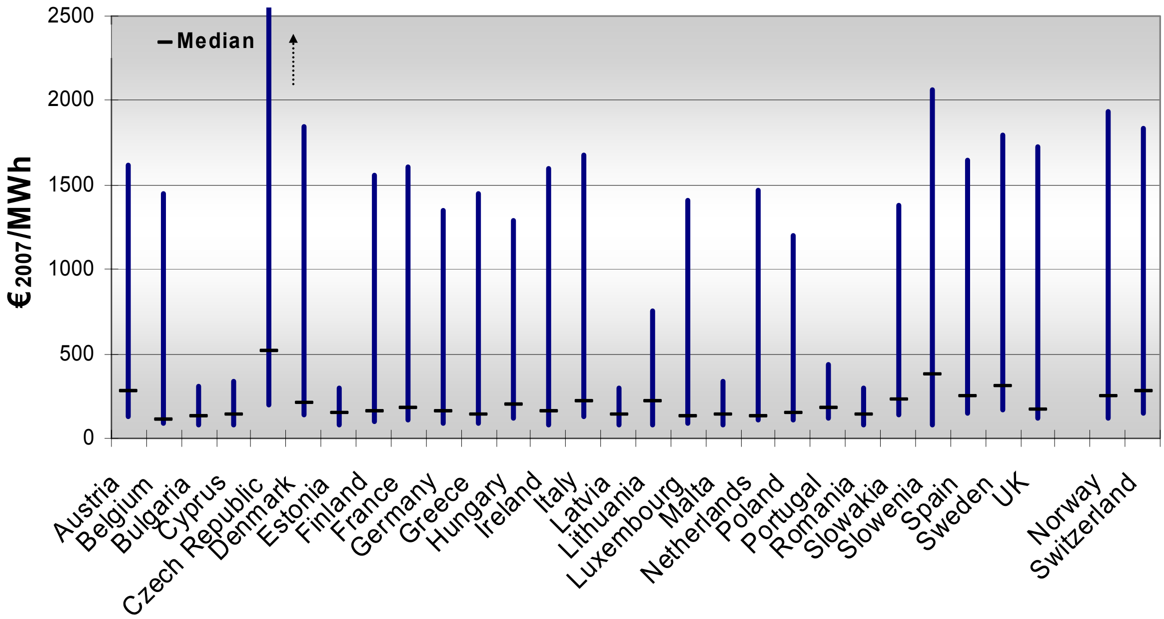
Table 6-10: Biomass investment and O&M costs in Germany in 2007

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
biosolid_1	6,700	549
biosolid_2	3,470	380
biosolid_3	2,180	142
biogas_1	3,168	309
biogas_2	2,673	265
bioliquid	1,740	225

Source: IE Leipzig.

In Figure 6-8 the electricity generation costs of stand-alone biomass in 2007 can be seen.

Figure 6-8: Electricity generation costs of stand-alone biomass in 2007



Source: EWI.

Fuel costs will rise until 2030 due to increasing demand. However, for the disposal of manure a fee must be ordinarily paid. In these cases no fuel costs result. Due to the costly processing and a specific required technology the costs for sewage sludge are relatively expensive.

In the calculation of the power production costs it is assumed that produced heat receives a heat bonus. The amount of the heat bonus depends on the price for alternative heat technologies like gas and differs between the countries. The future development of the heat bonus is coupled to the gas price development.

Biomass Full Load Hours

Because of the high investment costs a high load is necessary to recover fixed costs. Table 6-11 shows the full load hours for new plants.

Table 6-11: Biomass full load hours

Subtechnology	Full load hours
biosolid_1	7,500
biosolid_2	7,700
biosolid_3	7,500
biogas_1	7,500
biogas_2	7,500
bioliquid	6,500

Source: IE Leipzig.

6.2.2.4 Biomass Cofiring

The development of biomass cofiring is not part of the optimization process, due to the model-based disconnection between the conventional power market and the RES-E market. Comparable to the large hydropower development, a predetermined path is assumed. In a first step, the current European cofiring status has been assessed by literature research.[22] According to IE Leipzig (2006) the cofiring in coal fired power plants is the preferred option from an economic point of view. Therefore, it is assumed that the biomass cofiring development is linked to the electricity generation from coal fired power plants. Although, the cofiring share is rising until 2030, the absolute biomass cofiring generation shrinks at a certain point of time, since the coal based power generation will be reduced in the future. The required biomass potential for this development path is calculated and reduces the biomass potential, which is available for the pure biomass power generation.

6.2.2.5 Photovoltaics

Due to significant cost differences between different plant sizes three typical photovoltaics plant sizes have been deemed necessary to cover the relevant cost range (see Table 6-12). The smallest plant size of 4 kW_p represents the typical small

[22] www.ieabcc.nl (2008), IE Leipzig (2006).

residential roof top system.[23] Middle sized systems are set at an installed capacity of 30 kW_p. Large-scale plants are defined as all sizes of 1 MW and more. The latter is typically built on the ground rather than on top of a roof. All plant sizes are assumed to have crystalline modules.[24]

Table 6-12: Subtechnologies of photovoltaics

Subtechnology	Capacity [MW]	Place of installation
pv_1	0.004	roof
pv_2	0.030	roof
pv_3	1.000	base

Source: EWI.

In order to get as detailed data for energy earnings as possible, subregions are further introduced.

Photovoltaics potential

Corresponding to the manner of construction the photovoltaics potential has been subdivided into two distinct parts. While for those technologies that are mounted on roofs a maximum roof area suitable for photovoltaics applications has been determined, a maximum ground area has been determined for large-scale plants.

Concerning the roof area potential basically the approach of Gutschner and Nowak (2002) has been used. This approach is based on the estimation that every 1m² of ground floor area results in a solar architecturally suitable roof area of 0.4 m². The calculation takes into account architectural suitability (including construction, historical and shading elements) and solar suitability, defined as surfaces with "good" solar yield (≥ 80% of the maximum local annual solar input). Regarding the base area per capita country-specific data is taken. Otherwise the statistical value of 45m² per capita (including residential, agricultural, industrial, commercial and other buildings) is used. This is a typical value for Central Western Europe. Generally, densely populated areas have less area per capita available and visa versa. Furthermore a roof area of 3m² per capita for solarthermal heat use has been subtracted. The potential for each country is split into subregions by applying statistical data of inhabitants per region. As this approach for roof area potential (in m²) is based mostly

[23] EEG-Erfahrungsbericht (2007).
[24] During the last few years, thin film modules increased in their importance.

on capita per region, countries with large population like e.g. Germany have a high potential. The potentially useable are for the installation of large-scale photovoltaics plants is identified by summing up the area of arable lands and the grasslands of each country.[25] Competing land uses are considered (e.g. agriculture).

Photovoltaics costs

On the one hand the cost analysis has been based on observable module price indices.[26] The lower end of all observable net retail prices gives an indication for real costs. Furthermore, the cost analysis is complemented by market surveys and interviews. For modules our analysis resulted in 3.10 €/W. In case a higher quantity of modules is demanded prices decrease to below 3 €/W. Adding Balance of System (BoS) costs and the costs for installation a range in the investment costs of between 4,050 €/kW and 4,450 €/kW in Germany results (see Table 6-13). It has to be mentioned that cost-differences between the two smaller plant sizes are substantial whereas economics of scale are declining with increasing plant sizes.

Table 6-13: Investment and O&M costs of photovoltaics in Germany

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
pv_1	4,450	45
pv_2	4,200	44
pv_3	4,050	41

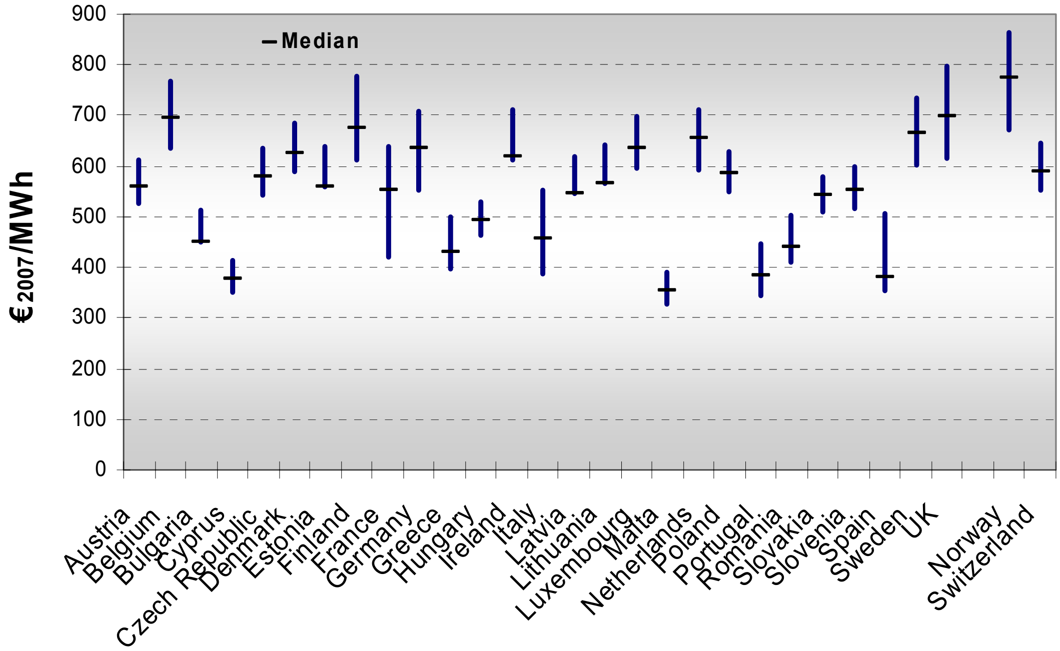
Source: EWI based on Solarbuzz (2008), IEA (2008).

In Figure 6-9 the electricity generation costs of photovoltaics in 2007 can be seen.

[25] CIA(2007).

[26] Solarbuzz (2008), IEA (2008).

Figure 6-9: Electricity generation costs of photovoltaics in 2007[27]



Source: EWI.

The future investment cost development depends on global deployment. According to Staffhorst (2006) typical progress ratios range between 76% and 84% depending on national policies, regional differences, technical shifts and maturity of technology. On average other studies on worldwide module prices analyzed by Staffhorst show a value of slightly below 80%. Unfortunately, the literature on BoS learning curves is scarce. However, Schaeffer et al. (2004) find BoS-progress ratios of 78% for Germany and 81% for the Netherlands. Therefore, this study assumes a progress ratio of 80%, i.e. with every doubling of the installed capacity a decline in system prices by 20% occurs.

The future development of the O&M cost share that comprises material costs is similar to the investment cost development. The other part of variable costs which is

[27] The specific generation costs of photovoltaics decreased significantly from 2007 until today. The investment costs for photovoltaics of 2009 are about 40% lower than in the year 2007. Within the modeling in this study this cost development is taken into account. However the differences between the electricity generation costs of photovoltaics in the different European countries shown in Figure 6-9 persist also for the case of an investment cost decrease which occurred in all European countries. The main reason for the differences in electricity generation costs depicted in Figure 6-9 is the difference of full load hours between the countries (see also Figure 2-5).

based especially on labor, rent, insurance and other costs is assumed to remain constant over time.

We assume the possibility of net-metering for small PV plants.. Therefore, the relevant price here is the price to the end-consumer and not the wholesale market price. Thus the relevant price includes also grid costs as well as taxes and levies.
This so-called grid parity option is included in this study. However, open questions remain regarding the comparability between household consumer price and PV electricity generation costs. The main question is a matter of cost allocation, which is subject to grid regulation. Grid costs form roughly one third of the consumer price (in €/kWh). If a household with a roof-top PV installation reduces its net consumption, other users need to cover the grid costs instead. Therefore, and since grid costs are dominated by fixed (capacity-related) costs, rather than by variable costs, in the long run, and especially in the context of increasing PV electricity fed into the grid based on grid parity, grid regulation may shift from a €/kWh calculation to a more access based €/kW calculation. In this case, the level for grid parity is reduced from e.g. 21ct/kWh to 14 ct/kWh, since the grid access is paid on a separate bill. In addition it is a decision of the government whether or not taxes and levies need to be paid also on electricity from PV based on grid parity. In this case, the wholesale power price would be the correct cost comparison.

Photovoltaics full load hours

Basis for full load hour calculation is the hourly irradiation data for all European regions by the database Meteonorm 6.0. Combined with regional and hourly data for temperature, the inclination angle, kind of system-elevation and the performance ratio[28] which includes deviation from optimal output caused by efficiency losses of cables or inverters full load hours are resulting. In the past an improvement of the performance ratio could be observed. With every cumulative doubling in the installation, the performance ratio will improve by nearly 2%.[29]

[28] The performance ratio is defined as the ratio of real output and optimal output.
[29] In this study a progress ratio of 1,017 for the performance ratio is set (Staffhorst, 2006).

6.2.2.6 Geothermal Energy

For the conversion of geothermal energy into electricity there are different technologies available, their application being tied to special geological conditions. Three geothermal subtechnologies are differentiated.

First, one has to separate hydrothermal and petrothermal resources. Hydrothermal resources are natural deposits of thermal fluids which can be developed by simply delivering the fluid and reinjecting it after having extracted the heat. They are distinguished by their thermodynamic potential, i.e. their enthalpy.

In case of low and medium enthalpy hydrothermal resources binary power plants are used. They do not use the thermal fluid directly but rather transfer its heat to another fluid with a lower boiling point. This technology is applied when fluid temperatures are between 90°C and 150°C. High enthalpy hydrothermal resources, however, deliver fluids with more than 150°C which can be used directly to generate electricity.

Petrothermal resources on the other hand do not contain natural fluids so that the respective exploitation technology is called Hot-Dry-Rock technology (HDR). It commonly requires deep wells (about 4,000m and more) in order to reach temperatures sufficient for electricity production. Instead of extracting thermal fluids out of the depth a stimulation medium is extruded into the rock to open up small fractures. These make the rock permeable and turn it into an artificial aquiferous shift. Currently the HDR-technology is still immature.

With respect to a typical plant size of each technology scientific literature as well as interviews with specialists have formed the basis of determination. For low and medium enthalpy hydrothermal power plants a typical size of about 3 to 5 MWe has been set, whereas power stations exploiting high enthalpy resources provide approximately 20 MWe capacity (see Table 6-14). By virtue of their early stage of development the typical size of HDR-systems has had to be estimated. According to experts nowadays a plant size of 5 to 10 MWe seems to be a reasonable figure. Although bigger plant sizes would benefit of economies of scales, finding a willing investor is quite challenging regarding the capital intensity, the low maturity of the technology, and the associated risk. With increasing experience, however, the trend to enlarge the plant size stepwise by more modules will presumably be aggravated in the future. Therefore, we assume a gradual increase in plant size until 2030, in 2016 to 30 MW and in 2021 to 50 MW capacity respectively.

Table 6-14: Subtechnologies of geothermal energy

Subtechnology	Type of resource	Capacity [MW]
geotech_1	hydrothermal high enthalpy	20
geotech_2	hydrothermal medium enthalpy	3
geotech_3	HDR	5 to 50

Source: EWI.

Geothermal energy potential

The potential for the technology classes mentioned above has been based on available studies dealing with this problem. In case of hydrothermal resources potential a study of Karytsas, C./Mendrinos, D. (2006) delivers detailed estimations for Europe. The potential of geothermal electricity production using HDR-technology was assessed on the basis of the study from Myslil et al. (2005) who estimated the potential in depths until 5,000 meters and a minimum temperature of 130°C in the Czech Republic. Within the European continent, high enthalpy hydrothermal resources are sited only in Italy. In contrast petrothermal resources can be found everywhere in Europe. Medium and low temperature hydrothermal resources are located e.g. in the alpine Molassic basin (Germany, Switzerland), in the Rhine basin or the Pannonian basin (Hungary, Austria, Slovakia, Romania, Slovenia).

Geothermal energy costs

When determining the investment costs of geothermal electricity generation plants for the different subtechnologies one has to distinguish between field related costs like exploration, stimulation and drilling, power plant related costs, financing costs and others. Thereby, drilling costs account for about 2/3 of total investment costs. Due to their beneficial attributes high enthalpy hydrothermal resources allow for the by far lowest electricity production costs of the geothermal resources.

However, there are great differences in the specific investment costs between almost any of the projects realised until today. This is primarily due to varying geological conditions at different sites which affect drilling costs as well as the flow rate. As a consequence it has been reverted to average costs of the projects that are already realized. Extreme outliers were removed. Regarding O&M costs the same methodology was applied (see Table 6-15).

Table 6-15: Investment and O&M costs of geothermal power production in Germany

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
geotech_1	2,000	150
geotech_2	20,000	500
geotech_3	15,000	320

Source: operators, geothermal institutes.

With respect to future cost reductions of both investment and O&M costs, the development status of each subtechnology was taken into consideration. Hence, hydrothermal high enthalpy resources were conceded the lowest cost reductions whereas HDR-technology was allowed for significant cutbacks. Moreover, due to economies of scale effects there is a cost reduction jump in 2016 and 2021 for the HDR-technology.

The electricity generation costs of geothermal energy in 2015 to 2030 can be seen in Figure 6-12, Figure 6-13 and Figure 6-14.

6.2.2.7 Concentrating Solar Power

Concentrating Solar Power (CSP) like parabolic through or solar tower plants play a minor role in renewable energies so far. However, parabolic through could make an important contribution to the electricity production from renewable energy in the short term. Regarding important characteristics such as plant-size and flexibility in power supply due to storage CSP is very different to all other renewable energy technologies. Parabolic-through is designed as large-scale plant using solar radiation for electricity generation within conventional power cycles. Though, CSP installations require a lot of plain area and a high direct normal irradiation (DNI) thereby limiting the potential within Europe significantly.

As parabolic through is the CSP-technology that is already commercially approved and technically mature this technology is used in this analysis.[30] As reference-technology the plants that are currently realized and planned in Spain are chosen. They use molten salt thermal energy storage and co-firing of gas.[31] In the period from 2008 to 2015 a plant size of 50 MW is set as this is the typical plant size which is

[30] Also solar tower plants could play a more important role in future. However, it is very difficult to evaluate costs as first experiences are just in process.

[31] As defined in the Spanish promotion system co-firing of gas is limited to maximal 12% of the produced electricity.

currently built.[32] From 2016 onwards the plant size is assumed to increase to 200 MW. According to interviews this is considered to be the optimal size regarding cost-effectiveness.

CSP potential

Basis for the potential of parabolic through is the study of Trieb (2005). He estimates the technical potential by requiring an annual direct normal irradiation of more than 1,800 kWh per m^2. Numerous exclusion criteria (slope of terrain, kind of land cover, hydrological and geomorphologic criteria and kind of land use) are applied. In addition competing land uses are taken into account. Spain has by far the most favorable conditions for the installation of CSP as it combines a high amount of suitable areas and a sufficient high DNI.

CSP costs

Investment costs of parabolic-through plants amount to about 6,000 €/kW for the projects currently being realized in Spain (see Table 6-16). O&M-costs are based on interviews with companies as well as the study of Geyer (2002).

Table 6-16: CSP investment and O&M costs in Spain in 2007

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
CSP	6,000	100

Source: EWI based on industry, Geyer (2002).

The future development of investment costs depends on the future installed global capacity. Although progress ratios of 88% or even 86% have been established for the development of parabolic through plants in the 1980s,[33] in this analysis 93% is used. This figure is based on expert interviews and Nitsch (2007). With every doubling of

[32] This is due to the current Spanish promotion system which limits the plant size at an installed capacity of 50 MW.
[33] These experiences have been made with the SEGS plants in the Californian Mojave desert. There an overall capacity of 354 MW was built in the period between 1984 and 1990.

the aggregated installed capacity, costs drop by 7%.[34] Furthermore from 2015 onwards plant size is assumed increase to 200 MW which leads to a one time 25% cost reduction due to economies of scale.
The electricity generation costs of concentrating solar power in 2015 to 2030 can be seen in Figure 6-12, Figure 6-13 and Figure 6-14.

CSP full load hours

Full load hours are generated by conform the typical daily and seasonal structure of electricity generation for the reference plants in Spain to all other regions. This is done by putting the DNI of the Spanish reference plant sites into relation to all other regions. DNI-data is taken from the study of Trieb (2005).

6.2.2.8 Small Hydro Power

Small hydro power is a technology including power plants with a capacity less than 10 MW. While large hydro projects are facing increasing barriers small hydro plants offer a higher public acceptance and have a large potential to be exploited in the future decades. Statistics and hydro power associations[35] make a differentiation between two subclasses within the small hydro technology: < 1 MW and 1 – 10 MW. In this study two exemplary power plant sizes are chosen (0.25 MW plants; 2.5 MW plants) to typify this generally accepted scheme. These seem to be a good approximation to an average plant within the subclasses.

Small Hydro Power Potential

Total potential for each country was determined by evaluating different studies and publications.[36] Moreover, experts such as managing directors, scientists and engineering offices have been consulted. Environmental restrictions have been taken into account.

Small Hydro Power Costs

Similarly, a survey among hydro power specialized engineering consultancies formed the basis for identifying investment costs. In Germany investment costs amount to

[34] IEA (2005).
[35] Eurostat (2008), EurObserver (2008), ESHA (2008) etc.
[36] ESHA (2008), Tichler/ Kollmann (2005), Horlacher (2003).

5,500 €/kW in case of the smaller plant (see Table 6-17). Bigger plants benefit from economies of scale and thus have lower specific costs. Half of the investment costs are made up of technical costs (e.g. turbine), the other half are construction costs. Annual O&M costs per kW constitute about 0.8 to 1% of the investment costs. As small hydro power can be characterised as a mature technology costs are assumed to remain constant over time.

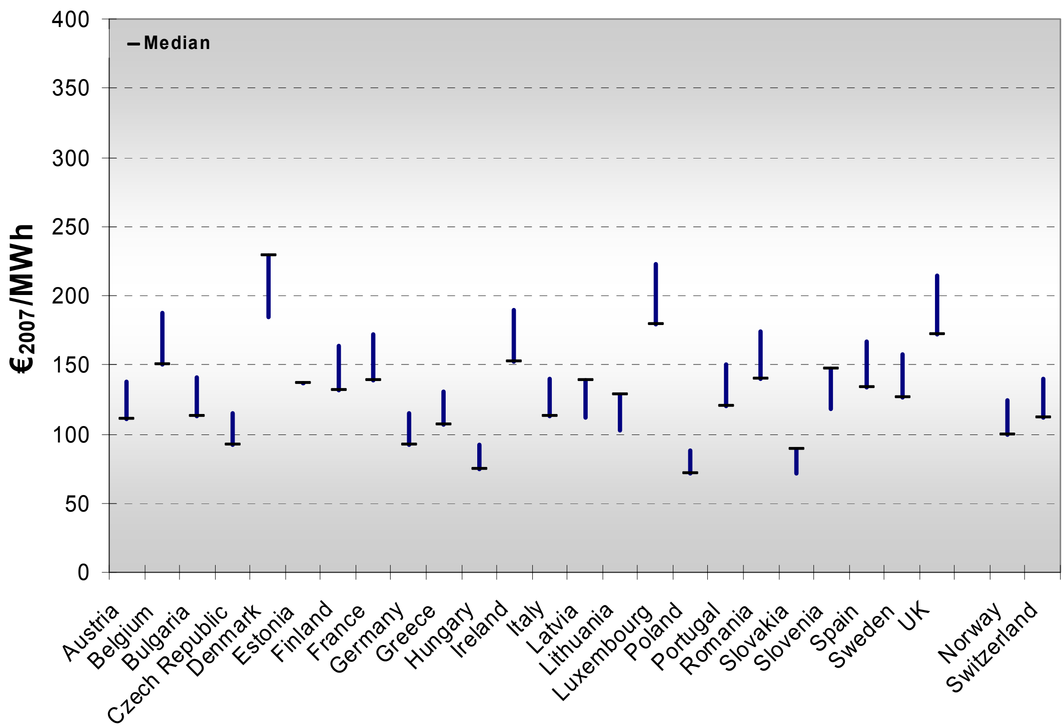
Table 6-17: Investment and O&M costs of small hydro power

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
hydrotech_1	5,500	55
hydrotech_2	4,500	36

Source: EWI.

In Figure 6-10 the electricity generation costs of small hydro power in 2007 can be seen.

Figure 6-10: Electricity generation costs of small hydro power in 2007



Source: EWI.

6.2.2.9 Wave Power

The considered technology for wave power is the Pelamis ocean snake. It is the only technology with realized quasi commercial deployment. One wave power converter has a capacity of 750 kW. Recently, a plant in Portugal with an installed capacity of 2.25 MW has been realized and a 3 MW project is planned in Scotland.

Wave Power Potential

The national available coast lines have been estimated by assuming that 20% of the coast length is available for wave power technologies.[37] Denmark is an exception, since it has a relatively long coastline with high marine traffic. For Denmark, therefore, 10% are assumed. Various converters can be connected to wave farms. The literature assumes a possible deployment of between 20 and 36 MW/km shore length. This study takes up a conservative stance assuming the lower end of the range of 20 MW/km. Results have been validated by comparisons with different national studies, especially from the UK and Ireland.

Wave Power Costs

The literature review shows a high deviation of investment costs. While e.g. Carbon Trust (2006) assumes investment costs of 6,287 €/kW, the California Energy Commission (2008) plans with 2,169 €/kW. The currently erected plant in Portugal has been reported by the Scottish Government (2006) with investment costs of 3,500 €/kW. EWI assumes initial investment costs of 4,000 €/kW (see Table 6-18). The O&M costs are assumed to be 4.5% of the investment costs (Sustainable Energy Ireland, 2006), which is within the common bandwidth for marine offshore technologies. The deployment of this technology requires a specific expert skill set. Therefore it is assumed that no national cost differences exist.

Table 6-18: Investment and O&M costs of wave energy

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
wave	4,000	180

Source: EWI.

[37] California Energy Commission (2008).

The technology is too immature to use a learning curve approach. Learning curves tend to overestimate the cost reduction when only a few projects have been realized.[38] It requires a certain deployment level to predict cost reductions more accurately. The electricity generation costs of wave energy in 2015 to 2030 can be seen in Figure 6-12, Figure 6-13 and Figure 6-14.

Wave Power Full Load Hours

National load hours are calculated by utilizing a wave power matrix, which defines an output based on wave height and frequency of waves. Technology improvements can be expected due to the maturity state of the technology. As an assumption, the efficiency is improved by one percent point every five years. To take the seasonal variability into account, the annual utilization has been subdivided. Due to the lack of widely available data, the Atlas of UK Marine Renewable Energy Resources[39] provides data that serve as proxy for the relative differentiation between the seasons.

6.2.2.10 Tidal Power

The technology, which currently shows the highest maturity, is the Seagen technology. Each tidal power converter has a capacity of 1.2 MW. A 300 kW Prototype has been installed at Lynmouth, Devon and a full-scale prototype is currently under construction in Strangford Lough, UK.

Tidal Power Potential

The potential has been estimated on the basis of literature research. In some cases, such as the United Kingdom with a potential of 2.8 GW[40], national studies exist. When no data were available, assumptions have been made on the basis of comparisons with countries, for which data were available.

Tidal Power Costs

Investments costs in the literature have relatively high deviations. The range starts at 1,700 to 3,500 €/kW[41] and ends at 8,949 €/kW[42]. Carbon Trust (2006) assumes a cost range of 2,047 – 4,386 €/kW for tidal farms with several MW installed capacity.

[38] Kahouli-Brahmi (2008).
[39] BERR (2008).
[40] Carbon Trust (2006).
[41] Sustainable Energy Ireland (2006).
[42] Sustainable Development Commission (2007).

EWI assumes initial investment costs of 5,000 €/kW (see Table 6-19). The O&M costs are assumed to be 4.5% of the investment costs (Sustainable Energy Ireland, 2006), which is within the common bandwidth for marine offshore technologies.
The underlying assumptions are the same as for the Pelamis wave power technology. The deployment of this technology requires a specific expert skill set. Therefore it is assumed that no national cost differences exist. Moreover, the technology is too immature to use a learning curve approach.

Table 6-19: Investment and O&M costs of tidal energy

Subtechnology	Investment costs [$€_{2007}$/kW]	Annual O&M costs [$€_{2007}$/kW]
tidal	5,000	225

Source: EWI.

The electricity generation costs of wave energy in 2015 to 2030 can be seen in Figure 6-12, Figure 6-13 and Figure 6-14.

Tidal Power Full Load hours

The literature provides a high bandwidth of possible capacity utilizations, which vary by far more than 100%. Technology improvements can be expected due to the maturity state of the technology. As an assumption, the efficiency is improved by one percent point every five years. The daily infeed structure has been implemented according to the tidal frequency.

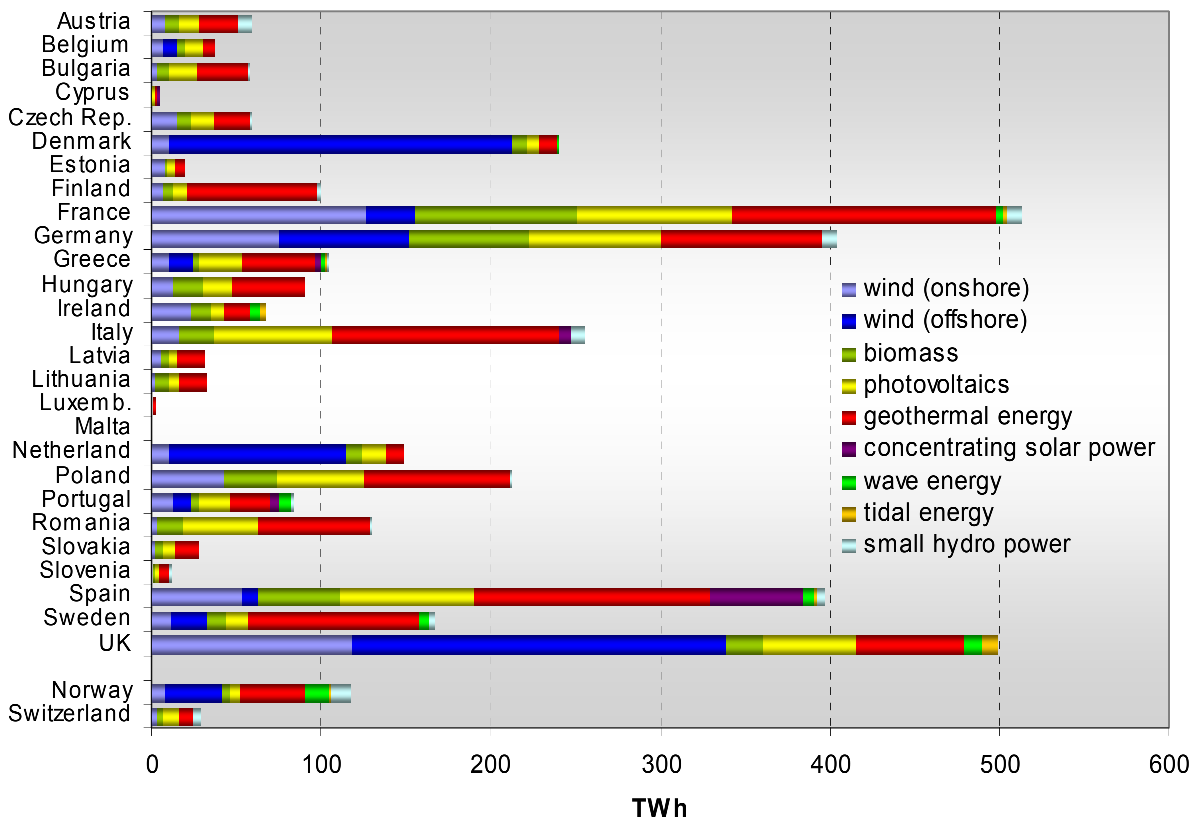
6.2.3 Overview of resulting RES-E potentials and RES-E generation costs

This section provides an overview of the results of the potential and cost assessment described in the previous section. First, the resulting RES-E potential for all EU27++ countries and for each considered technology is shown. Second, the bandwidths of RES-E costs for all technologies in 2015, 2020 and 2030 are presented.

In Figure 6-11 the renewable energy potential within the EU27++ countries can be observed. For conceivability and comparability reasons the values are expressed in TWh, although the terms of measurement has been mostly different, e.g. in case of wind onshore the potential area in km² has been determined. To convert the original unit into TWh, it is assumed that only the best available technologies of each technology class (state-of-the art in 2020) utilize the potential given their properties such as full load hours and space requirements.

Countries such as France, Germany, the UK and Spain offer a high potential for electricity generation by RES. Whereas France and Germany have a similar mix, in the UK potential can be ascribed mostly to wind power. Here, countries located at the coast (Denmark, the Netherlands) also have favorable conditions for the development of offshore wind technology as they benefit from huge areas which are well accessible due to low water depths.

Figure 6-11: Realisable RES-E potential in EU27++ countries

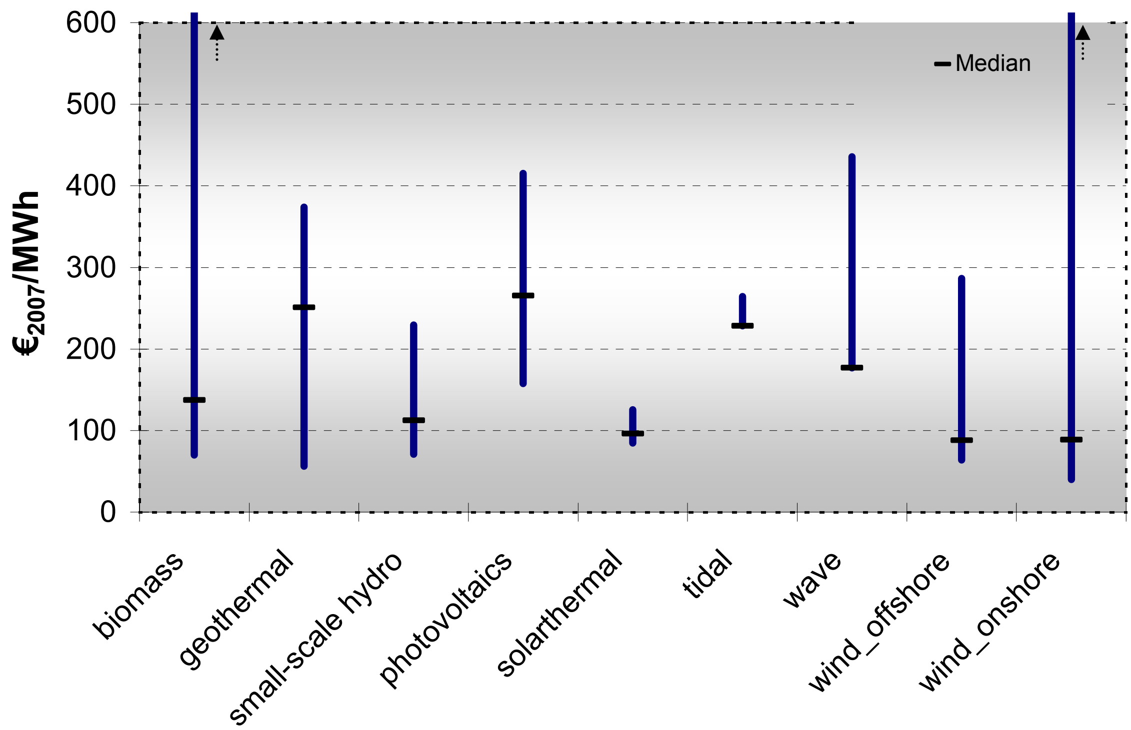


Source: EWI.

Spain exhibits a relatively high potential for concentrating solar power. While other southern countries as well (Greece, Italy, Cyprus, and Malta) offer a high direct normal irradiation they do not bring along open areas at the same time but are characterised rather by craggy and hilly areas. The geothermal Hot-Dry-Rock technology also contributes a substantial share to the total renewable energy potential as it can theoretically be applied everywhere. Likewise photovoltaics and biomass can be applied in many countries. However, small countries like Luxembourg and Malta hardly have any potential (about 1 TWh). This is in principal caused by their small size. The tidal and wave potential has been identified mainly at the Atlantic coast, where oceanic activities are rough and tidal performances are vast.

Figure 6-12 shows the electricity generation cost ranges of all technology classes of the EU27++ countries in 2015. Thereby, the median cutting the distribution in half can be interpreted as the "typical" electricity generation cost of the respective technology class. While wind on- and offshore are on average the most economic technologies photovoltaics is commonly quite expensive.

Figure 6-12: Electricity generation costs by RES in EU27++ countries in 2015[43]

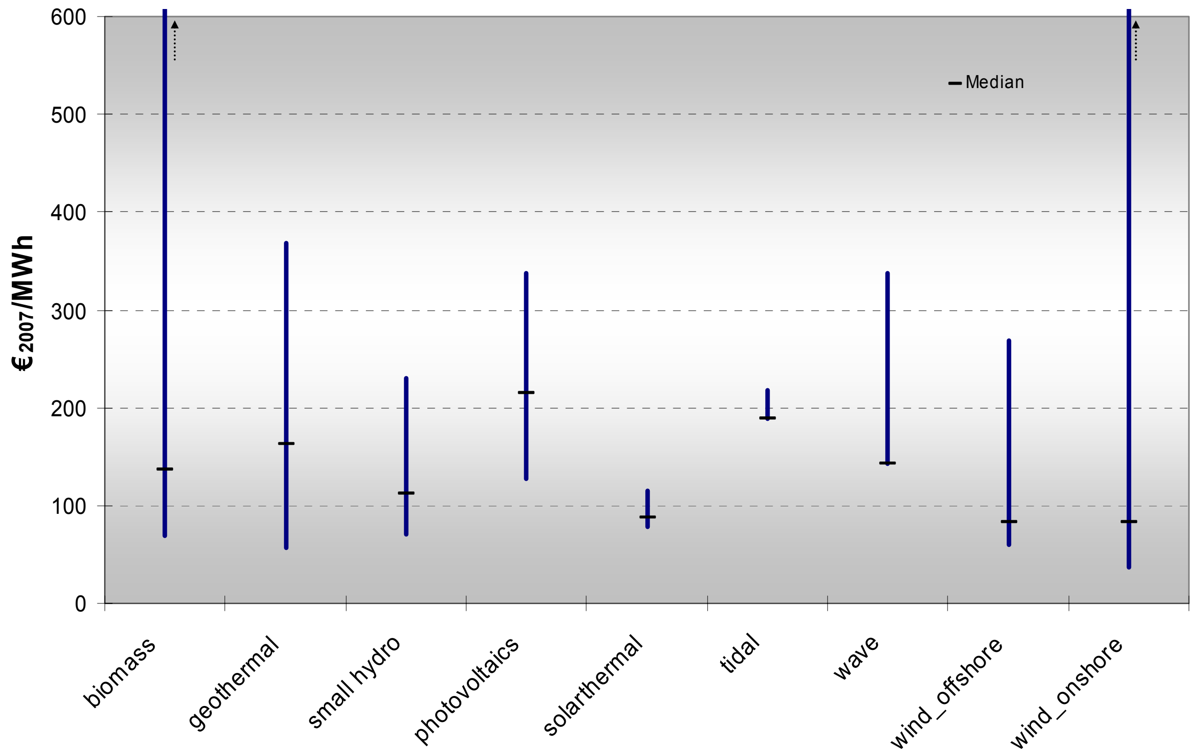


Source: EWI.

[43] Biomass only stand-alone.

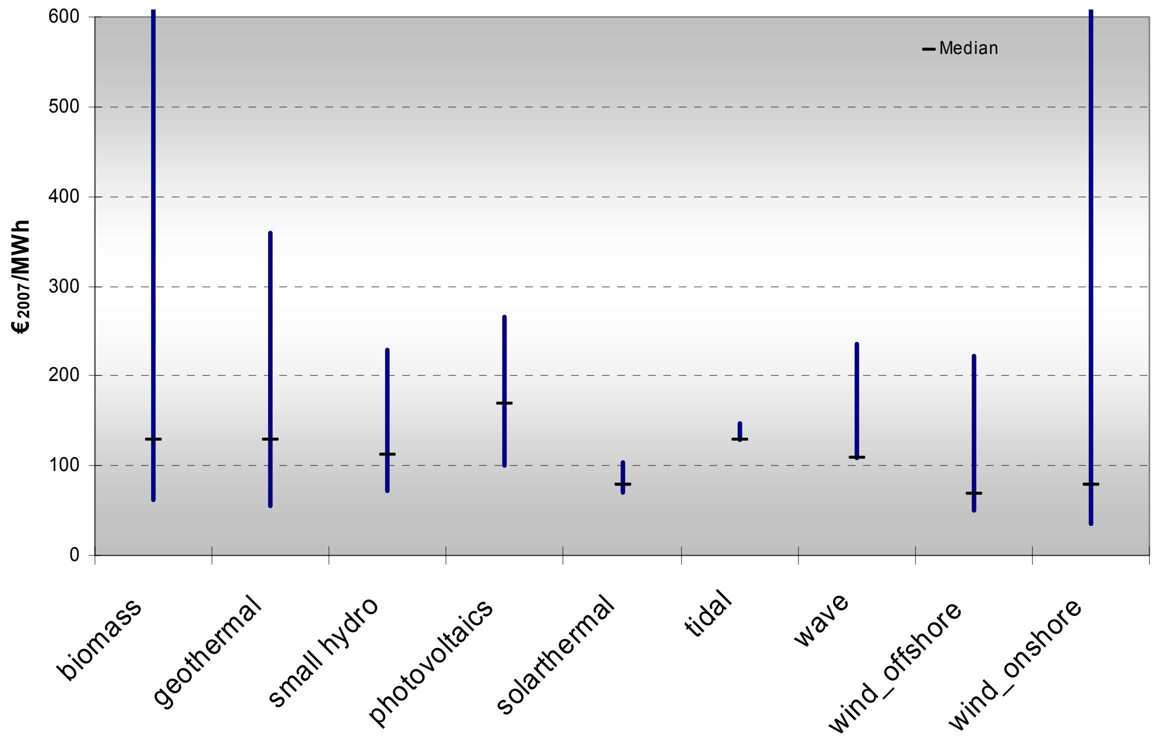
In Figure 6-13 and Figure 6-14 the electricity generation costs in 2020 and 2030 respectively can be seen.

Figure 6-13: Electricity generation costs by RES in EU27++ countries in 2020



Source: EWI.

Figure 6-14: Electricity generation costs by RES in EU27++ countries in 2030



Source: EWI

6.3 RES-E Targets

As explained in the motivation chapter, the individual MS only received targets for the overall renewable share on the final energy demand. It is in the responsibility of the MS to publish targets for the particular sector in their National Action Plan. Since these action plans are not available yet, RES-E targets have to be calculated for this study. This has been done by the following methodology: The 2005 RES-E share has been increased by a flatrate share, which is the same for all MS and the remaining amount has been assigned by a GDP distribution.

Figure 6-15 shows the RES-E targets of all MS. While the 2010 targets have been taken from the 2001 renewables directive, the 2020 and 2030 targets have been calculated. A sensitivity case with a GDP per capita assignment is additionally discussed in the results chapter.

Figure 6-15: RES-E Targets

Country	2010	2020	2030
Austria	78%	82%	93%
Belgium	6%	22%	33%
Bulgaria	11%	23%	29%
Cyprus	6%	18%	29%
Czech Republic	8%	17%	25%
Denmark	29%	58%	75%
Estonia	5%	14%	21%
Finland	32%	41%	50%
France	21%	32%	43%
Germany	13%	30%	42%
United Kingdom	10%	29%	43%
Greece	20%	29%	40%
Hungary	4%	20%	29%
Ireland	13%	40%	54%
Italy	25%	36%	48%
Latvia	49%	58%	66%
Lithuania	7%	18%	26%
Luxembourg	6%	27%	40%
Malta	5%	17%	26%
Netherlands	9%	31%	44%
Norway	100%	105%	110%
Poland	8%	17%	25%
Portugal	39%	40%	50%
Romania	33%	46%	53%
Slovakia	31%	29%	36%
Slovenia	34%	41%	49%
Spain	29%	35%	46%
Sweden	60%	65%	74%
Switzerland	63%	63%	66%

Source: EWI.

As an overall target for the calculation, the sector distribution of the EC roadmap served as a guideline, which calculated an approximate RES-E share of 34 % for 2020. If a country has already defined a national RES-E target, it has been taken instead. As an overall target for 2030, 45 % has been assumed and broken down to MS level through the same methodology. Note that in the case of Norway the RES-E share exceeds 100% implying that Norway is a net-exporter of electricity generated from renewable energy sources.

PART III: Results and Discussion

The third part of this report presents and discusses quantitative scenario results. Chapter 7 describes in a first step the results of the "Harmonized Quota System" (HQS) scenario with regard to the development in the RES-E submarket and its effects on the conventional power system. This scenario is in the focus of the discussion since it reaches the RES-E targets due to the quantity-based setting. This order emphasizes that this study includes comparative scenario study and no forecast. Scenarios are extrapolations under given sets of assumptions. They do not reflect most likely developments. Especially, our BAU scenario freezes current national RES-E promotion laws. It does not include likely, but in detail unforeseeable adaptations of these laws.
Chapter 8 compares HQS with the Business-as-usual (BAU) scenario which is dominated by technology and region specific feed-in tariffs. HQS and BAU are the scenarios which differ the most. Chapter 9 presents a hybrid case (Cluster scenario). Chapter 10 draws conclusions.

Since the European targets are only defined until 2020, the detailed analysis focuses on this time frame, the results for 2030 serve as further outlook.

It is important to emphasize that all scenario results depend on scenario-specific policy assumptions, and on the set of assumptions outlined in Part II of the study. Therefore the scenarios should not be confused with prognoses.

7 The Harmonized Quota System (HQS) Scenario

This chapter discusses the effects that result in the renewable and the conventional power market if RES-E become deployed in a Europe-wide cost optimizing process within the RES-E market. The costs that occur in the conventional power market, especially in the grid, are not considered in this study.

First, the renewable sub-market will be discussed in greater detail (Section 7.1). Second, the effects on the conventional power market and the interdependencies between the markets are discussed (Section 7.2).

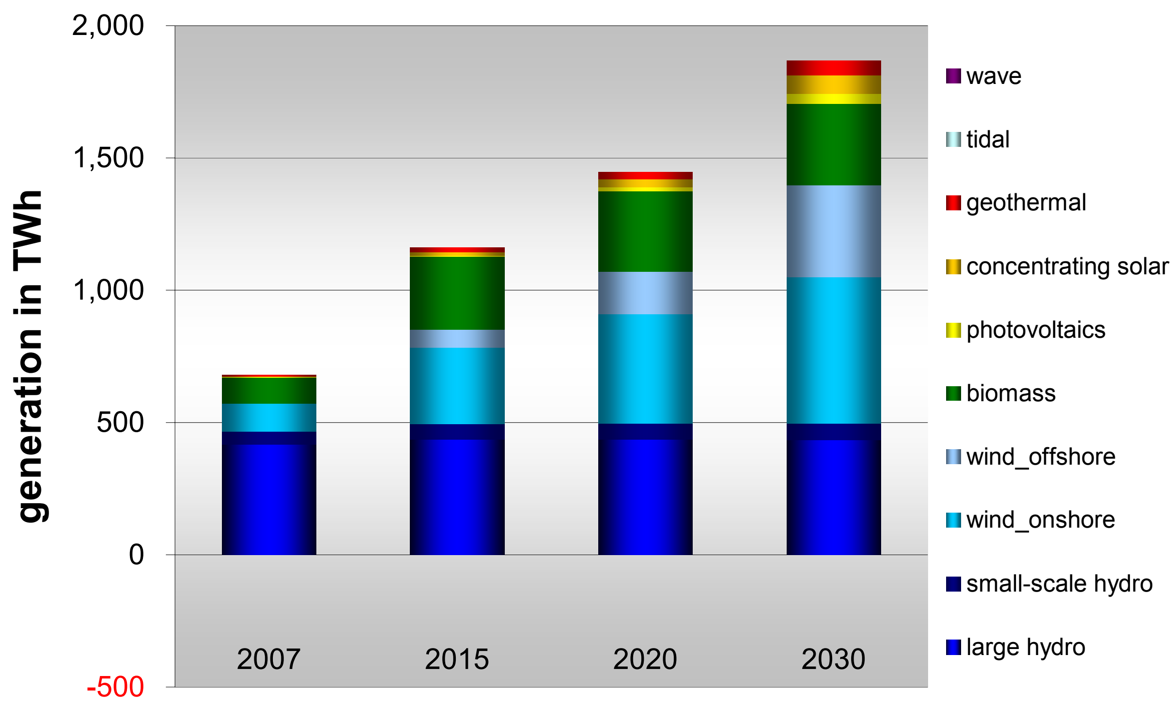
7.1 Developments in the RES-E submarket

In this section, the HQS scenario is discussed regarding RES-E generation and capacity development, investment costs, and the distribution of RES-E deployment throughout Europe. The latter results in potential cost reductions compared with national target achievement and the corresponding trade streams of green certificates (TGC).

RES-E Generation and Capacity Investments in HQS

The growth of the RES-E market is defined by the RES-E quota target. The cost-minimal RES-E technology mix is based on the resource quality throughout all European regions. The resulting total RES-E development is illustrated in Figure 7-1.

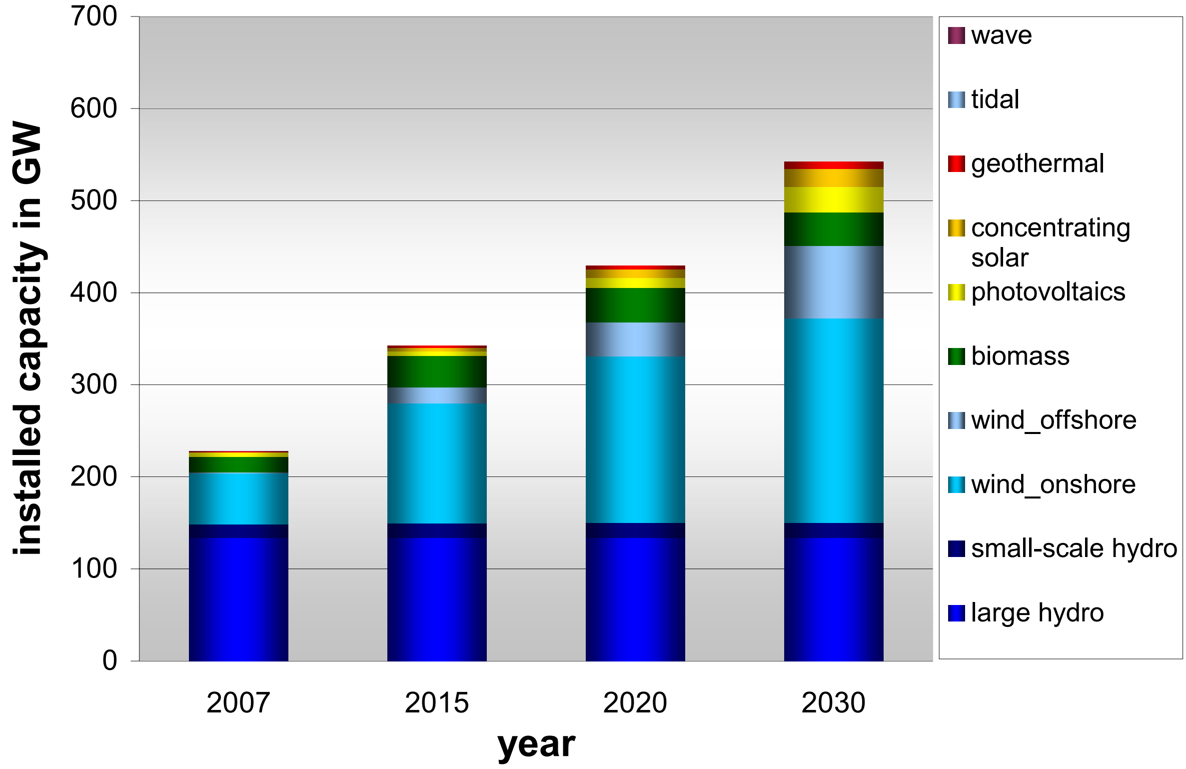
Figure 7-1: RES-E Generation EU27++ in Harmonized Quota System



Source: EWI.

The RES-E growth is mainly based on wind onshore and offshore as well as on biomass. In the longer run, the generation from solarthermal, geothermal and photovoltaics also plays a role. The potentials of large- and small-scale hydro power are already to a great degree utilized and show therefore only a small growth.
The same development can be seen in the capacity deployment overview in Figure 7-2. Mainly wind onshore and offshore becomes deployed to a great extent. One can see that the utilization of wind onshore is lower than of wind offshore. In the biomass sector, existing capacities become replaced by capacities which are utilized to a greater degree and therefore show a higher generation. The photovoltaics capacities become mainly deployed after 2020 and are relatively prominent due to the comparatively low utilization hours of this technology. The concentrating solar capacities on the other hand show a higher utilization.

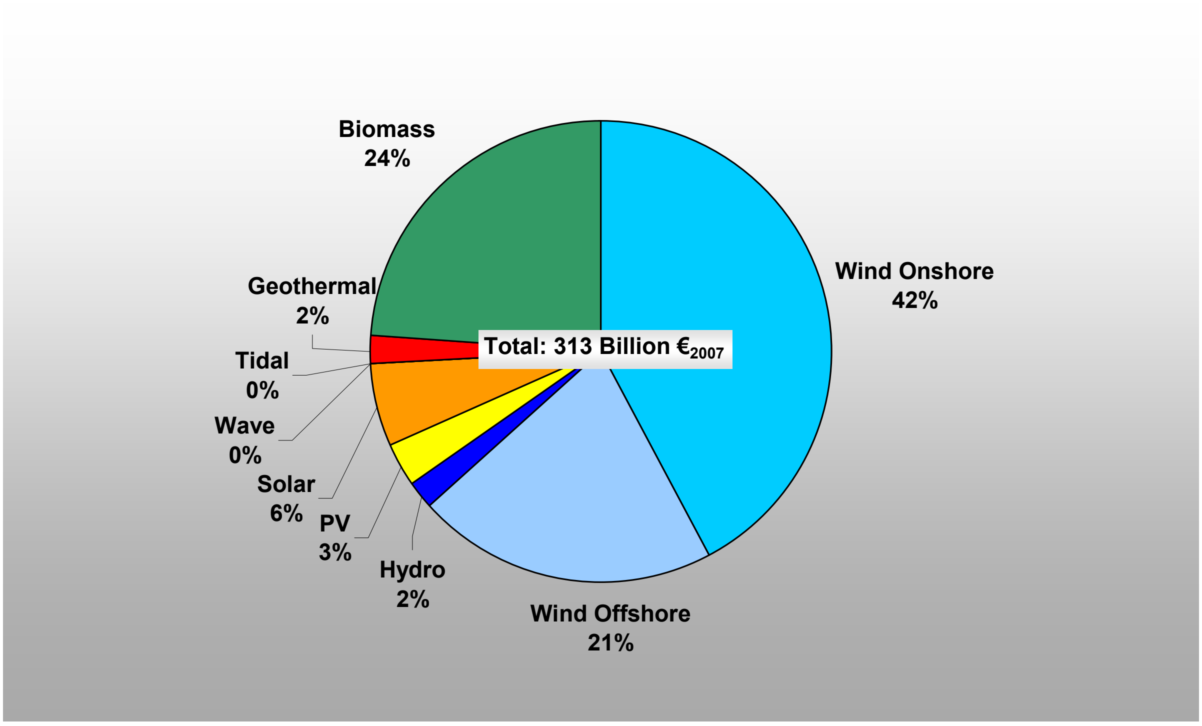
Figure 7-2: RES-E capacities in HQS



Source: EWI.

In order to construct the capacities which are necessary to reach the 2020 RES-E target, cumulative investments of 313 billion $€_{2007}$[44] are necessary in the least-cost deployment assumption of the HQS. Figure 7-3 shows that the lions´ share of 42% of the total investment costs is spent for wind onshore construction, followed by biomass with 24% and wind offshore with 21%. The remaining 13 % are spent for the less mature technologies, with a 6% share of concentrating solar as the largest share of the minor technologies.

Figure 7-3: Cumulative RES-E Investment Costs 2008-2020 in HQS (EU27++)

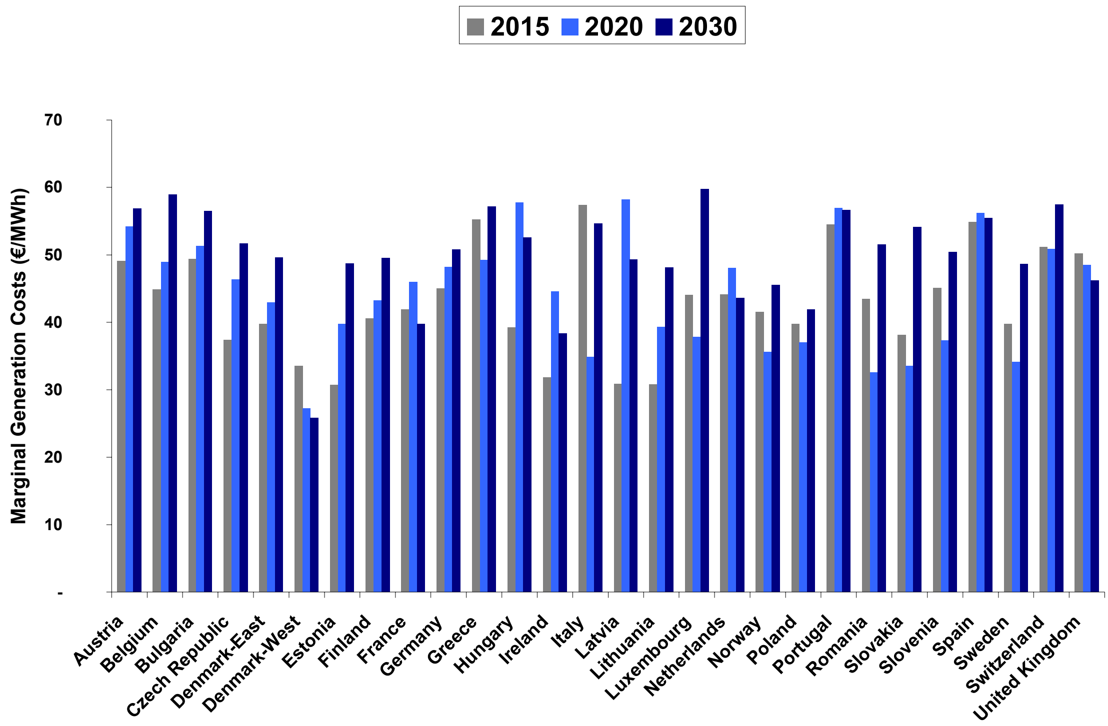


Source: EWI.

The distribution of RES-E throughout Europe is based on the generation costs of the renewable technologies as well as on national marginal generation costs in the conventional power system according to the model DIME.[45] Figure 7-4 provides an overview of the regional and temporal development of the marginal generation costs in the conventional power market.

[44] Actual cash value with the base year 2007.
[45] As marginal generation costs resulting from DIME also include capacity payments, they can be interpreted as long-run marginal costs.

Figure 7-4: Development of Marginal Generation Costs in the Conventional Power Market - HQS scenario



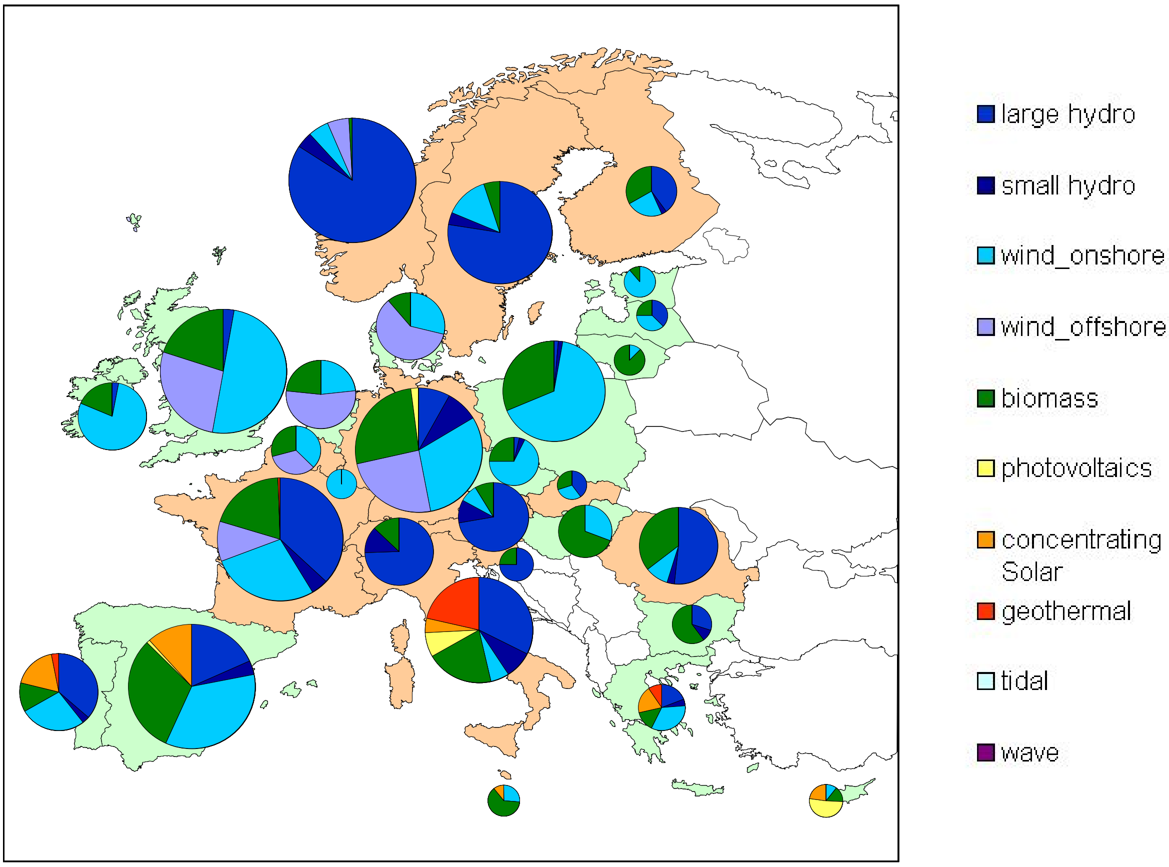
Source: EWI.

Generally, the development of marginal costs is influenced by the following opposing effects: First, an increasing RES-E in-feed lowers marginal generation costs as RES-E marginal costs are close to zero and result therefore in a lower-cost marginal technology. Secondly, the fuel costs of conventional power sources are assumed to increase until 2030 (see chapter 6.1), causing the costs of conventional power generation to rise, even if the share of conventional power generation decreases. Thirdly, as will be discussed in the next section, the structure of the conventional power generation changes, which can lead into both directions. Finally, as a result of cross-border trading, marginal generation costs in each country are also influenced by those in their neighbor countries.

Regional Distribution of RES-E Deployment

The marginal generation costs in the conventional power market together with the RES-E generation costs by region are the basis for the regional and temporal deployment of RES-E. The regional distribution of the different technologies in 2020 is displayed in Figure 7-5.

Figure 7-5: Regional RES-E generation mix in HQS (2020)



Source: EWI.

It is striking that most countries deploy wind power to a certain degree and that solar based technologies become deployed in some southern European countries. Additionally, it can be seen by the colour coding of the country area in Figure 7-5 which countries reach their RES-E target and which need to import TGC from countries that overshoot their targets due to their relative favorable potential compared to their national target. The national targets do not play a role in the optimization process. The quantity target is set Europe-wide. Whether a country reaches its target is analyzed ex-post. To which degree countries import and export TGC is quantified later.

Since wind power is the dominant RES-E technology, Figure 7-6 provides an overview on its development by countries. The concentration of wind power deployment is mainly based on the quality of the resource potential. It can be seen that the UK and Germany are dominant countries in 2020, followed by France, Poland, Spain, Denmark and the Netherlands. In 2030, wind offshore dominates the deployment in the UK and the Netherlands. Overall, the UK shows by far the greatest generation from wind power in 2030, followed by Germany, France, the Netherlands and Poland.

Figure 7-6: Wind Generation by Country in 2007, 2020 and 2030

	2007 [TWh]	2020 [TWh]			2030 [TWh]		
	Wind total	Onshore	Offshore	Wind total	Onshore	Offshore	Wind total
Austria	2.0	4.4	0.0	4.4	5.4	0.0	5.4
Belgium	0.5	8.6	8.1	16.8	9.6	8.3	17.9
Bulgaria	0.0	0.3	0.0	0.3	0.3	0.0	0.3
Cyprus	0.0	0.3	0.0	0.3	0.3	0.0	0.3
Czech Republic	0.1	19.3	0.0	19.3	19.9	0.0	19.9
Denmark	7.2	13.4	26.7	40.2	12.4	31.0	43.4
Estonia	0.1	8.5	0.0	8.5	9.8	0.0	9.8
Finland	0.2	7.3	0.0	7.3	7.6	0.0	7.6
France	4.1	42.4	15.6	58.0	62.5	36.9	99.5
Germany	39.7	48.5	39.0	87.5	68.7	49.2	117.8
Greece	1.8	6.7	0.0	6.7	8.0	0.0	8.0
Hungary	0.1	8.2	0.0	8.2	8.4	0.0	8.4
Ireland	2.0	24.9	0.0	24.9	29.4	0.0	29.4
Italia	4.0	6.4	0.0	6.4	8.2	0.0	8.2
Latvia	0.1	2.8	0.0	2.8	3.1	0.0	3.1
Lithuania	0.1	1.5	0.0	1.5	1.7	0.0	1.7
Luxembourg	0.1	1.0	0.0	1.0	1.1	0.0	1.1
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	3.4	11.3	25.5	36.8	13.3	78.2	91.5
Norway	0.9	6.7	8.0	14.6	7.2	8.1	15.3
Poland	0.5	47.9	0.0	47.9	82.0	0.0	82.0
Portugal	4.0	9.3	0.0	9.3	10.6	3.2	13.8
Romania	0.0	3.1	0.0	3.1	3.1	0.0	3.1
Slovakia	0.0	3.4	0.0	3.4	3.4	0.0	3.4
Slovenia	0.0	0.3	0.0	0.3	0.3	0.0	0.3
Spain	27.5	46.9	0.0	46.9	56.9	0.0	56.9
Sweden	1.4	10.6	0.3	11.0	13.1	0.0	13.1
Switzerland	0.0	0.1	0.0	0.1	0.1	0.0	0.1
United Kingdom	5.3	69.5	37.8	107.3	106.7	127.5	234.3

Source: EWI.

Comparing this development with the generation in 2007, it can be seen that mainly the UK has not utilized the wind power potential yet. However, most countries with sufficient potential increase the wind power generation substantially in the HQS scenario. The countries, which have already deployed considerable amounts of wind power until 2007, especially Germany, Spain and Denmark, show a significantly smaller increase until 2020.

Potential Harmonization Gains[46]

One advantage of modeling a technology-neutral harmonized scenario is the ability to compare it to a technology-neutral national scenario in order to quantify gains from harmonization. An intuition of the considerable potential harmonization gains from changing from a region-specific to a harmonized support system has been given in the introductory chapter through Figure 2-4 and Figure 2-5. It has been shown that current RES-E deployment is based solely on the fragmented national support systems and not on the resource potential qualities of the different European regions. We have seen that the German PV deployment is by far the greatest in the EU (with 2,811 GW in 2007). The generation costs could be much lower, if the capacity had been installed e.g. in Spain. Such regional effects alone cause significant harmonization gains.

Regarding harmonization gains, only the cost difference arising from a switch between national and harmonized support is of interest. Therefore the auxiliary scenario National Quota System (NQS) has been designed by the requirement to fulfill the national targets within the national borders, but compared to the BAU scenario, not with the current support system, but with the efficient deployment of a (technology-neutral) national quota system. As explained in section 6.3, the national RES-E targets are not yet officially set. The exact level of potential harmonization gains is influenced by the RES distribution between the sectors electricity, heat and transport, each individual MS is going to define in its National Action Plan. To take into account the influence of different target settings, the harmonization gains have been both calculated with the RES-E target setting described in section 6.3, and with a second approach, based on a GDP per capita weighted part instead of a GDP weighted part. The resulting RES-E targets for 2020 can be seen in Table 7-1. For most countries the targets hardly differ between the two approaches. The most significant differences arise for Sweden and Luxembourg due to their high GDP per capita.

[46] Gains from trade usually increase with system size. This study analysis an EU-wide harmonization under the consideration of Norway and Switzerland. In case additional countries joined the trade system, e.g. countries from south-east Europe or northern African countries, harmonization gains could increase.

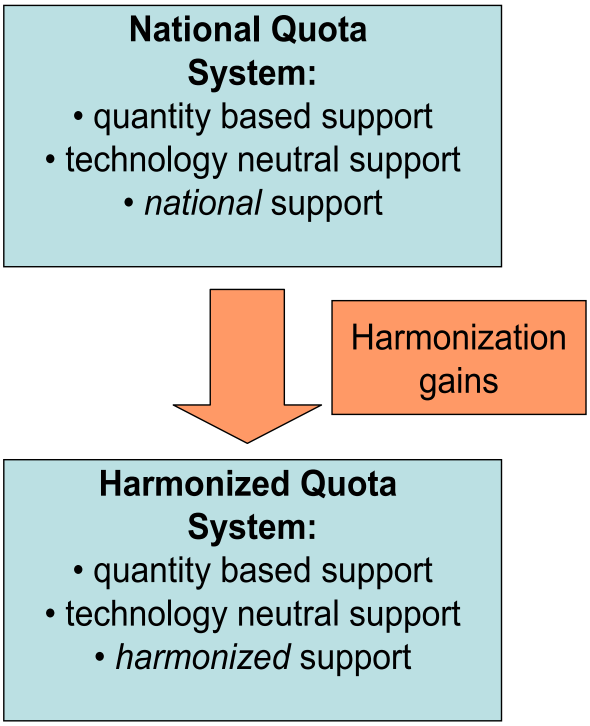
Table 7-1: RES-E targets 2020 weighted by GDP and GDP/capita factor

Country	GDP weighted 2020	GDP/capita weighted 2020
Austria	82%	83%
Belgium	22%	24%
Bulgaria	23%	22%
Cyprus	18%	17%
Czech Republic	17%	18%
Denmark	58%	54%
Estonia	14%	14%
Finland	41%	49%
France	32%	33%
Germany	30%	30%
United Kingdom	29%	26%
Greece	29%	29%
Hungary	20%	18%
Ireland	40%	40%
Italy	36%	35%
Latvia	58%	57%
Lithuania	18%	16%
Luxembourg	27%	40%
Malta	17%	15%
Netherlands	31%	30%
Norway	105%	105%
Poland	17%	15%
Portugal	40%	39%
Romania	46%	44%
Slovakia	29%	28%
Slovenia	41%	42%
Spain	35%	36%
Sweden	65%	72%
Switzerland	63%	63%

Source: EWI.

A comparison of the least cost RES-E deployment on national level (NQS) with the least cost Europe-wide deployment (HQS) allows calculating harmonization gains, as thereby the effect of harmonization is purely based on the quality of the regions, the national potential and the target (see Figure 7-7). In a subsequent step, the RES-E values need to be transferred between the countries according to their national targets. From a modeling point of view this is purely an ex-post distribution and has no effects on the optimization results.

Figure 7-7: Calculation of Harmonization Gains



Source: EWI.

For the interpretation of the harmonization gains, a few assumptions are crucial to mention. First, a penalty price has been introduced in order to avoid unrealistically high support costs. As upper ceiling of the RES-E certificate price, 500 € has been assumed to be high enough a price in order to allow both enough utilization of potential and to limit overall costs. Without such an upper barrier, the cost comparison would have been too much influenced by those countries, which do not have the required potential to meet the targets. Since the targets have been set based on GDP respectively on GDP per capita rather than on national resource potential, this approach would have generated misleading results.

Since the costs comparison (investment, O&M, fuel costs and heat remuneration) is based on the comparison of two least cost solutions (HQS vs. NQS), there is an additional effect. Above, the harmonization gains have been explained mainly through the cheaper resources, e.g. due to sunnier sites within one technology. In some countries, the harmonization leads also to the effect that the marginal technology, which is necessary to fulfill the national targets in the NQS would not have been built in the harmonized scenario. Therefore, in addition to a higher quality regional resource, the effect of a switch to a cheaper technology is inherent. It is important at this point to understand, that within the harmonization gains, there is already an implicit switch in the technology mix. The harmonization gains under the

GDP weighted target setting accumulate to 118 bill. €$_{2007}$ between 2008 and 2020[47], which means a cost reduction compared to the NQS scenario of almost one fifth. In the case of the GDP per capita weighted target setting, this number rises by almost one billion euro.

Harmonization gains arise because in HQS national targets do not have to be fulfilled by each country on its own. Still, an ex-post redistribution is necessary to assure that every country bears costs according to their national targets. This redistribution is based on TGC trade, which is a pure trade of the green certificate value without any physical transfer. Since the RES-E targets have been partially set either on the basis of the national GDP or the national GDP per capita, it is an inherent effect that countries with a relatively low GDP become net exporters and countries with a high GDP tend to be net importers due to their relatively higher ability to afford the RES-E support. Of course, besides the target setting, a dominant role plays the national RES-E potential. Also a low GDP country with a corresponding low target could have low RES-E potentials and would therefore depend on TGC imports. Gains from trade arise because every country can either utilize its resource base or has the chance to import TGC. Consequently, net importing countries of TGC gain from the possibility to import TGC instead using their less favorable resources, while net exporting countries gain by receiving remuneration for utilizing their favorable locations. Figure 7-8 and Figure 7-9 provide an overview of the TGC trade streams under the afore-mentioned target settings. Net exporting countries of TGC have been marked green (positive values), while the red color coding indicates, that a country is a net importer of TGC (negative values). In both figures, the countries have been grouped into the EU15 and the EU12 countries (plus Norway and Switzerland, which form a third group), in order to illustrate the effects of the target distribution based on national GDP respectively GDP per capita: In sum, the EU15 imports in 2020 TGCs with a total value of 3,917 Mill.€$_{2007}$ .under the GDP weighted target setting and 4,603 Mill.€$_{2007}$ .under the GDP per capita approach reflecting the higher GDP per capita in the Western European MS. Generally, under both methodologies the netexporting and netimporting countries remain the same and differ only regarding the absolute value.

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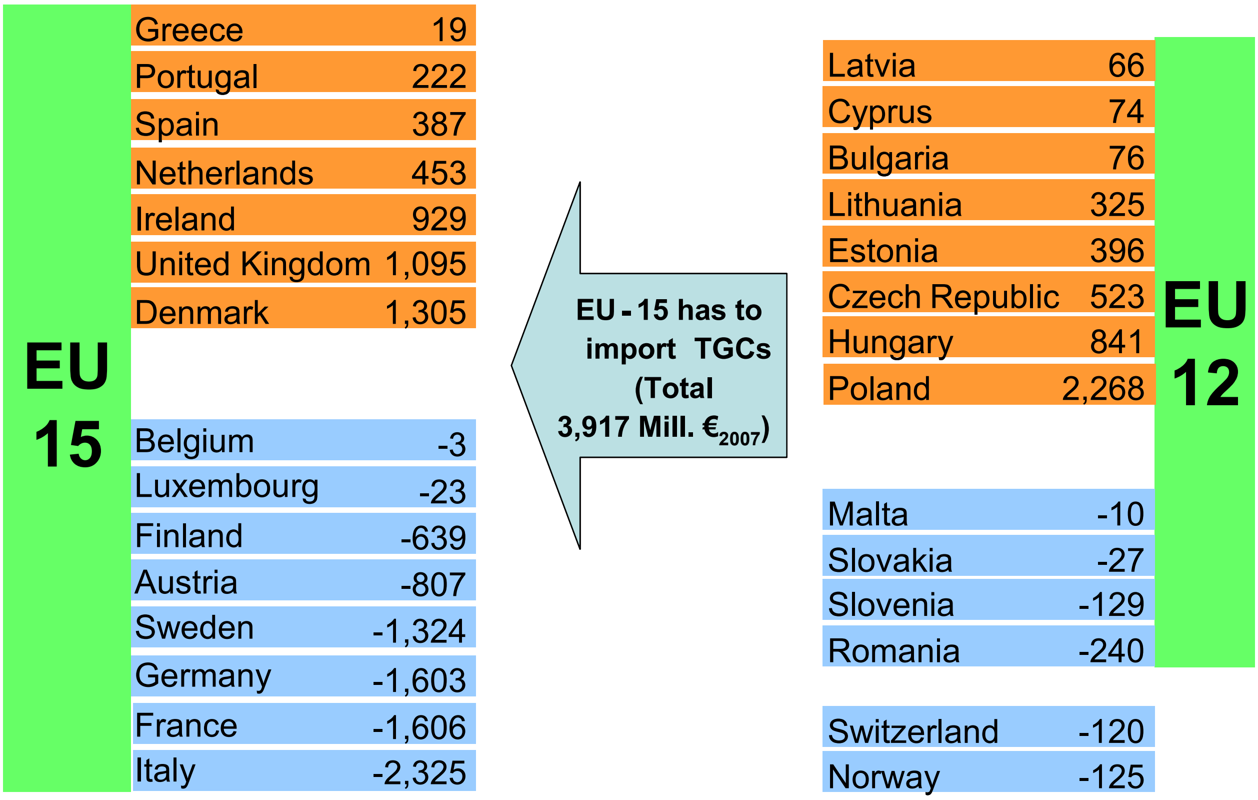
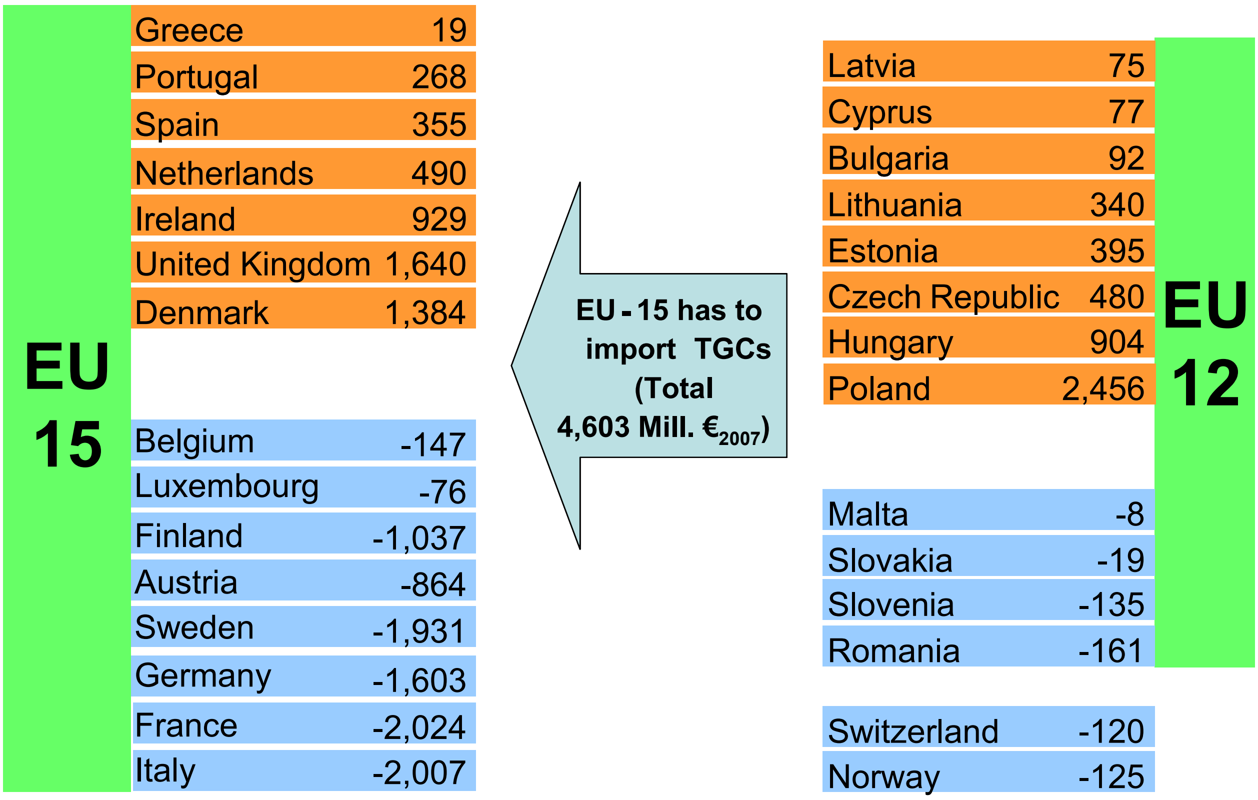
[47] Net Present Value with base year 2007.

Figure 7-8: TGC Trade Streams (2020); GDP weighted target-setting



Source: EWI.

Figure 7-9: TGC Trade Streams (2020); GDP per capita weighted target-setting



Source: EWI.

7.2 Effects on the conventional Power Market in Case of Target Fulfillment

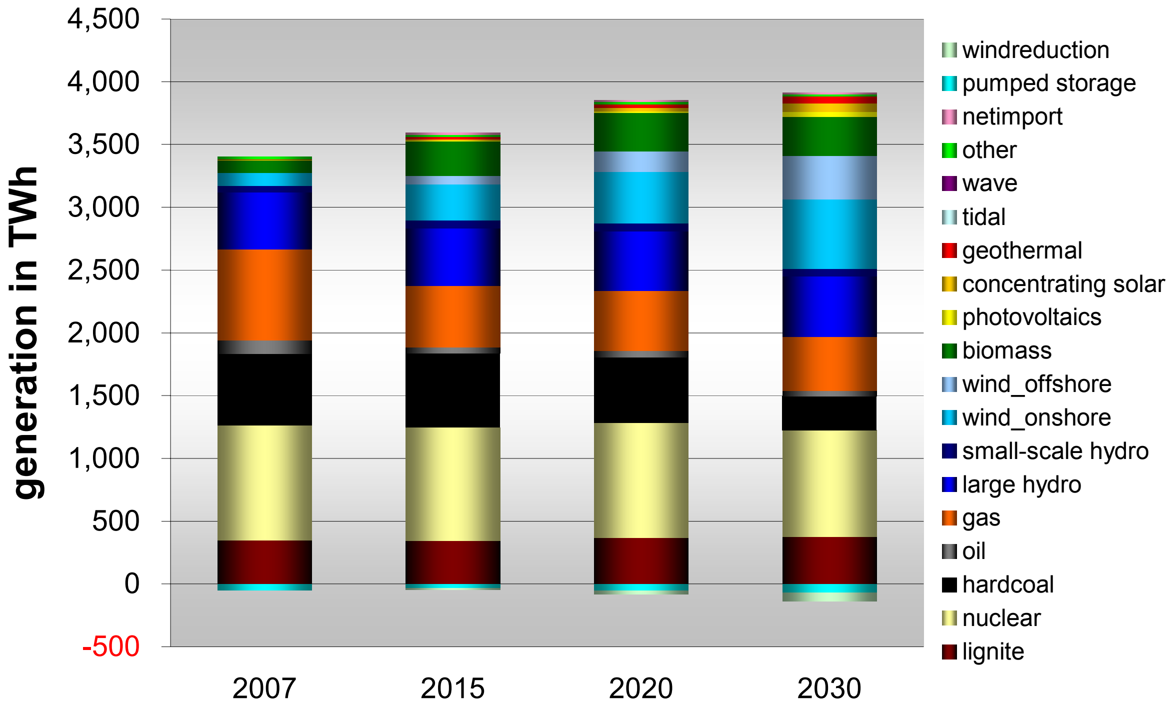
This chapter explains the effects of the RES-E increase in the HQS scenario on the conventional power market. Again we emphasize that the results are scenario results, conditioned by numerous assumptions and a rigorous optimization calculus; they should not be confused with a prognosis.

We discuss the generation mix, capacity effects, and the utilization of the conventional power plants in the HQS scenario.

Total Generation Mix

An overview of the total generation mix within the EU27++ is displayed in Figure 7-10. According to the quantity targets, the RES-E share rises significantly at the expense of mainly coal- and natural gas-based generation.

Figure 7-10: Generation EU27++ in Harmonized Quota System



Source: EWI.

It can be seen from Figure 7-10 that the main share of additional RES-E generation stems from onshore wind power followed by offshore wind power and biomass. Large scale hydro power remains one of the most important RES-E technologies. It is striking that lignite and nuclear remain the most important conventional energy sources on the European scale, while especially generation from hardcoal becomes significantly reduced and gas-based generation remains at approximately the same level after a significant drop at the beginning of the modeling period.

The increasing RES-E share leads by definition to a decreasing total share of energy generated by non-renewable energy sources. Due to the higher RES-E in-feed, hardcoal and natural gas based electricity shrink until 2030. In contrast, the shares of lignite and nuclear remain relatively constant and the RES-E generation satisfies the additional demand increase.

The change of the generation mix is a direct result of the RES-E increase. Before the effects on the conventional capacity become analyzed, some fundamental interdependencies between RES-E infeed and conventional system requirements are discussed.

Effects on Conventional Generation Capacities[48]

Security of electricity supply includes a short run and a long run aspect. In the short run, security is understood as the readiness of existing generation capacity to respond when needed to meet the actual load. Balancing power and intraday markets are supposed to close the gap between supply and demand in a real-time timeframe. The deviations from the day-ahead spot-market plant dispatch can be triggered through unplanned power plant shutdowns, forecast errors of load or infeed of intermitting RES-E technologies (such as e.g. wind power or pv).

In order to provide the required system security level, it is crucial to have sufficient capacity available for either increasing the power supply or reducing it by ramping down running power plants. Alternative options include adaptations on the demand side (DSM) or storage dispatch. The required amount of reserve capacity is usually a responsibility of the grid operators. However, the reserve can only be available if it is already installed. This leads us to the long run aspect of security of supply, which is

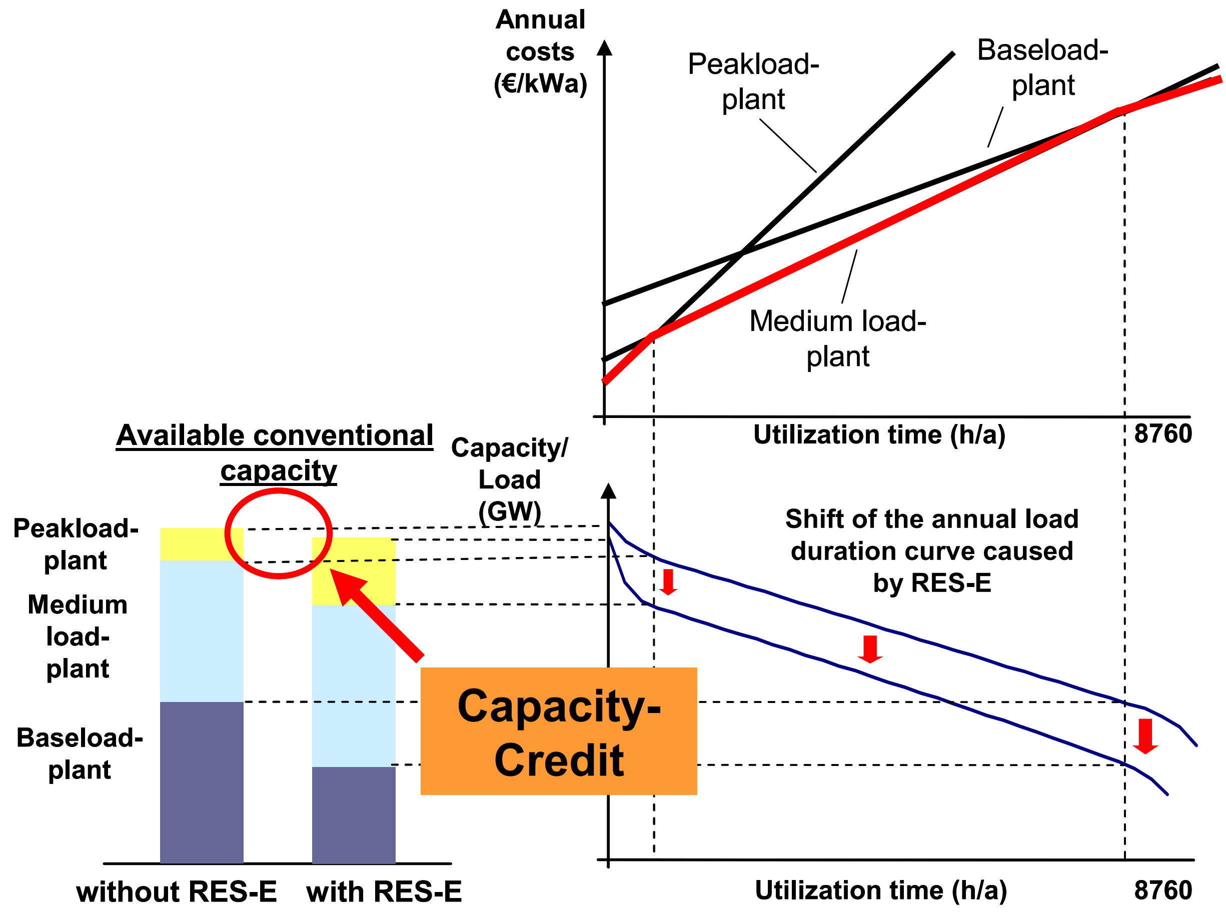
[48] Conventional capacity is defined in this study as generating capacity which is not part of RES-E support schemes and therefore a part the competitive power market.

usually called system adequacy. An adequate system has sufficient installed capacity, grid as well as generation, to meet demand (for a more detailed discussion see e.g. Battle and Pérez-Arriaga, 2009).

One fundamental attribute of some RES-E technologies is their intermitting infeed structure since they are dependent on natural local circumstances, such as wind, rain or sun irradiation. This means, it cannot be guaranteed that the RES-E infeed is present in high load hours, which lowers the positive effects on system adequacy.

By now, electricity from onshore wind power plants is one of the cheapest RES-E options. One particular attribute of wind power is that it is strongly dependent on the natural circumstances in form of wind. Therefore, the RES-E generation is not guaranteed in the hours of peak demand. On the other hand, through regional distribution, it is unlikely that there is no wind simultaneously in all regions. Thus, a certain amount of wind capacity can be accounted as guaranteed at a certain security level. This secured capacity, which is called capacity credit, is able to substitute a certain amount of conventional capacity in the power plant mix. Compared to the RES-E infeed however, the share of secure capacity is relatively low. Within the Dena (2005) study, EWI calculated that the installed wind capacity of 14.5 MW in 2003 in Germany had a capacity credit of between 7 and 9%, meaning that between 1.0 and 1.3 GW conventional capacity can become substituted. It is important to note that an increasing penetration of wind power reduces its relative capacity credit. The above mentioned study also calculated that the planned 35.9 GW wind capacity in 2015 would have a capacity credit of only 5 to 6%. Figure 7-11 illustrates, which effects this attribute has on the conventional power plant mix.

Figure 7-11: RES-E induced shift in the conventional power market

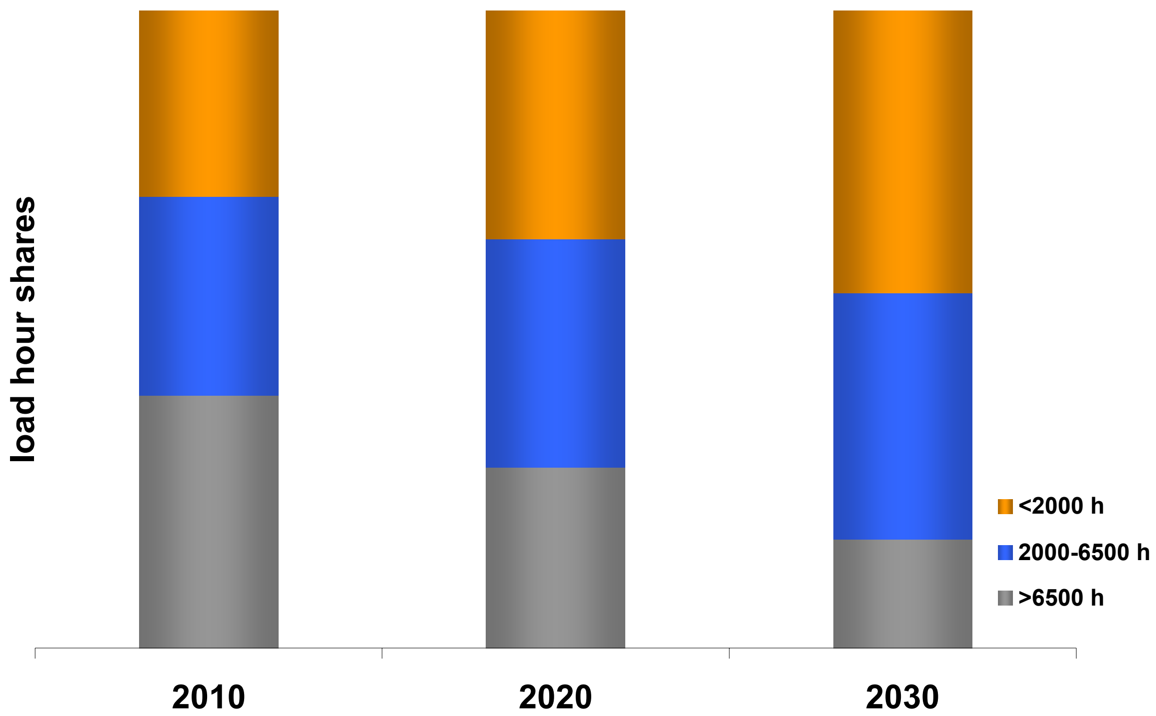


Source: Adapted from Wissen and Nicolosi (2008), see also Nabe (2006).

The upper right graph shows marginal cost curves with annuity capacity costs as starting point at the ordinate. It can be seen, that base load plants have relatively high investment cots and low variable costs (especially fuel costs). Peak load plants on the other hand have low investment costs and relatively high variable costs. The abscissa shows the annual utilization time at which the plant types are efficient. Base load plants are economically viable when a high utilization time can be reached, peak load plants are only the efficient choice when the utilization remains at a low level (see e.g. Stoft, 2002). In the lower right graph, two annual duration load curves are depicted. The annual load hours are arranged in descending order. The highest load hour (peak demand) is arranged at the left end and the hour with the lowest demand at the right end. The upper curve is the total load and the lower curve is the residual load curve. The latter is the load curve less the electricity production which is not part of the conventional power market or has no variable costs, such as prioritized RES-E feed-in or heat-controlled cogeneration of electricity. In other words, part of the load is already covered by market-exogenous generation. The increasing RES-E infeed leads therefore to a steeper slope of the residual load curve. The resulting shift of the shares of the different power plant types can be seen in the lower left graph. The result of high RES-E infeed with a relatively low capacity credit is an increase in peak load capacity and a decrease in base load capacity.

Since the RES-E infeed covers already a certain share of demand, the utilization time of the total conventional power market will be reduced. This effect will apply especially in hours with low load and high RES-E infeed, when large parts of the conventional capacity need to ramp down. The shift of load hours can be seen in Figure 7-12.The model results of the total EU27++ generation capacities have been evaluated according to their utilization time. It can be seen, as already qualitative explained above, that the conventional capacity shift towards generation with less load hours as RES-E deployment increases.

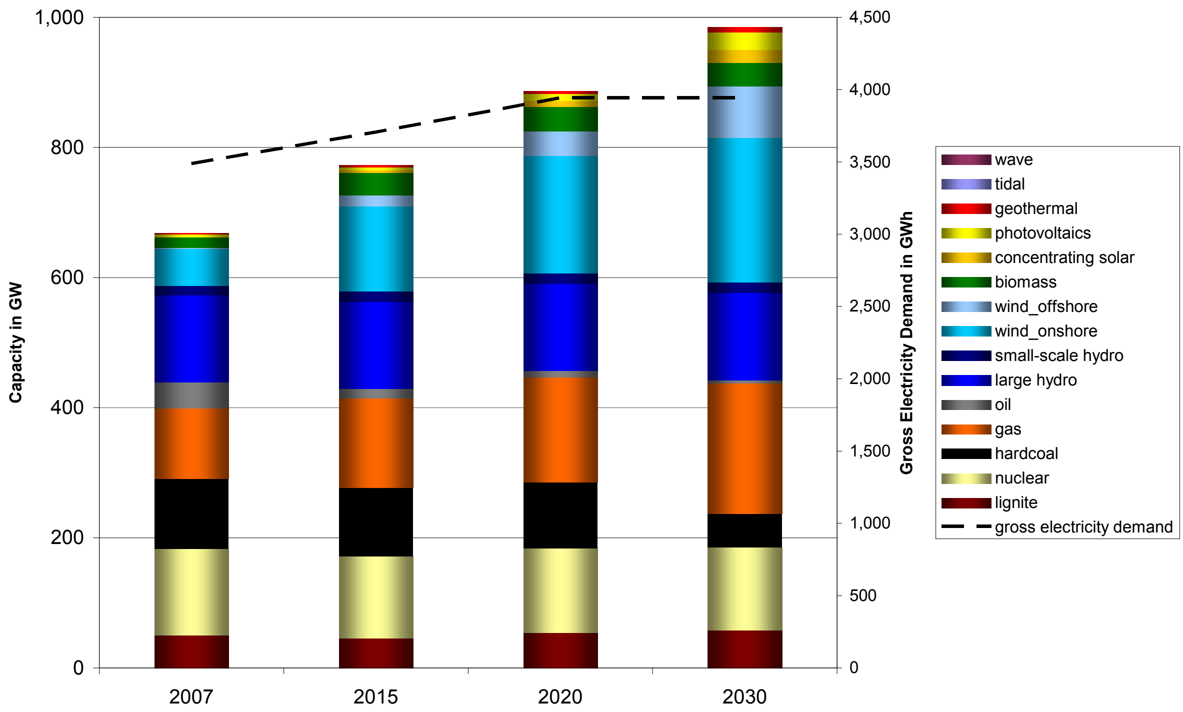
Figure 7-12: Shift of load hours in EU27++ (HQS scenario)



Source: EWI.

The reduction in conventional load hours lies in the fundamental attributes of intermitting RES-E capacities. The overall energy infeed becomes quite significant in the HQS scenario, since the political target becomes fulfilled. The secured capacity (capacity credit) primarily of wind power plants is quite small. Sufficient back-up capacity needs to be installed in order to secure the electricity supply (e.g. biomass can also serve as secured capacity to a large extent). Since the conventional capacity reductions due to RES-E increase are not very significant, the installed conventional capacity fleet is utilized at reduced load hours. This leads to the above explained shift in the distribution of load hours. Figure 7-13 shows the overall installed capacity mix in the EU27++, which is required to produce sufficient RES-E as well as guarantee the required supply security.

Figure 7-13: Total installed capacity in EU27++



Source: EWI.

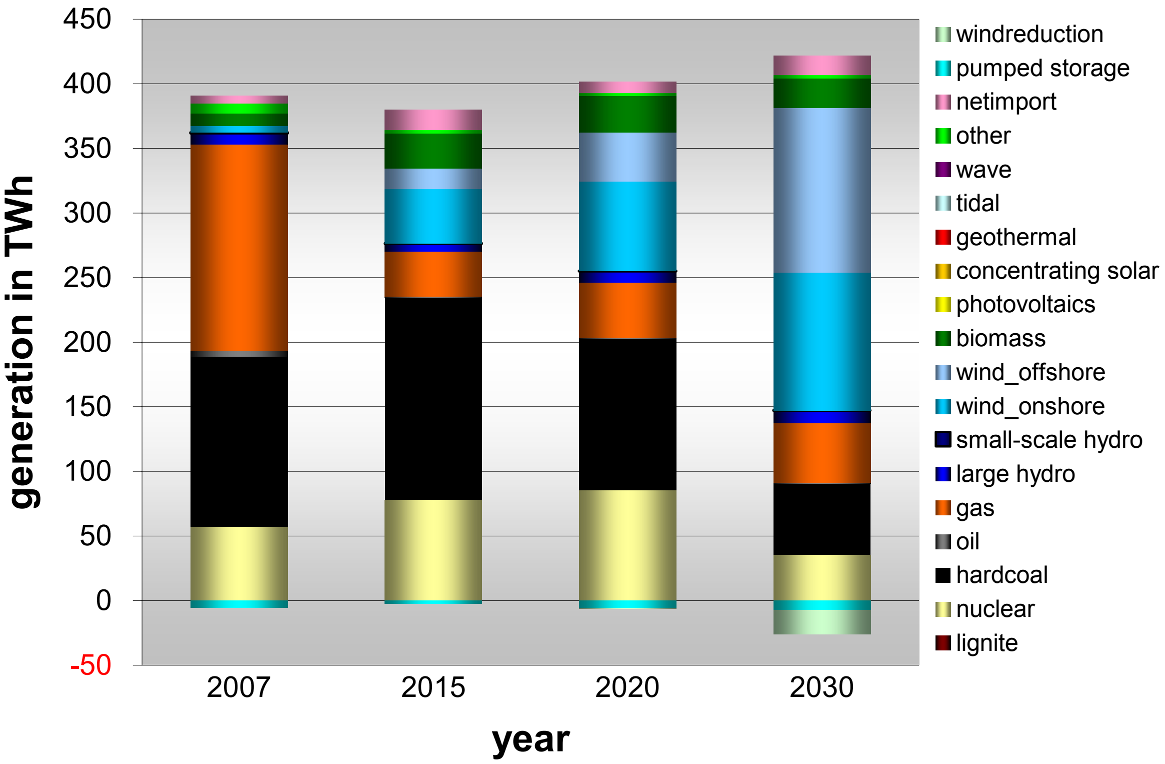
It can be seen in Figure 7-13 that conventional capacity becomes hardly substituted by the RES-E capacity increase. The only fuel type, which shows an effect (that is also influenced by the CO_2 policy) is hardcoal. The increase in volatility, which leads to the reduction of load hours for the conventional power market, favors clearly investments in natural gas-fired technologies. The relatively low investment costs lead to lower load hour requirements.

The main implication in this context is the continuing demand for conventional generation capacity, since older power plants which phase-out need to become substituted, and intermitting generation capacities contribute only little to secured capacity. Apart from their limited contribution to secured capacity, intermitting RES-E capacities become added on top of the conventional system.

Flexibility Requirements of the Power System

In order to integrate the RES-E generation modeled by LORELEI into the DIME model of the competitive power market, certain flexibilities need to be integrated to enable a feasible solution. It is important to mention that the flexibility requirements in the model outcomes underestimate the actual integration challenges due to the copper plate assumption, which ignores national grid situations and due to the reduction of temporal resolution through day types. But even with these remarks integration challenges become visible. The first flexibility, which needed to be integrated is a procedure which is also undertaken in reality in case of system stability issues. In e.g. Germany, the TSOs are allowed to shut down wind infeed, if system stability is in danger. This is the case if wind power infeed exceeds the load to a degree that even under consideration of cross border exchange, power cannot be integrated into the system. This action is named “wind reduction” in the model and can be seen exemplary in Figure 7-14 for UK.

Figure 7-14: Windreduction as an example in UK under the HQS[49]



Source: EWI.

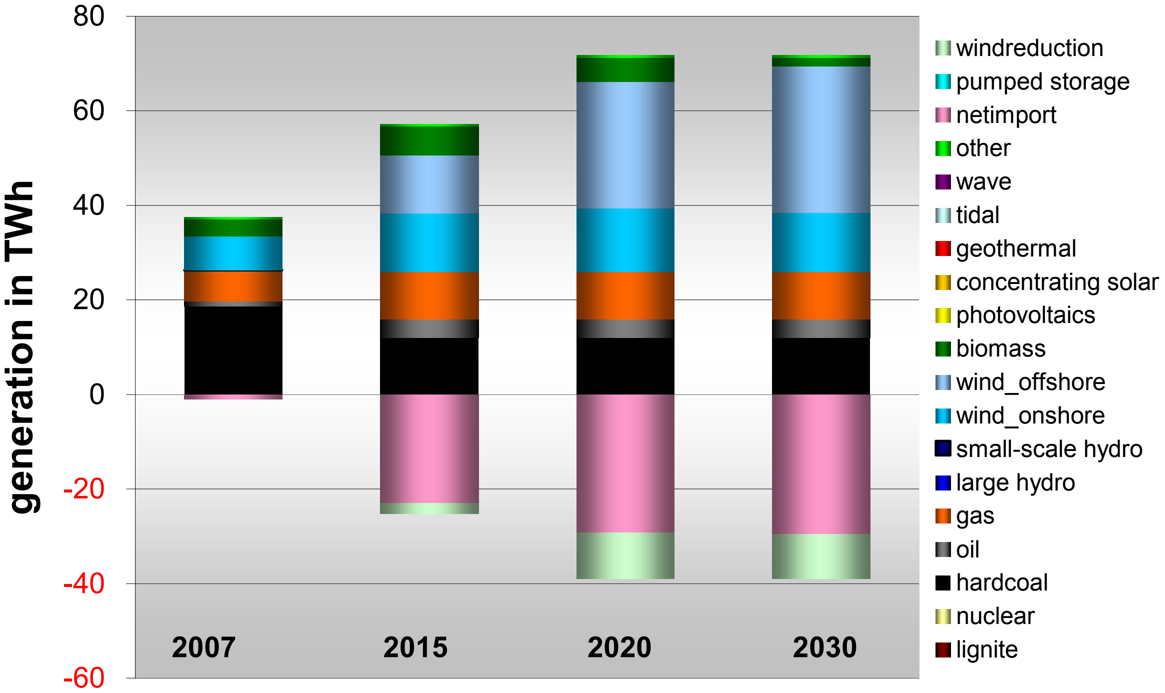
In 2030, UK in the HQS scenario needs to shut down wind power plants in order to maintain system stability. This can be seen as the mint colored area underneath the abscissa in 2030. Since this theoretical generation is included in the generation mix, total generation exceeds demand in this year. This flexibility becomes increasingly important when wind infeed overshoots demand in single hours.

Since windreduction is not sufficient to guarantee system stability at all times, an additional backup technology needed to be implemented in order to reduce the infeed of more decentral generation, such as PV, biomass, etc. This backup flexibility can be interpreted as different kinds of technologies. This is an indication that these regions show future flexibility requirements, which could be solved through, e.g. demand side management or storage solutions. Another flexibility which certainly becomes increasingly important with higher deployment of intermitting RES-E

[49] Regarding conventional power generation in the scenario, different assumptions on relative comodity prices in 2015/2020 could lead to different outcomes in terms of coal and gas generation.

technologies is the possibility to exchange power through cross border interconnections. Figure 7-15 shows the example of Denmark.

Figure 7-15: Example for the usage of NTC as flexibility



Source: EWI.

It can be seen, that RES-E generation exceeds national consumption to a significant degree which makes the flexibilities of wind-reduction and interregional power exchange necessary.

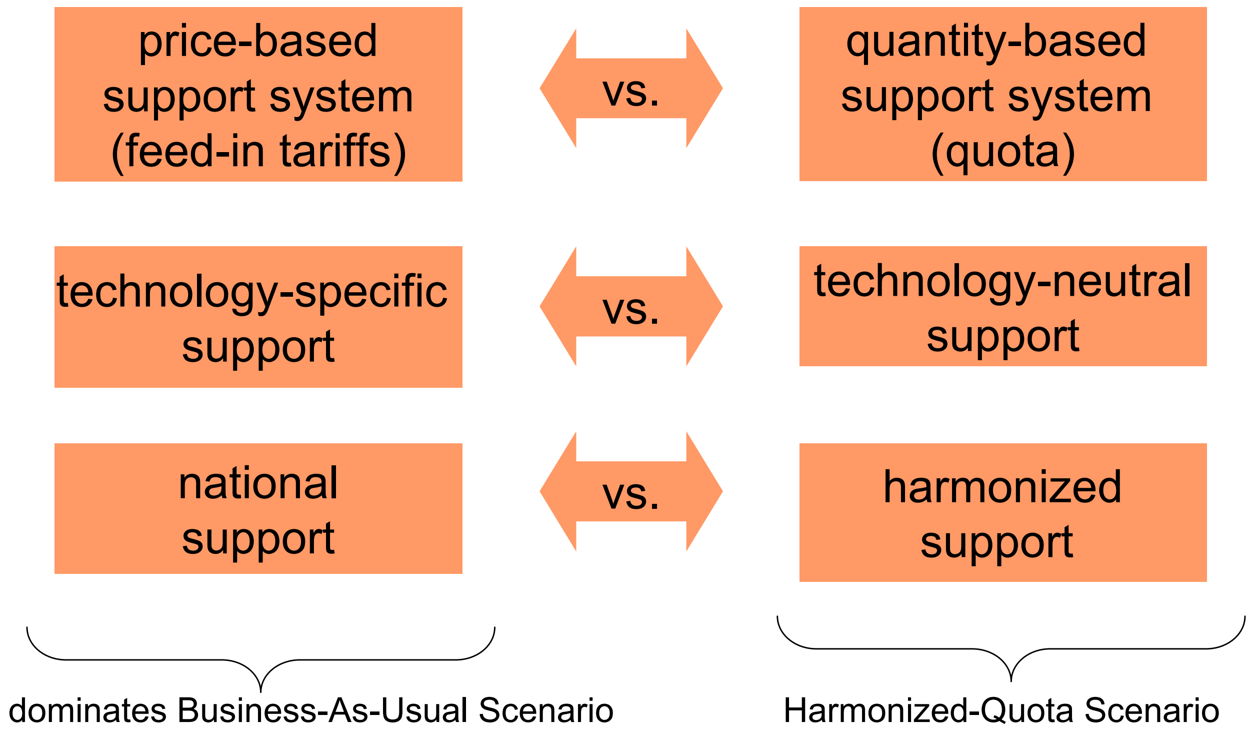
Of course the latter option requires that the exported power can be integrated in the neighboring power system at the particular point in time. This issue requires additional grid and load flow analyses, which are beyond the scope of this study.

8 Comparison of the “Business-as-Usual (BAU)” and the “Harmonized Quota System (HQS)” Scenario

While in the HQS scenario, RES-E is supported by a Europe-wide technology-neutral quota, in the BAU scenario promotion policies of every EU27++ country are modeled in accordance with their current promotion policy. Differences in the outcomes of both scenarios are thus influenced by a RES-E support which differs on three levels: As in BAU most countries have a feed-in tariff system, which in addition in most countries supports RES-E in a technology-specific manner, BAU and HQS differ with regard to the issues of price-based versus quantity-based support and technology-specific versus technology-neutral support (see Chapter 4 for a more detailed explanation).

In addition, currently each country has its own national support system while HQS implies by definition a harmonized support system. Figure 8-1 provides an overview on the different design elements. It is crucial to emphasize that the BAU scenario is neither a baseline scenario, nor a prognosis. As chapter 4 explains, the currently implemented policies are rigorously extrapolated into the future. In reality, these policies become amended on a regular basis to adjust the feed-in tariffs according to the performance of the past years. Therefore, the main weakness of the FIT system, which is the uncertain quantity outcome, is accentuated by this methodology since future policy adaptations are not taken into account.

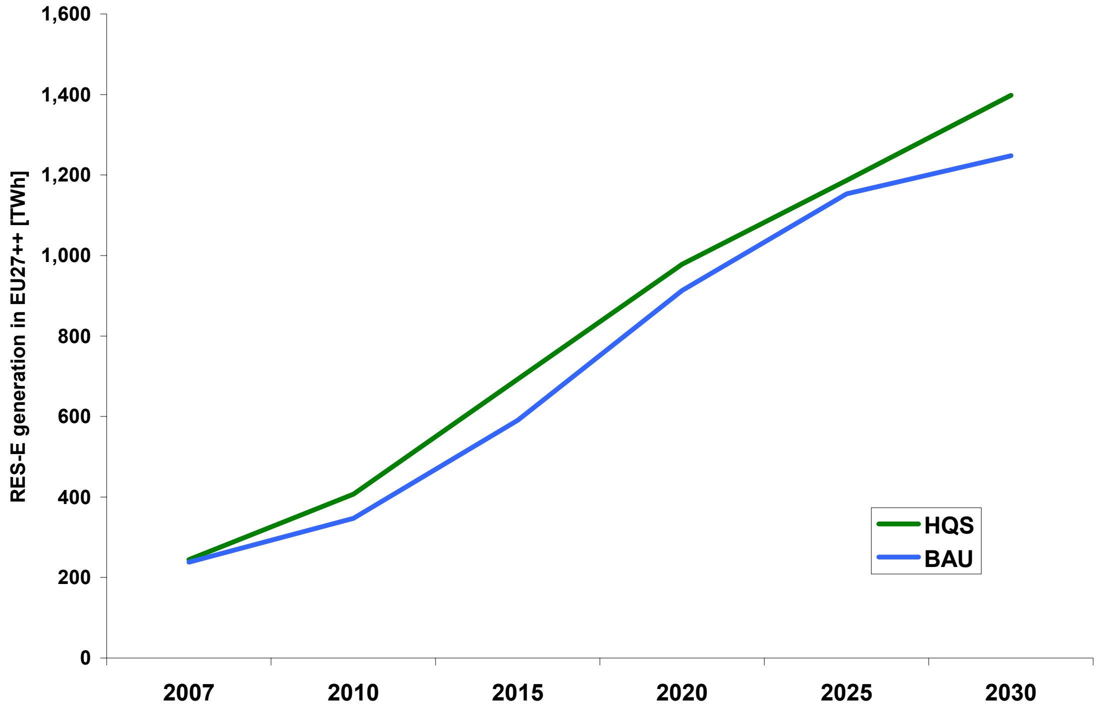
Figure 8-1: Design Differences of the RES-E support systems in BAU and HQS



Source: EWI.

The first difference between the support systems (price-based versus quantity-based support) leads to different RES-E quantity deployment paths in the HQS vs. the BAU scenario (see Figure 8-2). While the quantity-based support leads per definition to a target fulfillment, the price-based support can lead to over- and/or underfulfillments at different points of time.

Figure 8-2: Deployment path of RES-E generation in BAU and HQS (EU27++)

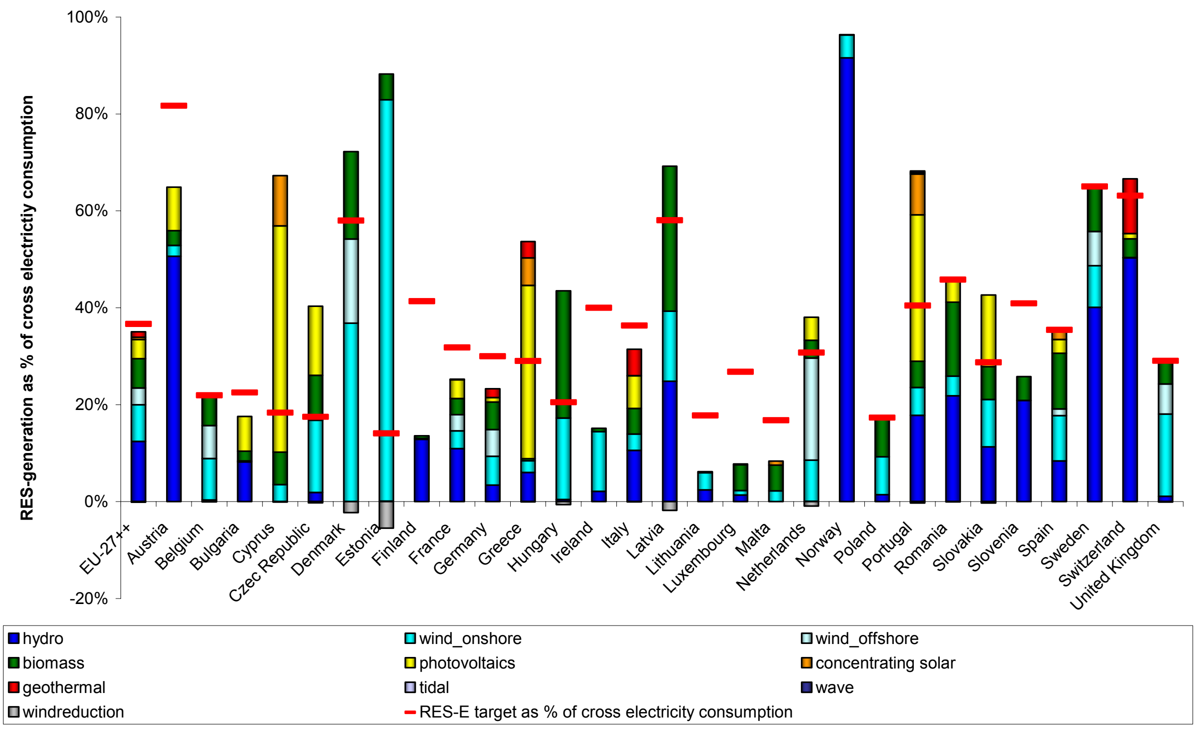


Source: EWI.

While on a EU27++ level the targets are underfulfilled throughout the considered period, on a national level the extrapolation of current promotion systems leads to an undershooting in some but also to an overshooting of the 2020 targets in other countries (see Figure 8-3). In BAU, the attained RES-E shares (as far as the majority of the countries, the FIT-countries, are concerned) result from the maximization of margins by the investors, thus from the design of the feed-in-tariff-system.[50] It is the national setting of the feed-in tariffs which decides whether the national RES-E targets are reached or not.

[50] Note again that in HQS only the EU-wide quota and not the national targets are decisive for the RES-E deployment. An adjustment to the national targets only takes place ex-post via the trade of TGCs.

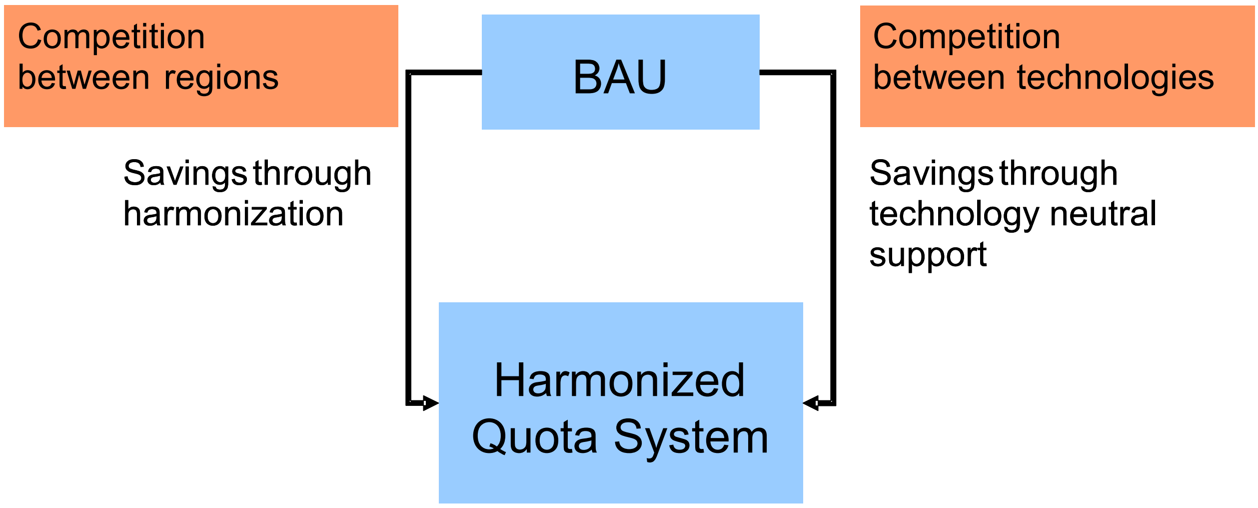
Figure 8-3: RES-E shares vs. RES-E targets 2020 in BAU scenario



Source: EWI.

The differences between BAU and HQS on the other dimensions (technology-specific versus technology-neutral and national versus harmonized support) can be seen in Figure 8-4. While in BAU neither the different RES-E technologies nor the different European regions compete with each other, HQS is characterized by both competition between technologies and competition between regions.

Figure 8-4: Introduction of competition between regions and competition between technologies (switch from BAU to HQS)

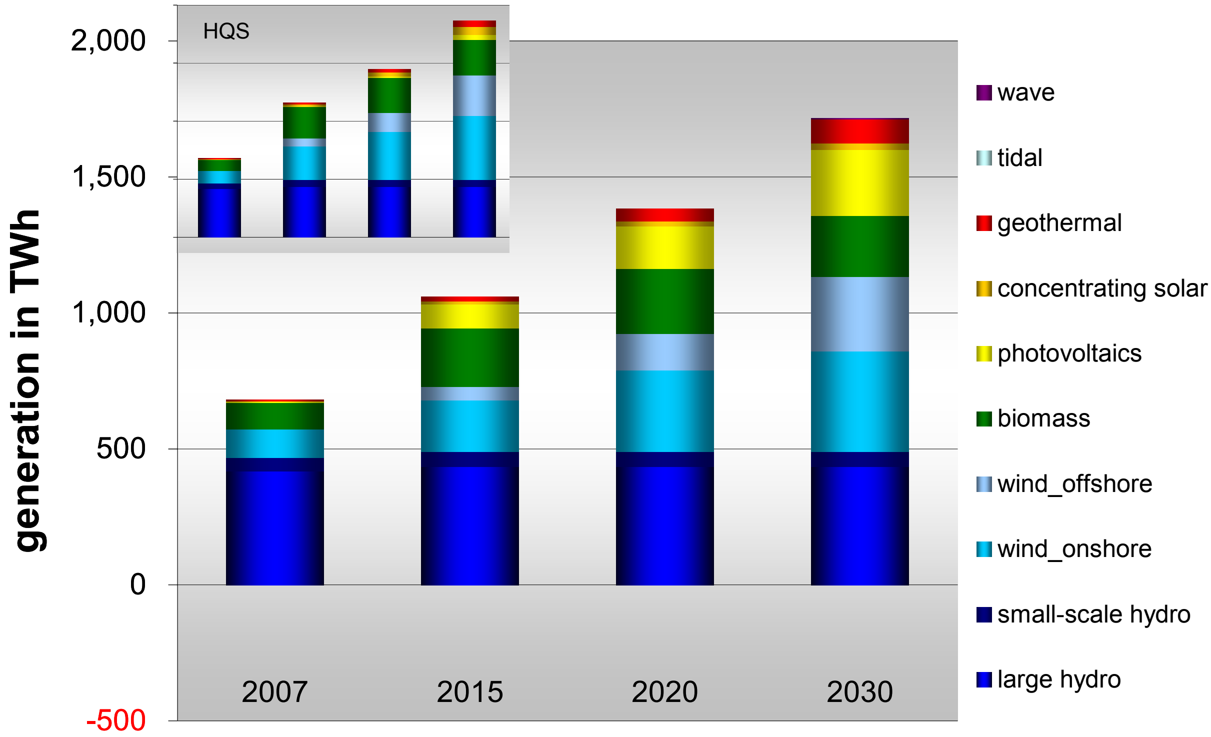


Source: EWI.

Developments in the RES-E submarket

In Figure 8-2 could be seen, that although the total RES-E quantity in EU27++ is lower in BAU scenario that in HQS throughout the considered period, also in BAU the RES-E generation increases significantly from 2007 until 2030. Figure 8-5 shows the contribution of the different RES-E technologies to this increase. As in HQS, the increase is largely driven by wind power, especially by offshore-wind power. In addition, also as in HQS, biomass generation contributes significantly to the high RES-E shares reached during the considered period. In contrast to HQS, rather expensive technologies like geothermal and especially photovoltaics play a largely more important role.

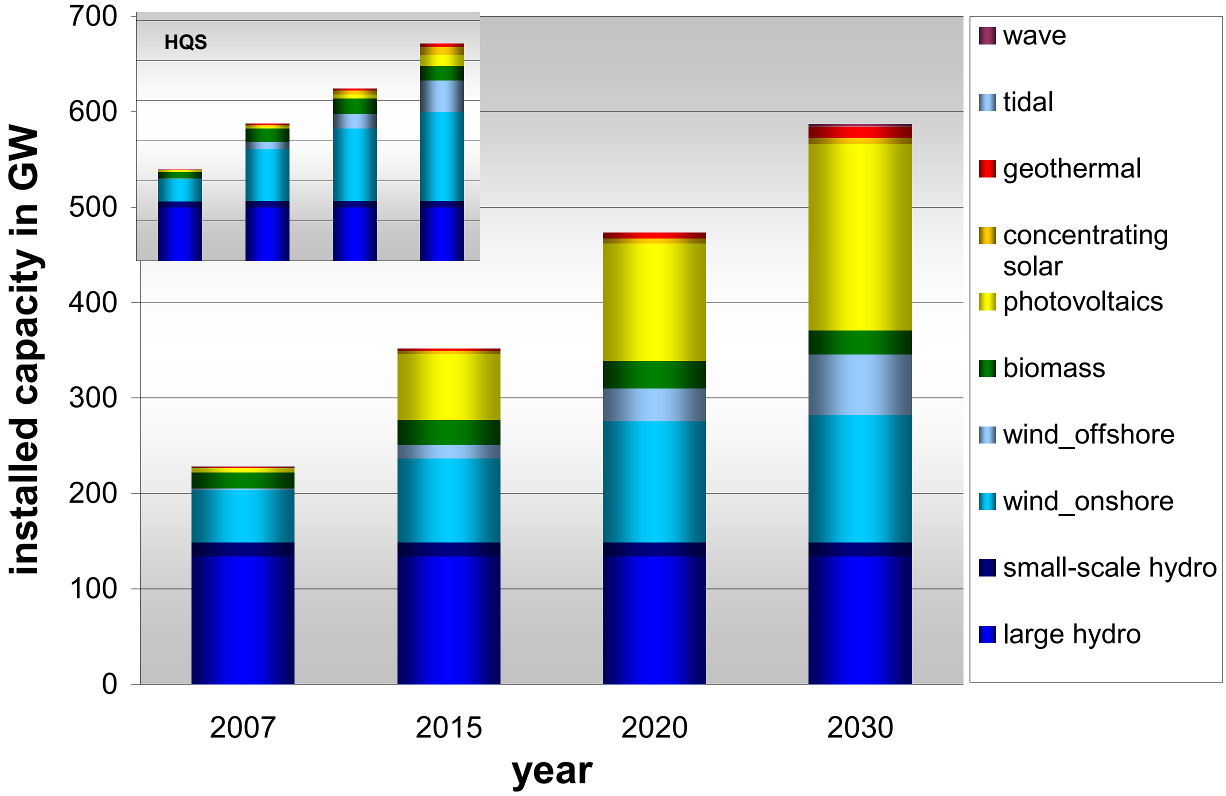
Figure 8-5: RES-E Generation EU27++ in BAU Scenario



Source: EWI.

Comparing the development of RES-E capacities between BAU and HQS, it becomes even more obvious, that BAU is characterized by mainly technology-specific support. As with regard to the RES-E generation, it catches the eye that especially photovoltaics-capacities play a largely more important role in BAU than in HQS. In BAU, the increase in photovoltaics capacity from 2007 to 2030 exceeds the increase in wind power capacity, so that in 2030 the share of photovoltaics and wind (on-shore and off-shore) capacities are nearly equal. Still, with regard to RES-E generation in BAU, wind power contributes more than 2.5 times as much as photovoltaics to total RES-E generation. This reflects that under the BAU scenario in many countries the technology-specific support leads to a photovoltaics deployment also at locations with less favorable potential.

Figure 8-6: RES-E capacities in BAU scenario (EU27++)

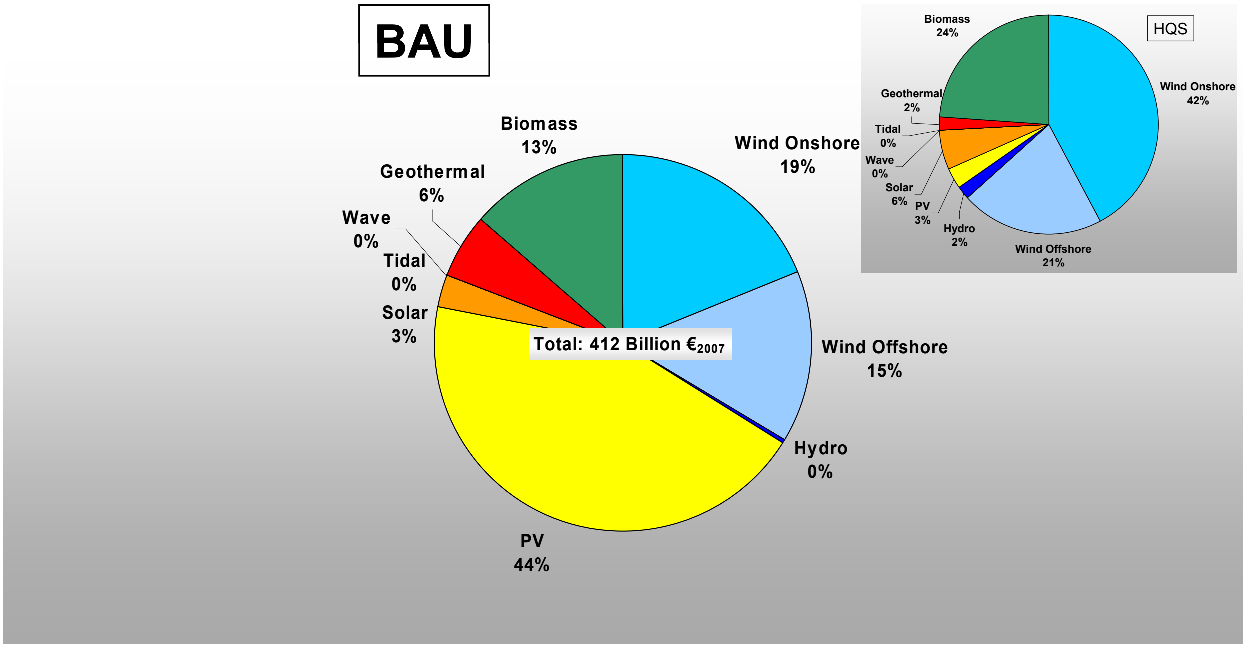


Source: EWI.

Since the RES-E deployment in BAU is not cost-efficient, but based on price-based support, the structure of RES-E investment costs differs significantly from HQS (see Figure 8-7). While in HQS the largest shares of investment costs are spent for wind and thus match with the largest shares of RES-E generation, in BAU the largest share of investment costs is spent for photovoltaics.

A comparison of total investment costs of the two scenarios would be misleading because of the different RES-E deployment paths resulting in each scenario (see Figure 8-2). It still can be noted that while RES-E generation in HQS is higher, cumulated investment costs are lower. This can be easily explained with the different investment structure of the technology shares in Figure 8-7.

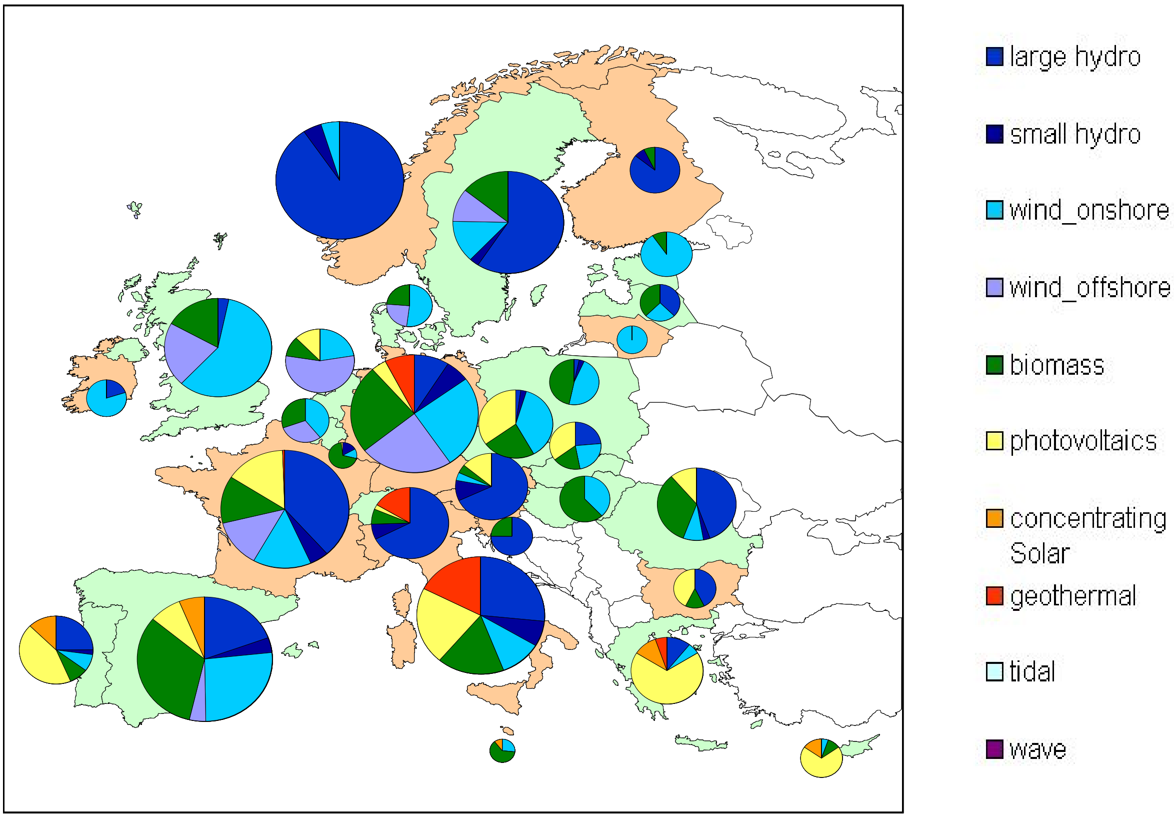
Figure 8-7: Cumulative Investment Costs 2008 – 2020 in BAU scenario (EU27++)



Source: EWI.

Figure 8-8 shows the regional distribution of RES-E generation in BAU. It can be seen that the extent of the technology-competition effect depends on the specific support system design of each country in BAU: This design influences to what extent the RES-E generation mix differs between BAU and HQS. While some countries only support technologies which are also deployed in an optimal RES-E mix for this country and thus show little deviations in the generation mix of the two scenarios, some countries also support high cost technologies at locations with rather low potentials for this technology. For example in France, a significantly larger amount of photovoltaics-based electricity is generated in BAU than in HQS. This results from a support for photovoltaics power which is relatively high in France in comparison to other European countries, especially after 2010, when support payments for photovoltaics in most other countries decrease significantly while remaining on a high level in France. Other countries, especially the quota countries which have a technology-neutral support also in BAU, do not show deviations between BAU and HQS with regard to the RES-E technology-mix. Still, they show deviations with regard to the amount of RES-E produced in the two scenarios. For example Poland and United Kingdom are both countries with high wind potentials which thus do not only fulfill their own quotas in HQS, but also help to fulfill the other countries´ quotas in a cost-efficient manner. For this reason the amount of RES-E generation in HQS in these countries exceeds the one in BAU.

Figure 8-8: RES-E generation mix in BAU (2020)



Source: EWI.

Analysis of potential efficiency gains

The comparison of generation mix, RES-E capacities and investment costs in BAU and HQS indicate that a transition from BAU to HQS would lead to substantial efficiency gains – at least as far as static efficiency is concerned. As pointed out in chapter 3, dynamic efficiency is difficult to measure and is not included in the model calculations.

As pointed out before, a direct cost comparison between BAU and HQS is not possible due to different deployment paths. Comparison would imply that costs are compared for different RES-E quantities. In addition cost differences would arise solely because RES-E deployment takes place at different points in time.

Thus, it has been necessary to build an auxiliary scenario in which the harmonized quota scenario reaches exactly the same RES-E quantity paths in time as in BAU.

The total cost savings (regarding total RES-E costs, which are investment costs, O&M costs as well as fuel costs and heat remuneration for biomass plants)[51] due to a switch from BAU to the auxiliary HQS scenario is 174 bill. $€_{2007}$[52], which is a cost reduction of more than one fourth of the total costs in the BAU scenario.

[51] Note that these cost savings only refer to the RES-E submarket. Costs arising in the conventional power market are not included.
[52] Net Present Value with base year 2007.

9 Discussion of the Cluster Scenario

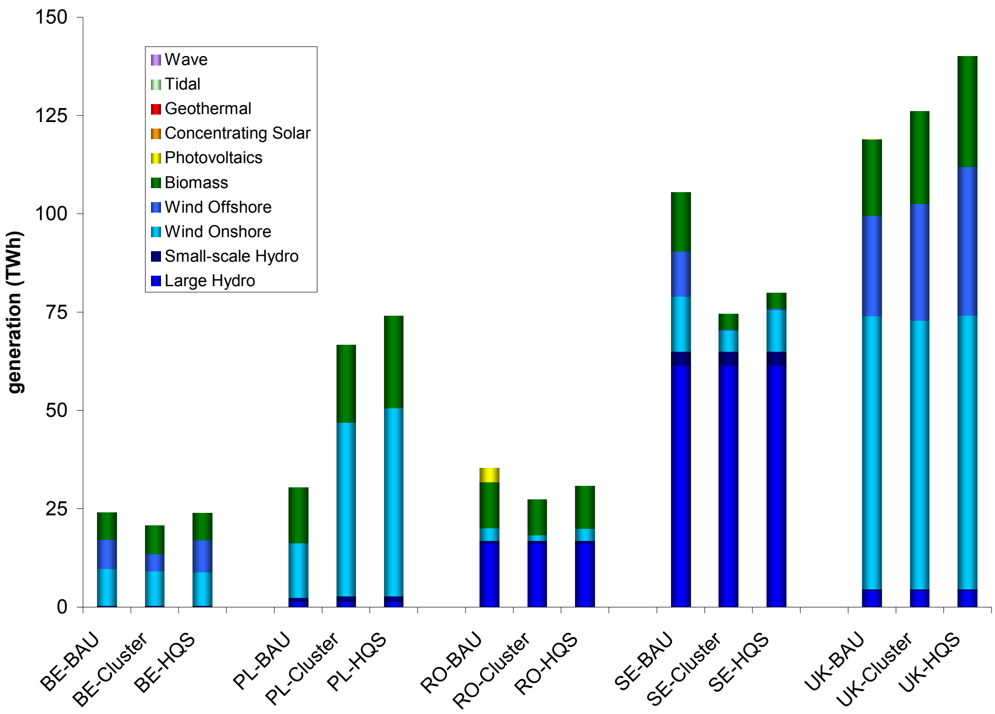
As explained above, the cluster scenario is a scenario in-between BAU and HQS, in which the countries which currently have a quota system (Belgium, United Kingdom, Poland, Romania, Sweden) form a cluster and can thus benefit from harmonization effects within this trade-cluster.

The total generation mix of EU27++ does not change much from the mix in BAU scenario, as the generation mix in the majority of the countries in BAU have a FIT system and are consequently not influenced by the quota cluster. Therefore, this section focuses solely on the countries which participate in the trade cluster.

Taking a closer look at the generation in the five quota countries, it can be noticed that in 2020 in the cluster scenario Belgium, Romania and Sweden generate less RES-E than in BAU.[53] The three countries thus benefit from the possibility to not fulfill their quota on their own but to use the better RES-E potential in UK and Poland. In Poland and UK, the RES-E generation in Cluster exceeds the one in BAU because they fulfill not only their own quota but also partly the quota of other quota countries. In HQS the RES-E generation is even higher than in Cluster, since UK and Poland still have good wind potentials which can be used to help to fulfill the quota of other countries and thus to contribute to a European-wide least cost RES-E deployment.

[53] In 2020 United Kingdom and Poland generate more RES-E in Cluster than in BAU.

Figure 9-1: Differences in the RES-E generation 2020 between Cluster, BAU and HQS

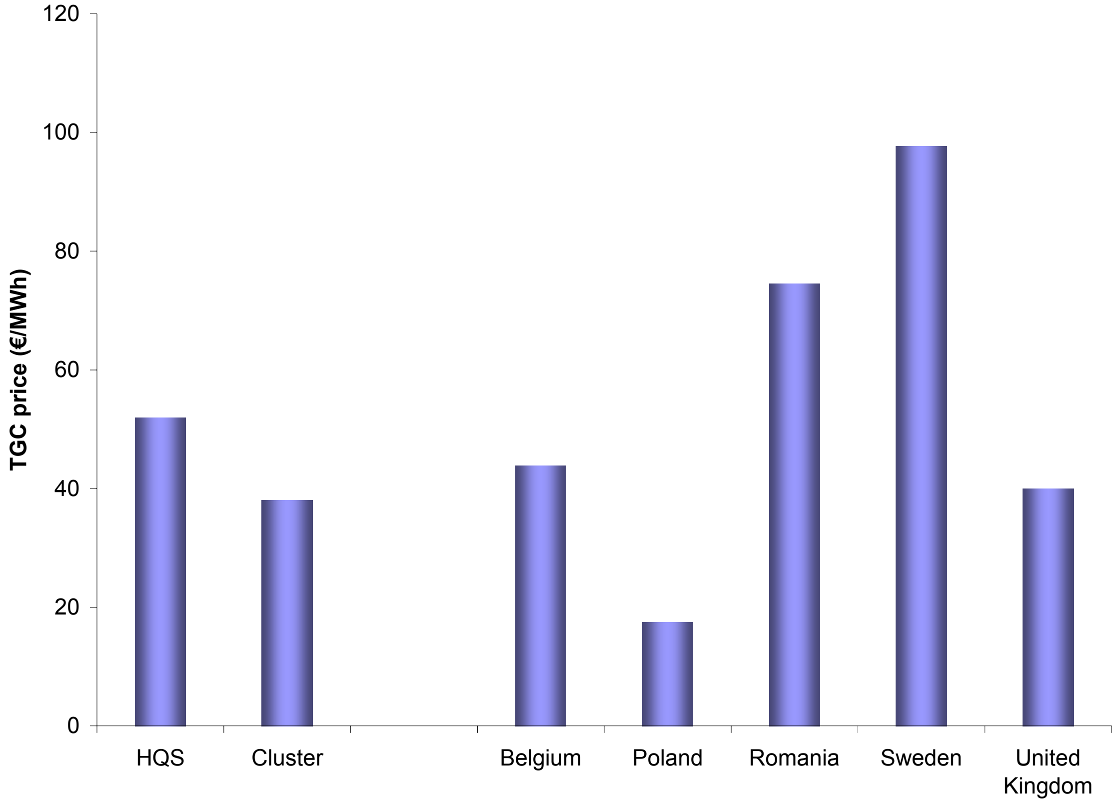


Source: EWI.

As a consequence of the use of better RES-E locations, cost savings of 35 bill. €$_{2007}$ (accumulated between 2008 and 2020) compared to BAU can be realized. It can be seen that Romania avoids the utilization of PV by switching to the Cluster scenario and Sweden avoids the deployment of offshore wind power. While the additional generation stems mainly from wind power and biomass from Poland and the UK.

In addition, a comparison of the certificate prices in the three scenarios also shows the effect of a use of more favorable RES-E locations. Figure 9-2 depicts the certificate prices in 2020, which result in each scenario from the intersection between the quota obligation and the marginal costs of the most expensive RES-E technology needed to fulfill the quota. By definition of the different scenarios, each quota country has an independent certificate price in BAU while there is only one common certificate price in Cluster and HQS for all participating countries.

Figure 9-2: Certificate Prices in 2020 in HQS, Cluster and BAU



Source: EWI.

Comparing the certificate prices in HQS and Cluster, it can be seen that the participating countries in Cluster have altogether relatively favorable resource potentials compared to their cumulated target. This effect can also be seen by the generation comparison in Figure 9-1. The RES-E generation in Belgium, Romania and Sweden is the lowest in the Cluster scenario because they benefit from the exports from Poland and UK. In HQS, these three countries generate more RES-E to contribute to the Europe-wide target fulfillment. However, in BAU, especially Romania and Sweden pay a high price for their isolated support scheme.

10 Conclusion – Lessons Learned and Implications for Future Developments

According to the assessment of regional RES-E potentials, the EU-wide RES-E target is feasible – however posing significant challenges for the development of the conventional power system.

Since the HQS is the only scenario which reaches the European RES-E targets due to the quantity-based setting, and since it does so at minimal RES-E generation cost, this normative scenario is at the center of our discussion. We summarize the main findings of HQS and compare it with the scenarios BAU and Cluster. This order emphasizes that this study includes comparative scenario analyses and no forecast. Scenarios are extrapolations under given sets of assumptions. They do not reflect most likely developments. Especially, our BAU scenario freezes current national RES-E promotion laws. It does not include likely, but in detail unforeseeable adaptations of these laws.

RES-E support in HQS Scenario

1. RES-E Generation Mix

In HQS RES-E are promoted in a Europe-wide and technology-neutral manner. Optimization of RES-E deployment takes into account regional RES-E generation costs and national power prices.

In HQS, intermitting wind power deployment plays a dominant role. Especially the currently still uncertain deployment of offshore wind increases significantly in HQS. Still expensive technologies like photovoltaics or geothermal power are hardly deployed under technology-neutral support.

2. RES-E costs

The **investment costs** in the HQS scenario are bill. 313 €$_{2007}$ accumulated net-present value between 2008 and 2020. The dominant technologies are wind onshore with 42%, wind offshore with 21% and biomass with 24%. The remaining 13 % are spent for less mature technologies, with a 6% share of concentrating solar as the largest share of the minor technologies.

3. Regional Distribution and TGC Trade Streams

Since the harmonized quota scenario calculates one single Europe-wide RES-E quota, the individual national targets are reached through an ex-post TGC trade. It is important to note that national RES-E targets have not been defined by all MS yet. Therefore in this study these targets needed to be assumed.

Some MS with low or expensive resource potentials gain from buying certificates to reach their targets, while MS with larger potentials and relatively low targets gain from deploying additional RES-E above their targets and selling TGCs on the market. Mainly countries with a high wind power potential deploy RES-E above their national target. Within the target setting, the wealth of the individual MS has been taken into account. Eastern European countries received lower targets according to their GDP. Therefore, it can be seen that altogether the 12 Eastern European countries are net-exporters of TGCs due to their comparatively low RES-E targets. However, since some Eastern European MS have still considerable demand growth rates, the target fulfillment can also require these countries to become net importers. Altogether, the 15 Western European MS import TGC with a value of 3.9 bill $€_{2007}$ in 2020 when a GDP weighted target setting is assumed, and 4.6 bill $€_{2007}$ when a GDP per capita target-setting is assumed.

4. Harmonization Gains

In this study harmonization gains are defined as cost savings in RES-E generation (investment, O&M, fuel costs and heat remuneration), solely through a switch from national to harmonized support. In order to calculate these savings, the harmonized quota scenario is compared with an auxiliary scenario which differs only in this respect. Therefore, the auxiliary scenario simulates national technology-neutral quota systems. The potential RES-E cost reduction between these two technology-neutral scenarios is bill. 118 $€_{2007}$ accumulated net present value 2008-2020. It is important to note that this harmonization gain in RES-E generation may be counteracted by additional costs of e.g. grid enhancements due to higher concentration of intermitting RES-E in certain regions resulting from harmonized support. Grid costs and additional costs in the conventional power systems are not considered in this study, but would need to be assessed to find an overall efficient solution.

Conventional Power Market in HQS Scenario

5. Total Generation Mix

The RES-E share in the EU27 rises to a significant degree of roughly 34 % in 2020 and 45 % in 2030, due to the quantity-based target setting.

Power generation from lignite remains approximately constant, due to relatively low costs of providing lignite from indigenous mines. Nuclear power generation remains an important energy source in the European generation mix. The share of hard coal shrinks in the generation mix, also due to the relevance of the CO_2 price and the lower demand for conventional generation. Due to its lower CO_2 intensity, higher flexibility, and relatively low investment costs natural gas will play a relatively larger role in the power generation mix.

6. Capacity Effects and Shift in Power Plant Utilization

Since RES-E cover an increasing share of demand, the utilization of the installed conventional power capacities is reduced. In the longer run, this results in a shift towards a higher share of peak load capacity and a smaller share of base load capacity. In addition, sufficient backup capacity needs to be installed since only a small share of the RES-E capacity can be counted as securely available capacity. This results in a hardly reduced demand for conventional power capacity in order to fulfill the required security of supply. Altogether the total installed (renewable and conventional) generating capacity rises significantly to fulfill both the RES-E targets and the system adequacy criterion.

7. Required Flexibilities in the Power Market

The intermittent wind power and to a lesser extent photovoltaics infeed changes the patterns of the power market in most regions significantly. In addition to demand structures, especially wind situations become increasingly important for the power plant dispatch. Especially hours with low demand and high wind power infeed challenge the power system.

- The model results show that in hours with low load and high wind power infeed, notable shares of wind infeed are turned down. The absolute amount of turned-down wind infeed rises over the years, which shows increasing integration challenges. This indicates that the possibility of wind power reduction is important to guarantee system stability at all times.
- Additionally, the model requires a backstop technology, which is utilized if generation from other RES-E exceeds load. This indicates demand for additional flexibilities in the power system, which could be provided by various measures, such as additional power storages, demand-side management in industry or households, or more flexible RES-E infeed, e.g. through a more demand-oriented dispatch of biomass-fired plants.
- The model results also show that electricity exports increase in countries with high shares of wind power. This indicates additional demand of both cross border transmission capacities and national grid enhancements. The reason is that wind power generation is relatively concentrated regionally compared to other RES-E technologies and that the transport of electricity to demand regions becomes increasingly challenging. Endogenous extensions of the electricity grid were however not considered in this study.

Comparison with BAU Scenario

While in the HQS scenario, RES-E is supported by a Europe-wide technology-neutral quota, in the BAU scenario promotion policies of every EU27++ country are modeled in accordance with current policies. For the majority of countries this implies RES-E support by a technology-specific feed-in tariff system. Differences in the outcomes of both scenarios are thus influenced by a RES-E support which differs with regard to the issues of price versus quantity-based support and technology-specific versus technology-neutral support.

8. RES-E generation in BAU

The mainly price-based support in BAU leads to a lower RES-E deployment than HQS throughout the considered period. (In reality, of course tariffs are likely to be adjusted, if failure of target achievement is anticipated.) Also in BAU the RES-E share increases significantly to 32% in 2020. As in HQS the increase is largely driven by the deployment of wind power, especially offshore-wind power. In addition, again similar to HQS, biomass generation contributes significantly. In contrast to HQS, rather expensive technologies like geothermal and especially photovoltaics play a more important role.

9. RES-E costs in BAU

In the BAU scenario the investment costs of bill. 412 €$_{2007}$ (accumulated NPV 2008-2020) are dominated by photovoltaics (44%) and sizeable shares of wind onshore (19%) and offshore (15%) as well as biomass (13%).

When it comes to the comparison of the generation mix, RES-E capacities and investment costs in BAU and HQS indicate that HQS contains potential efficiency gains within the RES-E sector. A direct comparison of costs between BAU and HQS is however problematic, due to the different quantity deployment paths. Thus, it has been necessary to build an auxiliary scenario in which the harmonized quota scenario reaches exactly the same RES-E amount as in the BAU scenario with the same timely deployment path. Total RES-E cost savings of a switch from BAU to the auxiliary HQS is 174 bill. €$_{2007}$ net present value accumulated 2008-2020. These cost savings arise from two effects, first due to the change from a national to a EU-harmonized support, and secondly due to the change from a mainly technology-specific to a technology-neutral support of RES-E in Europe.

Comparison with the Cluster Scenario

The cluster scenario is a scenario between BAU and HQS, in which the countries which currently have a quota system (Belgium, United Kingdom, Poland, Romania, Sweden) form a cluster and can thus benefit from harmonization effects within this trade-cluster. Countries which currently support RES-E by feed-in tariffs, bonus systems or tax incentives, are modeled as in BAU.

10. RES-E generation in Cluster

On a EU27++ level the generation mix in the Cluster scenario does not change much from the mix in BAU, as generation in the majority of countries in BAU have a FIT system and are consequently not influenced by the quota cluster.

Within the cluster countries, it can be noticed that in 2020 Belgium, Romania and Sweden generate less RES-E than in BAU. The three countries thus benefit from the possibility to not fulfill their quota on their own but rather import TGC from UK and Poland. As a consequence of the use of better RES-E locations, cost savings of 35 bill. $€_{2007}$ accumulated NPV 2008-2020 compared to BAU can be realized.

11. Outlook

Currently, many different promotion schemes for electricity generation from renewable energy sources (RES-E) are in effect in Europe. A more harmonized approach would enable to utilize considerable cost-savings in RES-E generation, as a result of competition between plant locations. In addition, the introduction of competition between technologies would lead to substantial cost-savings. Such efficiency gains however have to be balanced with additional integration costs, especially grid costs due to a regionally more concentrated deployment of some RES-E technologies under a more harmonized and technology-neutral promotion scheme. A detailed balancing of such costs and benefits of harmonization has not been considered in this study.

Utilizing cost-efficient RES-E potentials throughout Europe is essential. Therefore, an integrated geographical and intertemporal optimization is crucial to balance the different lead times, lifetimes and deployment times between the grid infrastructure as well as conventional and renewable generating capacities. One can conclude that while a more EU-harmonized approach to RES-E promotion than in place today is certainly recommendable, a strategy for optimum integration of RES-E calls for further research, encompassing aspects of both generation and transport of electricity in Europe.