Improvement of the Social Optimal Outcome of Market Integration of DG/RES in European Electricity Markets

# Scenarios for DG/RES energy futures on case study, country and European level

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*Project objectives*

The IMPROGRES project aims to identify possible improvements in the social optimal outcome of market integration of distributed generation (DG) and electricity production from renewable energy sources (DG/RES) in European electricity markets. This will be achieved by:

- Identification of current interactions between DG/RES businesses, distribution system operators (DSOs) and energy markets in coping with increased DG/RES penetration levels.
- Developing DG/RES scenarios for the EU energy future up to 2020 and 2030.
- Quantifying the total future network costs of increasing shares of DG/RES for selected network operators according to the DG/RES scenarios.
- As a comparison to regular DSO practices, identify cost minimising response alternatives to increasing penetration levels of DG/RES for the same network operators.
- Recommend policy responses and regulatory framework improvements that effectively support the improvements of the socially optimal outcome of market integration of DG/RES in European electricity markets.

*Project partners*

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- Liander NV, The Netherlands
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# CONTENTS

# EXECUTIVE SUMMARY

The recently observed increase in renewable energy sources/distributed generation (RES/DG) in the European electricity system is most likely to continue or even increase its growth rate in the future. Distributed Generation (DG) as one core focus of the IMPROGRES project is mainly meant to be connected to distribution grid areas. Thus, Work Package 3 of the project aims at deriving scenarios for DG/RES energy futures on case study, country and European level in order to provide a basis for further calculations on the economic impact of DG on overall system costs in a latter stage of the project (compare IMPROGRES project Report D5). The time horizon analysed therefore is set between 2005 and 2030 in order to calibrate the model according to historic developments with respect to possible future evolvements.

Countries and case study regions where the installation of additional DG/RES is analysed are located in the Netherlands, Germany and Spain, These areas have different characteristics in terms of already existing load and the type of generation installed whereas the penetration levels evaluated can vary significantly. For derivation of future DG/RES scenarios the simulation software **Green*Net*** has been updated for specific needs of the IMPROGRES project. **Green*Net*** has been developed within the Fifth Framework project **Green*Net*** (EU-15) and has recently been extended in the EIE project **Green*Net* – EU27** to the EU-27 region and, finally, the Western Balkan region was included in the EIE project **Green*Net* -Incentives** in 2009 (finally covering the major 35 European countries). The model is capable to derive future DG/RES development scenarios on an aggregated basis (e.g. EU-27 region as a whole) as well as on disaggregated country (e.g. The Netherlands) or even case specific level (e.g. case study region in Spain).

One of the already mentioned case study areas is located in Spain named Aranjuez, which is an urban and semi-urban area with about 60.000 customers and mainly wind and CHP capacity currently installed. In the future, photovoltaic (PV) capacity is also expected. DG is concentrated in a few specific places. Up to 35% DG penetration levels are expected for 2020. High voltage, medium voltage and low voltage distribution networks are considered. Another case study area is located in Kop van Noord Holand in the Netherlands, which is a semi-urban area with 80.000 customers and very large in size (800 km²). DG installed and expected is mainly wind and CHP and DG penetration levels, which are already very high, will probably reach 500% of the contracted load in 2020. Only high voltage and medium voltage distribution networks are considered. The entire grid must be built underground. The third area is located in Mannheim in Germany. It is a residential area with about 6000 customers where generation expected is PV and Micro-CHP located within the households of consumers. DG penetration levels are nowadays negligible but are expected to reach about 30% of the contracted load in 2020. Only medium voltage and low voltage distribution networks in this area are considered.

On country level the existing and future potentials of DG/RES were updated according to results of national or international studies, ongoing projects as well as expert estimations. The data inputs provided were implemented, updating the existing **Green*Net*** database for each country analysed. In addition to that, a very similar database update was performed for the case studies in the Netherlands, Germany and Spain on a more disaggregated level taking into account solely realistic DG/RES technologies applicable for the region.

Furthermore, scenario projections until 2030 are performed based on **Green*Net*** simulation results. Therefore, inputs of recent reports of the European Commission (EC) including the PRIMES model (for a model description see [9]) scenarios (compare [4] and [5]) are used to

identify a possible DG/RES development gradient in order to perform projections beginning from 2020 until 2030. In addition to the DG/RES simulation results and projections until 2030 a further update was performed taking into account conventional CHP developments. Again according to the PRIMES 2007 model (compare [4]) data on conventional CHP generation and capacity development is added to the derived **Green*Net*** scenarios.

As it was decided to use BAU scenario and policy settings (2005) of **Green*Net*** it must be mentioned that policy changes of course influence the future DG/RES scenario evolvement. For example such policy changes influence photovoltaic or solar thermal development significantly due to better subsidiary conditions. But, as these national policies may change from year to year, it was decided within the IMPROGRES project to keep originally implemented policies within the **Green*Net*** software focusing on DG/RES potential updates in order to provide concise scenarios for all countries and case studies analysed. In general, these scenarios should provide a better understanding of which tendencies of DG/RES energy futures can be expected on country as well as specific case study level. Overall, these tendencies – even if they are not considering most recent policy updates – imply a significant growth of DG/RES on European as well as on national levels. As a result, distribution grids are further charged and put to their limits by integration of renewable electricity generation (RES-E) and of course conventional generation technologies.

Simulation results show, that on European level according to a Business As Usual (BAU) scenario total DG/RES electricity generation within the EU Member States (EU-27) increases from 490 TWh/yr in 2005 to about 1280 TWh/yr in 2030. While generation from DG/RES technologies like hydro power and biowaste remain almost stable, especially for wind power, biomass and biogas a considerable increase up to 2030 can be observed. The share of electricity generated from DG/RES regarding overall electricity demand increases from about 15% in 2005 to approximately 26% in 2020. According to the reference scenario wind power (onshore and offshore) is likely to be the dominant DG/RES technology up to 2030. Within this technology also offshore installations are becoming increasingly important as from 2010. Besides that, also future promising technologies like PV and solar thermal electricity show increasing installations as from 2013.

On country level the BAU scenario results in an overall DG/RES capacity increase from 1797 MW in 2005 to about 10600 MW in 2030 within the Netherlands. Conventional CHP development increases from approximately 9300 MW in 2005 to about 11100 MW in 2030. The Dutch DG/RES technology mix consists basically of wind power, biomass and biowaste with very little shares of hydro power and a growing photovoltaic development as from 2010 (see Figure 11). Compared to Germany also in the Netherlands the wind potential is significant whereas limited potential at economically feasible prices for hydro power and photovoltaic technologies can be observed there due to the geographic conditions in the country.

With respect to Germany the BAU scenario indicates a total DG/RES capacity increase from 24600 MW in 2005 to about 75000 MW in 2030. Conventional CHP development decreases from 36900 MW in 2005 to about 30000 MW in 2030. As well as in the Netherlands the German DG/RES technology mix consists basically of wind power with big offshore potentials, biomass, biogas and hydro power but with very little shares of biowaste and a constantly growing photovoltaic potential as from 2005. On the other hand in comparison to Spain the photovoltaic potential is limited because even high feed-in tariffs are not able to compensate the relatively low yearly full load hours in the least cost approach.

In Spain the BAU scenario derives a total DG/RES capacity increase from 23400 MW in 2005 to about 69400 MW in 2030. Conventional CHP development keeps constant at approximately 7000 MW. The DG/RES technology mix in Spain consists basically of hydro power followed by wind power with minor offshore potentials. Biomass, biogas, solar thermal, tidal as well as photovoltaic technologies also show significant and growing shares as from 2010. Also high shares of solar energy utilisation can be realised.

On case study level within the Dutch case total wind power capacities increase from 87 MW in 2005 (including already existing installations) to about 491 MW in 2030 within the High and from 86 to 331 MW in the Low scenario. It is worth mentioning that the internal model scenario settings are chosen equal to country level in order to derive concise scenarios.

In Germany photovoltaic capacity development within the case study area increases from 1 MW in 2005 (including already existing installations) to about 16 MW in 2015 within the High and from 1 to 10 MW in the Low scenario. As from 2015 there is no additional Photovoltaic capacity installation any more. This is due to the currently implemented yearly decrease of the feed-in tariff for photovoltaic electricity generation in Germany. Costs for photovoltaic installations are too high and therefore economically not feasible in the least cost approach of **Green*Net***.

In the Spanish case study region there is capacity development for both wind and photovoltaic (PV) generators. Capacity development of PV until 2030 starts from about 0 MW in 2005 increasing to 80 MW in the High and to about 22 MW in the Low scenario. Wind starts at 12 MW in 2005 and increases to 56 MW in the High and 34 MW in the Low scenario. Again the development after 2020 is projected using forecasts in [4].

Taking into account a High Price Scenario, incremental changes of DG/RES developments were observed in the countries analysed, resulting in increases between 0.1% and 14.4% of total DG/RES installations depending on the country specific technology mix.

In further analysis an allocation of overall **Green*Net*** simulation results (incl. conventional CHP) to distribution level was performed. Average values (excluding wind offshore) show that DG/RES capacities are likely to be allocated to distribution level between 43% and 75% depending on the definition of distribution level (Netherlands ≤150kV 43%, Germany ≤110kV 61%, Spain ≤145kV 75%).

With respect to grid integration cost in the Netherlands, overall grid reinforcement cost increases to about 12 million € per year due to installed wind capacities (onshore and offshore). Due to about 6.3 GW of newly installed wind capacities in 2020 this results in approximately 1.9 €/kW of yearly grid reinforcement cost. In Germany, as from 2013 network reinforcement costs due to wind offshore installations get higher than for onshore technologies. This results in about 3.4 €/kW of yearly grid reinforcement cost if total wind capacities are ~34.4 GW in 2020. In Spain, compared to a newly built wind capacity of ~14.3 GW this results in a yearly cost of ~2 €/kW.

As one major part of grid integration cost, grid connection expenditures also rise in the future due to wind installations. In the Netherlands approximately 10.6 €/kW can be expected as yearly payments according to grid connected wind capacities. In Spain 6.7 €/kW of yearly cost due to lower wind offshore installations can be expected. On the contrary, in Germany high wind offshore capacities increase this yearly cost to about 20.3 €/kW.

As **Green*Net*** derives grid related cost calculations solely on country level it is not possible to derive cost components for grid connection and grid reinforcement for case studies as the modelling approach cannot be applied for specific network areas. Each grid segment has its specific historical development and geographically evolved design. Even loads and generation in the areas may highly deviate from average country values. Thus, it is neither possible to allocate country related cost elements to case study levels due to many differences of locally organised grid structures nor it can be performed the other way around. Detailed case study results are not eligible to perform projections on country or even European level. Therefore, the IMPROGRES project should provide a better understanding of DG/RES cost impacts from the energy systems' and societies' point of view. As a substantial contribution to that, the scenarios of DG/RES deployment derived in this report give a better insight to future DG/RES developments as well as grid integration cost developments.

Summarising, all **Green*Net*** simulation results show a significant growth in DG/RES capacities on European, country as well as on case study level. In addition to DG/RES development also conventional CHP capacity development is expected to increase in most of the analysed countries. With respect to wind capacities, significant grid related cost increases due to grid connection and grid reinforcement measures can be expected. Furthermore, calculation results show that in average ~60% (average value for the three countries) of DG/RES are to be connected to distribution levels. Hence, negative as well as positive cost impacts on overall system cost need to be evaluated in detail within specific case studies. This analysis will be performed in Work Package 4 of the IMPROGRES project.

# 1 INTRODUCTION

Concerns over security of supply and climate change are driving policies in the EU that will enable a significant increase in renewable energy sources/distributed generation (RES/DG) in the European electricity system in the coming decade and beyond. Distributed Generation (DG) as one core focus of the IMPROGRES project is mainly meant to be connected to distribution grid areas. These distribution grid areas are defined by specific voltage levels within each European country in a different way. Furthermore, due to the increase of electricity supply from DG and intermittent sources, the recurrent costs (e.g. line losses, grid operation) will increase as well. At the same time, in certain niches and at low penetration levels, DG/RES is often said to reduce overall system costs. Even more, it is expected that the cost of renewable electricity will decline over time, resulting in more competitive distributed generation units compared to conventional electricity supply. Yet, as partly indicated above, at least in the short to medium run the grid integration costs may increase substantially with a rising share of DG/RES in the electricity mix. Network innovations such as active network management, respond options as well as aggregation of system services by DG/RES generators and flexible loads facilitating “virtual power plants” may offset these cost increases to some extent.

This is why the IMPROGRES project analyses the impact of large scale DG/RES deployment in distribution grids for the whole electricity supply system, i.e. considering the interactions and trade-offs between the physical and economic system as power generation (incl. DG/RES), transport (transmission and distribution networks), energy wholesale trading and retail supply, system services (balancing, power reserves, ancillary services) and energy consumption (incl. demand response). Furthermore, the boundary conditions such as policy (support schemes) and regulation (e.g. network regulation) are of essential importance. Also external effects will be considered (e.g. environmental impacts). To avoid a too generic and only qualitative approach the analysis of the total supply system will be applied for three concrete cases for which quantitative data are available.

In order to provide a basis for further analysis in a latter stage within the IMPROGRES project the focus of this report is laid on future DG/RES development within selected European countries and specific case study regions including calculations on grid related cost (e.g. for necessary grid reinforcements).

## 1.1 Research topics

The core model to be used to derive the DG/RES scenarios of this report is the simulation software **Green*Net***. **Green*Net*** has been developed within the Fifth Framework project **Green*Net*** (EU-15) and has recently been extended in the EIE project **Green*Net* – EU27** to the EU-27 region and, finally, the Western Balkan region was included in the EIE project **Green*Net* -Incentives** in 2009 (finally covering the overall 35 European countries). The model is capable to derive future DG/RES development scenarios on an aggregated basis (e.g. EU-27 region as a whole) as well as on disaggregated country (e.g. The Netherlands) or even case specific level (e.g. case study region in Spain). Thus, the **Green*Net*** software provides simulation results on DG/RES developments as a basis to analyse the impact on the whole electricity supply system within the IMPROGRES project.

The following main research questions are addressed within this report:

- DG/RES Scenarios on country and case study level

    - *Reference scenario* - The reference scenario in **Green*Net*** uses the default settings of the currently implemented DG/RES policy promotion instruments, cost allocation philosophies of DG/RES grid integration (deep versus shallow approach), demand scenarios, primary energy price scenarios, electricity price scenarios, baseline settings of "soft parameters" like socioeconomic/administrative barriers etc. within each country analysed. Even more this analysis can be performed even on a more specific case study level which should enable a more system related view (e.g. a future DG/RES deployment reference scenario can be derived for a preliminary chosen distribution grid area as well).
    - *Alternative scenario* - In order to derive an alternative scenario (and to conduct sensitivity analyses in relation to the reference scenario) in the simulation model **Green*Net*** variations are possible for several parameters described above. Within this report a variation of the electricity price is performed and analysed.

- Scenario analysis and assessment of grid related cost

    - Based on derived energy futures cost for DG/RES grid integration are calculated up to 2020 taking into account grid connection and grid reinforcement cost on country level.

In this report three countries (the Netherlands, Germany and Spain) will be analysed in detail as three distribution system operators (DSOs) provide quantitative data for case specific analysis within these countries.

## 1.2 Methodology

As mentioned above, this report derives different scenarios on future development of distributed generation and renewable energy sources (DG/RES) on European, country as well as disaggregated case study level. Therefore, mainly results based on the software tool **Green*Net*** are discussed until 2030. As the simulation software **Green*Net*** derives scenarios until 2020, projections until 2030 are made using country specific growth rates taken from reports of the European Commission (e.g. the report on "European Energy and Transport - Trends to 2030 - update 2007", see [4]).

To apply the **Green*Net*** model within the IMPROGRES project a number of adaptations are carried out. The following disaggregated elements in the context of DG/RES grid integration are modelled/derived (using also numbers/outcomes from other DG/RES models) within the **Green*Net*** model:

- Potentials of DG/RES technologies on country as well as case study level
- Historic development of DG/RES in each country and case study
- Overall grid connection cost of DG/RES scenarios on country level
- Overall grid reinforcement cost of DG/RES scenarios on country level.

In general, several of the disaggregated cost elements mentioned above can be allocated in the **Green*Net*** model either to

- the DG/RES-E producer,
- the end-user or
- the market actors.

The impact of the commodity prices of the electricity market on DG-RES penetration is also analysed. Furthermore, as the **Green*Net*** model derives DG/RES development both on transmission as well as distribution level, a separation is performed. In addition to that, as **Green*Net*** derives scenarios on each renewable energy source, the development of conventional combined heat and power (CHP) units, which are likely to be installed in distribution areas, will be included in overall DG capacity development taking into account further studies and literature (compare e.g. [4] or [5]).

## 1.3 Reading guide

The report is organized as follows:

In **chapter 2** a short introduction to the implemented methodology of the used simulation Model **Green*Net*** is given. Further relevant information on the database structure (including originally implemented potentials on country level) of the model is described in detail in order to avoid misinterpretations of performed updates.

**Chapter 3** summarizes performed database updates on country level as well as implemented scenario projections until 2030 unless the simulation software **Green*Net*** derives results of future DG/RES scenarios until 2020 in its most recent version.

In **chapter 4** simulation results for a Business As Usual (BAU) Scenario are discussed on case study, country as well as on European level. Furthermore, incremental changes on country level are presented for a High Price Scenario in **chapter 5**.

Grid related cost of DG/RES for selected countries are derived in **chapter 6** discussing the difference of country analysis compared to case study levels from the grid perspective. **Chapter 7** sums up the main observations, conclusions and remarkable findings.

The **appendices** contain further **Green*Net*** simulation results, also for Denmark and the United Kingdom (UK).

# 2 THE MODEL **GREEN*NET***

The evaluation of DG/RES scenarios until 2030 considering an alternative price scenario is conducted based on the simulation software **Green*Net***. Section 2.1 and 2.2 below briefly describe this software tool, its database structure and originally implemented DG/RES potentials on country level.

## 2.1 Methodology

The **Green*Net*** model conducts a comparative and quantitative analysis of least-cost DG/RES grid integration strategies in the liberalised European electricity market. The analysis can be conducted on aggregated (EU Member States') level or for individual Member States on an annual basis for the period 2004 to 2020. The major purpose of this software tool is to investigate DG/RES deployment under different cost allocation policies on grid integration ("deep" versus "shallow" versus "hybrid") based on the currently implemented DG/RES promotion instruments in the different EU Member States (see Figure 1).

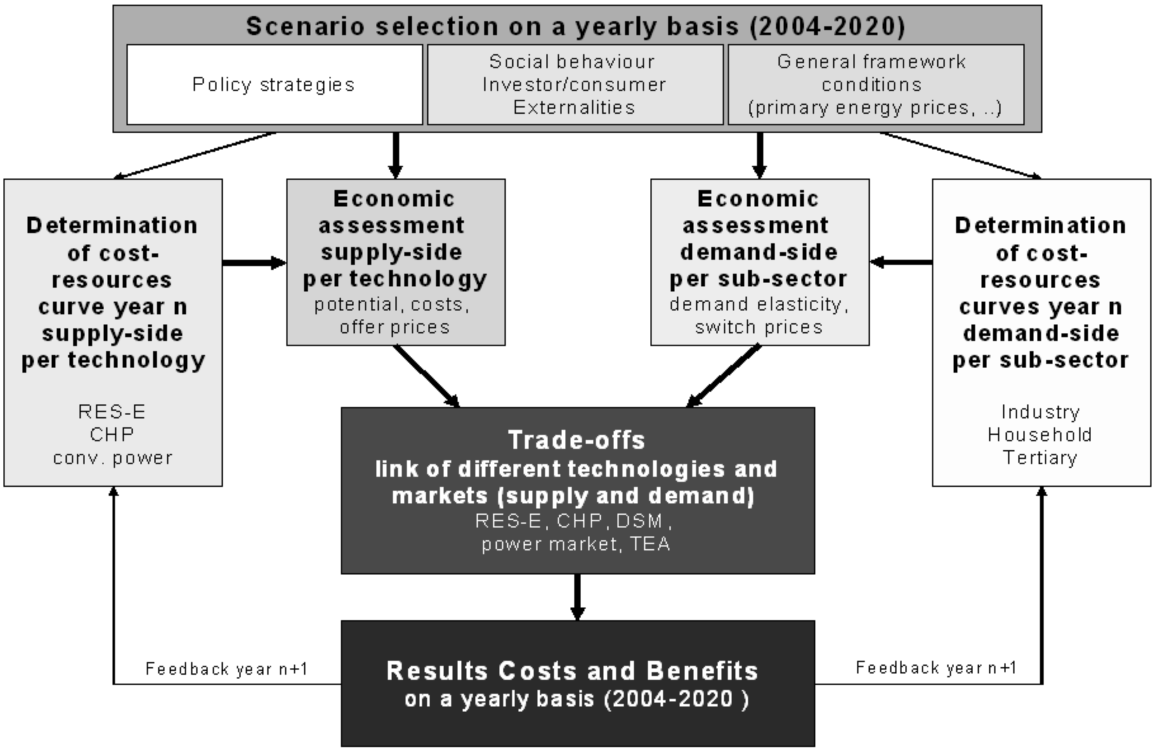

Figure 1: Overview on the least-cost modelling approach in **Green*Net***

The general modelling approach in **Green*Net*** is to describe both DG/RES generation technologies (supply curve) and energy efficiency measures (demand curve) by deriving corresponding dynamic cost-resource curves (for a detailed description see [3]). The costs as well as the potentials of these dynamic cost-resource curves can change year by year. These changes are given endogenously in the model depending on the outcome of the previous year (n-1) and the policy framework conditions set for the simulation year (n).

Based on the derivation of the dynamic cost-resource curves, an economic assessment takes place, considering scenario specific settings like DG/RES policy selection, socio-economic parameters (consumer/investor behaviour) as well as wholesale electricity price and demand forecasts. Wholesale electricity price projections on the conventional power market are implemented exogenously in **Green*Net***.

Then, in the economic assessment additional costs for system operation (with versus without storage options) and grid reinforcement/extension are modelled and – in case of selection – allocated to the marginal generation costs of the corresponding DG/RES technology.

Promotion instruments for DG/RES technologies include the most important price-driven strategies (feed-in tariffs, tax incentives, investment subsidies, subsidies on fuel input) and demand-driven strategies (quota obligations based on tradable green certificates - including international trade, tendering schemes). In addition, electricity taxes and other direct promotion instruments supporting energy efficiency measures on the demand side can also be chosen and investigated. As **Green*Net*** is a dynamic simulation tool, the user can change DG/RES policies and parameter settings within a simulation run on a yearly basis. Within the IMPROGRES project it was decided to use originally implemented policy settings of the software in order to derive BAU scenarios for each country and case study analysed.

The results are derived on a yearly basis by determining the equilibrium level of supply and demand within each market segment considered. For a detailed description of the **Green*Net*** modelling approach it is referred to [1]. Moreover, a detailed description of the deviation of dynamic cost-resource curves as well as the comprehensive **Green*Net*** database is conducted in [2].

## 2.2 Potential definition and database structure

The starting point for deriving the dynamic potentials is the determination of the additional mid-term potential for electricity generation for a specific technology in a specific country.[1] The additional mid-term potential is the maximal additional achievable potential assuming that all existing barriers can be overcome and all driving forces are active. The so-called ‘dynamic potential’ is the highest achievable potential for the year n. This means advantage must have been taken of all existing promotion strategies both on the investor and the consumer side. To illustrate this more clearly, the connections between the different potential terms are depicted in Figure 2.

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[1] Note: While the additional mid-term potential represents an important input parameter in the **Green*Net*** database, the additional annual potential (dynamic potential) is one of the essential output parameters of the cost curve development.

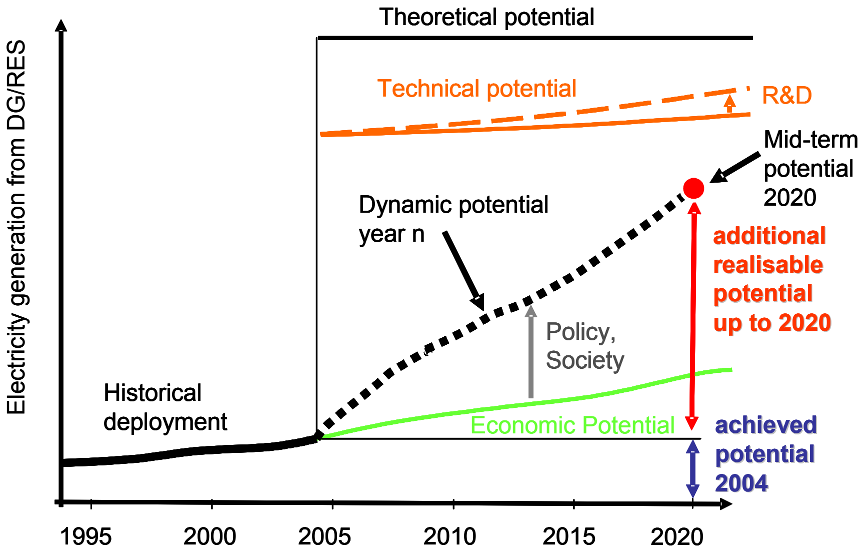

Figure 2: Methodology for the definition of different potentials (R&D = Research and Development)

In the toolbox **Green*Net*** the additional mid-term potential for electricity generation refers to the year 2020. The methodology for the analysis of the potential varies significantly from one technology to another.

In most cases a ‘top-down’ approach is used (e.g. for wind energy or for photovoltaic). In a first step the technical potential for one technology in one country for 2020 has to be derived by determining the total useable energy flow of a technology. Secondly, based on step one, the mid-term potential for the year 2020 is determined by taking into consideration the technical feasibility, social acceptance, planning aspects, growth rate of industry and market distortions. The additional mid-term potential is given by the mid-term potential minus existing penetration plus decommissioning of existing plants.

For a few technologies, a ‘bottom-up’ approach has been more successful (e.g. for geothermal electricity), i.e. by looking at every single site where energy production seems possible and by considering various barriers, the additional mid-term potential is derived.

In this context, one specific problem occurs with respect to biomass. The total primary energy potential for biomass is restricted. The actual distribution among the different options - pure electricity generation, CHP generation, heat generation or biofuel - depends on the net economic condition. As for the economic assessment, various support schemes must be considered, the final decision as to which options will actually be implemented is only feasible after including this step. To solve this problem, the values and the different options are linked in the database.

For a detailed description of the resource-specific approaches used within the project **Green*Net*** for the assessment of future DG/RES potentials see [3].

## Classification of DG/RES technologies

In order to increase the legibility of this report and to avoid any misinterpretation, the following definition of the investigated renewable technologies and their classification used within the project **Green*Net*** can be seen in the table below. Please note, that pumped hydro capacities as well as large scale installations, which are connected to transmission grids are not seen as DG/RES technologies. Thus, a reallocation of country specific **Green*Net*** simulation results to distribution level needs to be performed (compare chapter 4.2).

Table 1: Overview on classifications applied for the various DG/RES

| **Detailed classification**<br>(in accordance with 'DG/RES Directive' & sub-categories of **Green*Net***) | **Common classification** |
|---|---|
| Agricultural biogas[2] | **Biogas** |
| Landfill gas | |
| Sewage gas | |
| Forestry products (wood) | **Solid biomass** |
| Forestry residues<br>(bark, sawmill by-products etc.) | |
| Agricultural products (energy crops) | |
| Agricultural residues (incl. vegetal and animal substances, e.g. straw) | |
| Biodegradable fraction of waste (MSW+ISW) | **Biowaste** |
| Geothermal electricity | **Geothermal electricity** |
| Small scale hydro power (<10 MW) | **Small hydro** |
| Large scale hydro power (>10 MW) | **Large hydro** |
| Photovoltaics | **Photovoltaics** |
| Solar thermal electricity | **Solar thermal electricity** |
| Tidal energy | **Tidal & wave** |
| Wave energy | |
| Wind on-shore | **Wind onshore** |
| Wind off-shore | **Wind offshore** |

The resource definition, representing the most detailed classification (left), is done in accordance with the 'DG/RES directive' (European Council and Parliament, 2001; see [11]). A similar categorization is applied in the computer model **Green*Net*** and the accompanying database. For most graphical representations, e.g. of results, databases, etc., the common classification will be used in this document.

Due to comprehensive data-collection and statistical information gained on national level, the database was created representing the achieved and future potential on national and EU level. Thereby, each category of the database represents the generation potential of past and possible future annual installations within a country. In principle, it contains a set of information on costs (investment costs, O&M costs), potential (generation, full load-hours) and, of course, the construction year for already existing plants.

Based on this database **chapter 3** indicates the performed updates on country level, taking into account recent developments in DG/RES. Even more, the methodology of performed scenario projections until 2030 (including conventional CHP generation) is discussed.

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[2] Fuel sources are in this case farm slurries, usable agricultural residues (i.e. from sugar beet production), residues from pasture and the separated biodegradable fraction of municipal wastes.

# 3 DATABASE UPDATES AND SCENARIO PROJECTIONS (INCL. CONVENTIONAL CHP)

## 3.1 Database adaptations

Within the IMPROGRES project essential database updates were performed, both on country as well as on case study level. Therefore, the potential definition in chapter 2 was utilised in order to update national DG/RES potentials. In addition to this, data regarding potentials within three case study regions have been provided by distribution system operators (DSOs) within their grid operation areas following the same **Green*Net*** potential definition approach. For a more detailed explanation of the performed updates the following tables are shown.

### 3.1.1 Country level

On country level the existing and future potentials of DG/RES were updated according to results of national or international studies, ongoing projects as well as expert estimations. The data inputs provided by national and international studies as well as projects were implemented, updating the existing **Green*Net*** database for each country analysed. Table 2 indicates the original database for existing and future DG/RES potentials up to 2020 for the Netherlands (compare [3]).

Table 2: Overview on the implemented country database for the Netherlands in the most recent version of **Green*Net***

| **DG/RES: Netherlands** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant) | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Biogas | 0 | 2695 | **2695** | 0 | 515 | **515** |
| Biomass - Forestry products | 0 | 2111 | **2111** | 0 | 406 | **406** |
| Biomass - Forestry residues | 1036 | 2250 | **3286** | 196 | 411 | **607** |
| Biomass - Agricultural products | 0 | 1486 | **1486** | 0 | 284 | **284** |
| Biomass - Agricultural residues | 0 | 844 | **844** | 0 | 160 | **160** |
| Biomass - Biodegradable fraction of waste | 2622 | 571 | **3193** | 205 | 88 | **293** |
| Geothermal electricity | 0 | 0 | **0** | 0 | 0 | **0** |
| Hydropower - Small-scale | 1 | 8 | **10** | 2 | 17 | **19** |
| Hydropower - Large-scale | 101 | 0 | **101** | 36 | 0 | **36** |
| Landfill gas | 197 | 138 | **335** | 36 | 24 | **60** |
| Sewage gas | 120 | 182 | **301** | 27 | 32 | **58** |
| Solar electricity - Photovoltaics | 32 | 1173 | **1205** | 43 | 1778 | **1821** |
| Solar electricity - Solar thermal electricity | 0 | 0 | **0** | 0 | 0 | **0** |
| Tidal stream | 0 | 235 | **235** | 0 | 87 | **87** |
| Wave energy | 0 | 790 | **790** | 0 | 321 | **321** |
| Wind energy - Wind onshore | 1758 | 3169 | **4927** | 788 | 1641 | **2429** |
| Wind energy - Wind offshore | 58 | 19789 | **19847** | 19 | 6481 | **6500** |
| Biogas (CHP) | 0 | 871 | **871** | 0 | 166 | **166** |
| Biomass - Forestry products (CHP) | 0 | 1599 | **1599** | 0 | 282 | **282** |
| Biomass - Forestry residues (CHP) | 0 | 2551 | **2551** | 0 | 437 | **437** |
| Biomass - Agricultural products (CHP) | 0 | 1772 | **1772** | 0 | 318 | **318** |
| Biomass - Agricultural residues (CHP) | 0 | 961 | **961** | 0 | 160 | **160** |
| Biomass - Biodegradable fraction of waste (CHP) | 39 | 744 | **782** | 6 | 114 | **120** |
| Landfill gas (CHP) | 0 | 45 | **45** | 0 | 8 | **8** |
| Sewage gas (CHP) | 0 | 57 | **57** | 0 | 10 | **10** |

Within the project, the Dutch database content was changed according to the existing and new generation levels as indicated in Table 3 (green columns). The corresponding capacities of DG/RES were calculated automatically depending on the characteristic yearly full load hours of each DG/RES technology. In the Netherlands changes of existing potentials were performed for biomass, hydropower, landfill and sewage gas, photovoltaic as well as wind (onshore and offshore) technologies. With respect to new potentials almost all technologies excepting biogas were changed (compare [10]).

Table 3: Performed database updates on country level for the Netherlands

| **DG/RES update: Netherlands** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Biogas | 0 | 2695 | **2695** | 0 | 515 | **515** |
| Biomass - Forestry products | 0 | 416 | **416** | 0 | 80 | **80** |
| Biomass - Forestry residues | 1756 | 415 | **2171** | 333 | 76 | **409** |
| Biomass - Agricultural products | 0 | 1915 | **1915** | 0 | 366 | **366** |
| Biomass - Agricultural residues | 0 | 2845 | **2845** | 0 | 539 | **539** |
| Biomass - Biodegradable fraction of waste | 931 | 2532 | **3462** | 145 | 389 | **535** |
| Geothermal electricity | 0 | 0 | **0** | 0 | 0 | **0** |
| Hydropower - Small-scale | 0 | 200 | **200** | 0 | 400 | **400** |
| Hydropower - Large-scale | 95 | 0 | **95** | 48 | 0 | **48** |
| Landfill gas | 134 | 95 | **229** | 24 | 17 | **41** |
| Sewage gas | 127 | 150 | **277** | 28 | 26 | **54** |
| Solar electricity - Photovoltaics | 32 | 2599 | **2631** | 43 | 3939 | **3982** |
| Solar electricity - Solar thermal electricity | 0 | 0 | **0** | 0 | 0 | **0** |
| Tidal stream | 0 | 0 | **0** | 0 | 0 | **0** |
| Wave energy | 0 | 0 | **0** | 0 | 0 | **0** |
| Wind energy - Wind onshore | 1868 | 8200 | **10068** | 837 | 4247 | **5084** |
| Wind energy - Wind offshore | 0 | 26299 | **26299** | 0 | 8614 | **8614** |
| Biogas (CHP) | 0 | 871 | **871** | 0 | 166 | **166** |
| Biomass - Forestry products (CHP) | 0 | 315 | **315** | 0 | 56 | **56** |
| Biomass - Forestry residues (CHP) | 0 | 470 | **470** | 0 | 81 | **81** |
| Biomass - Agricultural products (CHP) | 0 | 2285 | **2285** | 0 | 410 | **410** |
| Biomass - Agricultural residues (CHP) | 0 | 3239 | **3239** | 0 | 540 | **540** |
| Biomass - Biodegradable fraction of waste (CHP) | 27 | 3295 | **3322** | 4 | 507 | **511** |
| Landfill gas (CHP) | 0 | 31 | **31** | 0 | 5 | **5** |
| Sewage gas (CHP) | 0 | 47 | **47** | 0 | 8 | **8** |

No database updates were necessary for Germany since the consortium agreed on already implemented potentials. Table 4 shows already achieved and future potentials of DG/RES within Germany as originally implemented in the **Green*Net*** model. The biggest future potentials in Germany can be identified in wind (onshore and offshore), several biomass and biogas, tidal stream, wave energy as well as hydropower technologies. Furthermore, as decided within the IMPROGRES project, original **Green*Net*** potential values were used for Denmark und UK as well.

Table 4: Overview on the implemented country database for Germany in the most recent version of **Green*Net*** (compare [3])

| **DG/RES: Germany** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Biogas | 1135 | 7045 | **8180** | 324 | 1419 | **1743** |
| Biomass - Forestry products | 0 | 15439 | **15439** | 0 | 2879 | **2879** |
| Biomass - Forestry residues | 0 | 13080 | **13080** | 0 | 2307 | **2307** |
| Biomass - Agricultural products | 0 | 9994 | **9994** | 0 | 1863 | **1863** |
| Biomass - Agricultural residues | 0 | 6482 | **6482** | 0 | 1198 | **1198** |
| Biomass - Biodegradable fraction of waste | 0 | 1926 | **1926** | 0 | 296 | **296** |
| Geothermal electricity | 0 | 0 | **0** | 0 | 0 | **0** |
| Hydropower - Small-scale | 7367 | 2228 | **9595** | 1488 | 450 | **1938** |
| Hydropower - Large-scale | 12576 | 2974 | **15550** | 2000 | 473 | **2473** |
| Landfill gas | 1550 | 2059 | **3609** | 282 | 361 | **643** |
| Sewage gas | 900 | 564 | **1464** | 200 | 99 | **299** |
| Solar electricity - Photovoltaics | 621 | 4840 | **5461** | 768 | 6645 | **7413** |
| Solar electricity - Solar thermal electricity | 0 | 0 | **0** | 0 | 0 | **0** |
| Tidal stream | 0 | 2494 | **2494** | 0 | 927 | **927** |
| Wave energy | 0 | 5232 | **5232** | 0 | 2124 | **2124** |
| Wind energy - Wind onshore | 29516 | 23803 | **53319** | 16636 | 14371 | **31007** |
| Wind energy - Wind offshore | 0 | 76842 | **76842** | 0 | 25000 | **25000** |
| Biogas (CHP) | 0 | 2273 | **2273** | 0 | 458 | **458** |
| Biomass - Forestry products (CHP) | 0 | 7460 | **7460** | 0 | 1314 | **1314** |
| Biomass - Forestry residues (CHP) | 3308 | 9812 | **13120** | 505 | 1701 | **2206** |
| Biomass - Agricultural products (CHP) | 0 | 7278 | **7278** | 0 | 1306 | **1306** |
| Biomass - Agricultural residues (CHP) | 27 | 4247 | **4273** | 4 | 729 | **733** |
| Biomass - Biodegradable fraction of waste (CHP) | 2027 | 1762 | **3789** | 322 | 271 | **593** |
| Landfill gas (CHP) | 0 | 666 | **666** | 0 | 117 | **117** |
| Sewage gas (CHP) | 0 | 175 | **175** | 0 | 31 | **31** |

In Spain only minor database changes were necessary. Based on the originally implemented database in Table 5 updates on existing potentials (indicated in Table 6) were performed.

Table 5: Performed database update on country level for Spain (compare [3])

| **DG/RES: Spain** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Biogas | 2 | 5024 | **5025** | 1 | 1012 | **1012** |
| Biomass - Forestry products | 0 | 7131 | **7131** | 0 | 1360 | **1360** |
| Biomass - Forestry residues | 0 | 6785 | **6785** | 0 | 1198 | **1198** |
| Biomass - Agricultural products | 0 | 7865 | **7865** | 0 | 1502 | **1502** |
| Biomass - Agricultural residues | 0 | 3435 | **3435** | 0 | 652 | **652** |
| Biomass - Biodegradable fraction of waste | 0 | 1526 | **1526** | 0 | 235 | **235** |
| Geothermal electricity | 0 | 95 | **95** | 0 | 16 | **16** |
| Hydropower - Small-scale | 4710 | 2630 | **7340** | 1699 | 949 | **2648** |
| Hydropower - Large-scale | 29687 | 15119 | **44806** | 11327 | 5768 | **17095** |
| Landfill gas | 355 | 4100 | **4455** | 65 | 725 | **789** |
| Sewage gas | 308 | 345 | **653** | 68 | 61 | **129** |
| Solar electricity - Photovoltaics | 34 | 5104 | **5138** | 25 | 4706 | **4731** |
| Solar electricity - Solar thermal electricity | 0 | 17209 | **17209** | 0 | 5597 | **5597** |
| Tidal stream | 0 | 2793 | **2793** | 0 | 727 | **727** |
| Wave energy | 0 | 10436 | **10436** | 0 | 3021 | **3021** |
| Wind energy - Wind onshore | 18592 | 20707 | **39299** | 8265 | 11237 | **19502** |
| Wind energy - Wind offshore | 0 | 14444 | **14444** | 0 | 5000 | **5000** |
| Biogas (CHP) | 0 | 1621 | **1621** | 0 | 326 | **326** |
| Biomass - Forestry products (CHP) | 0 | 3191 | **3191** | 0 | 544 | **544** |
| Biomass - Forestry residues (CHP) | 927 | 4551 | **5478** | 210 | 762 | **972** |
| Biomass - Agricultural products (CHP) | 0 | 5497 | **5497** | 0 | 934 | **934** |
| Biomass - Agricultural residues (CHP) | 3515 | 2115 | **5630** | 606 | 350 | **956** |
| Biomass - Biodegradable fraction of waste (CHP) | 651 | 1315 | **1966** | 109 | 202 | **311** |
| Landfill gas (CHP) | 0 | 1326 | **1326** | 0 | 234 | **234** |
| Sewage gas (CHP) | 0 | 107 | **107** | 0 | 19 | **19** |

These updates implied changes for biomass – forestry products, biomass – biodegradable fraction of waste, photovoltaic as well as wind onshore technologies. Updates for future potentials were not necessary in this case (see [8]).

Table 6: Performed database update for existing potentials on country level for Spain

| **DG/RES update: Spain** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Biogas | 2 | 5024 | **5025** | 1 | 1012 | **1012** |
| Biomass - Forestry products | 0 | 7131 | **7131** | 0 | 1360 | **1360** |
| Biomass - Forestry residues | 1640 | 6785 | **8425** | 311 | 1198 | **1509** |
| Biomass - Agricultural products | 0 | 7865 | **7865** | 0 | 1502 | **1502** |
| Biomass - Agricultural residues | 0 | 3435 | **3435** | 0 | 652 | **652** |
| Biomass - Biodegradable fraction of waste | 1382 | 1526 | **2908** | 216 | 235 | **451** |
| Geothermal electricity | 0 | 95 | **95** | 0 | 16 | **16** |
| Hydropower - Small-scale | 4710 | 2630 | **7340** | 1699 | 949 | **2648** |
| Hydropower - Large-scale | 29687 | 15119 | **44806** | 11327 | 5768 | **17095** |
| Landfill gas | 355 | 4100 | **4455** | 65 | 725 | **789** |
| Sewage gas | 308 | 345 | **653** | 68 | 61 | **129** |
| Solar electricity - Photovoltaics | 17 | 5104 | **5121** | 13 | 4706 | **4718** |
| Solar electricity - Solar thermal electricity | 0 | 17209 | **17209** | 0 | 5597 | **5597** |
| Tidal stream | 0 | 2793 | **2793** | 0 | 727 | **727** |
| Wave energy | 0 | 10436 | **10436** | 0 | 3021 | **3021** |
| Wind energy - Wind onshore | 15753 | 20707 | **36460** | 7003 | 11237 | **18240** |
| Wind energy - Wind offshore | 0 | 14444 | **14444** | 0 | 5000 | **5000** |
| Biogas (CHP) | 0 | 1621 | **1621** | 0 | 326 | **326** |
| Biomass - Forestry products (CHP) | 0 | 3191 | **3191** | 0 | 544 | **544** |
| Biomass - Forestry residues (CHP) | 927 | 4551 | **5478** | 210 | 762 | **972** |
| Biomass - Agricultural products (CHP) | 0 | 5497 | **5497** | 0 | 934 | **934** |
| Biomass - Agricultural residues (CHP) | 3515 | 2115 | **5630** | 606 | 350 | **956** |
| Biomass - Biodegradable fraction of waste (CHP) | 651 | 1315 | **1966** | 109 | 202 | **311** |
| Landfill gas (CHP) | 0 | 1326 | **1326** | 0 | 234 | **234** |
| Sewage gas (CHP) | 0 | 107 | **107** | 0 | 19 | **19** |

### 3.1.2 Case study level

A very similar methodology compared to performed database updates on country level was used for specific case study regions within the Netherlands, Germany and Spain. Those case study regions are representing real distribution grid areas described in the following:

**Case study area in the Netherlands**

Distribution grids in the Netherlands are characterised by voltage levels equal to and lower than 150 kV. The Kop van Noord Holland region is a rural/sub-urban distribution area located in the province of Noord Holland and serving approximately 80000 customers in an area of about 990 km$^2$ (see Figure 3). The most densely populated areas are located in the southern part of the area whereas horticultural exploitations are present all over the region. DG in the area comprises a large number of CHP units, that provide heat for greenhouses, and a number of wind farms.

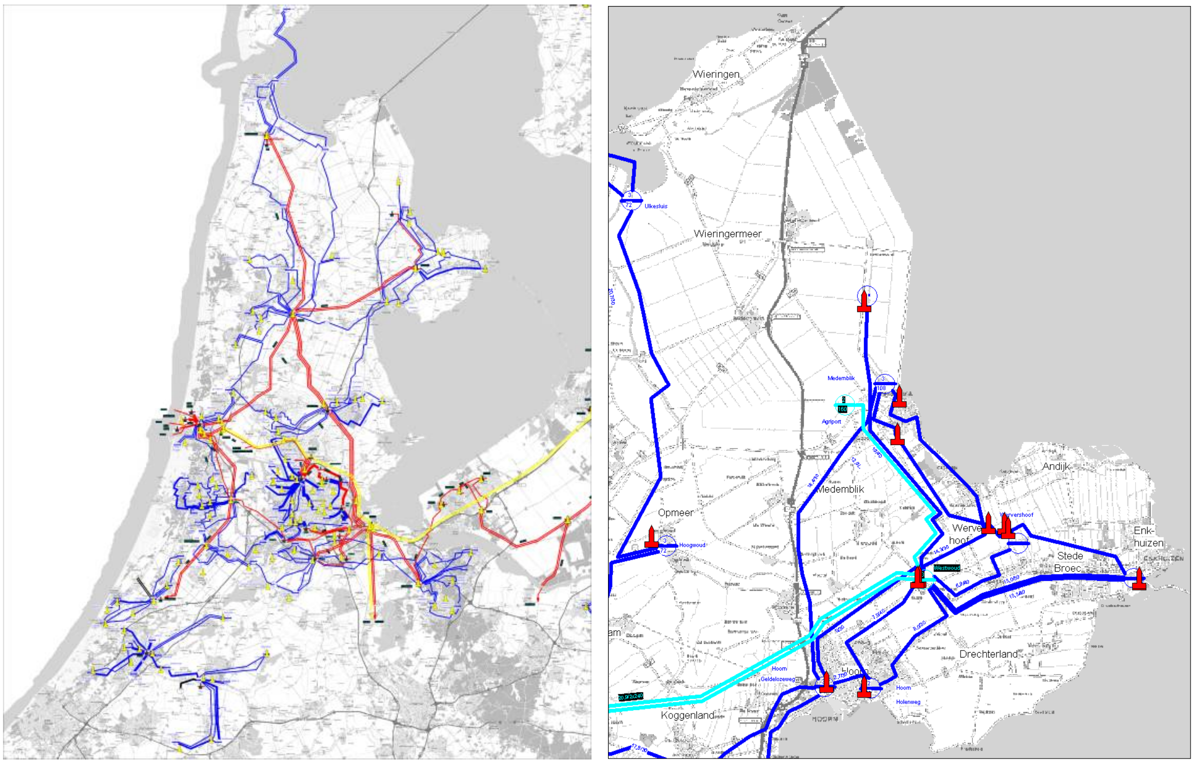

Figure 3: Left total province Noord-Holland; right the area of the case study named Kop van Noord-Holland indicating the grid structure (Source: Liander, Danish DSO)

**Case study area in Germany**

The German distribution area considered in the study – defined by voltage levels lower than and equal to 110 kV as well – comprises three residential areas in Mannheim: Wallstadt, Feudenheim, and Vogelstang. The DSO in the area is MVV Energie AG. Overall, more than 6100 customers are located in the case study region. Private customers only know the standard values for their power data. The peak demand is around 15 MW distributed over an area of 20 km$^2$. As a rule, the laying of cables is carried out at both sides along the course of the roads. In the central zones (study areas) MVV Energie owns a meshed network. Current DG penetration level is nearly negligible. This area is shown in Figure 4.

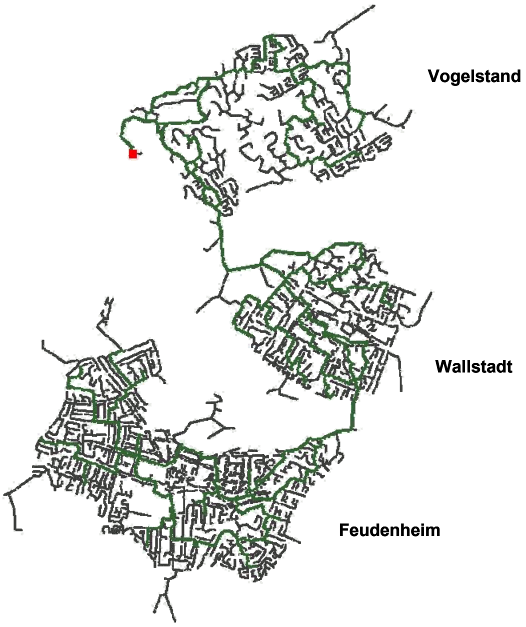

Figure 4: Mannheim area distribution network (Source: MVV Energie, German DSO)

### Case study area in Spain

In Spain distribution grids are characterised by voltage levels equal to and lower than 145 kV. The Aranjuez area, comprising the south of Madrid province and the northern part of Toledo province, has been selected as one of the case study regions within the project. This region has a surface area of 3400 km$^2$. Currently, there are approximately 61600 consumers located within it. 99.55% of these consumers are connected to the LV network, 0.44% to the MV and 0.01% to the HV. Therefore, most loads located in the region are connected at low voltage level, mainly within towns, although several hundreds are at medium voltage level and a few at high voltage. The largest settlement in the area is Aranjuez with over 52000 inhabitants (October 2008). An industrial zone exists in the outskirts of the town. Figure 5 shows a tentative picture of the HV and MV network for this area where the different towns can be seen within a thin polygonal line.

This sub-urban distribution grid is nowadays comprised of a sub-transmission grid at 132 and 45 kV (though most of the circuits at sub-transmission level are built at 45 kV, the DSO in the area, Unión Fenosa, is considering the possibility of upgrading the 45 kV grid to 132 kV in the near future), a medium voltage grid at 15 kV and a low voltage grid at 400 V. This network currently comprises one 132/45 kV substation with two transformers, six 45/15 kV substations totalling 11 transformers and 1075 15 kV/400 V substations amounting to 599 transformers. At HV level, the network includes eight circuits at 45 kV and 48 circuits at 15 kV. The structure of the 45 kV grid is a ring, as it can be seen in Figure 5.

The total amount of load contracted in the area is around 275 MW, which results in a maximum simultaneous load fed by HV/MV substations of over 140 MW. Regarding DG, at the moment there is only one 10 MW wind farm and three industrial CHP units in the area adding up to 35 MW of total generation capacity (see Figure 5).

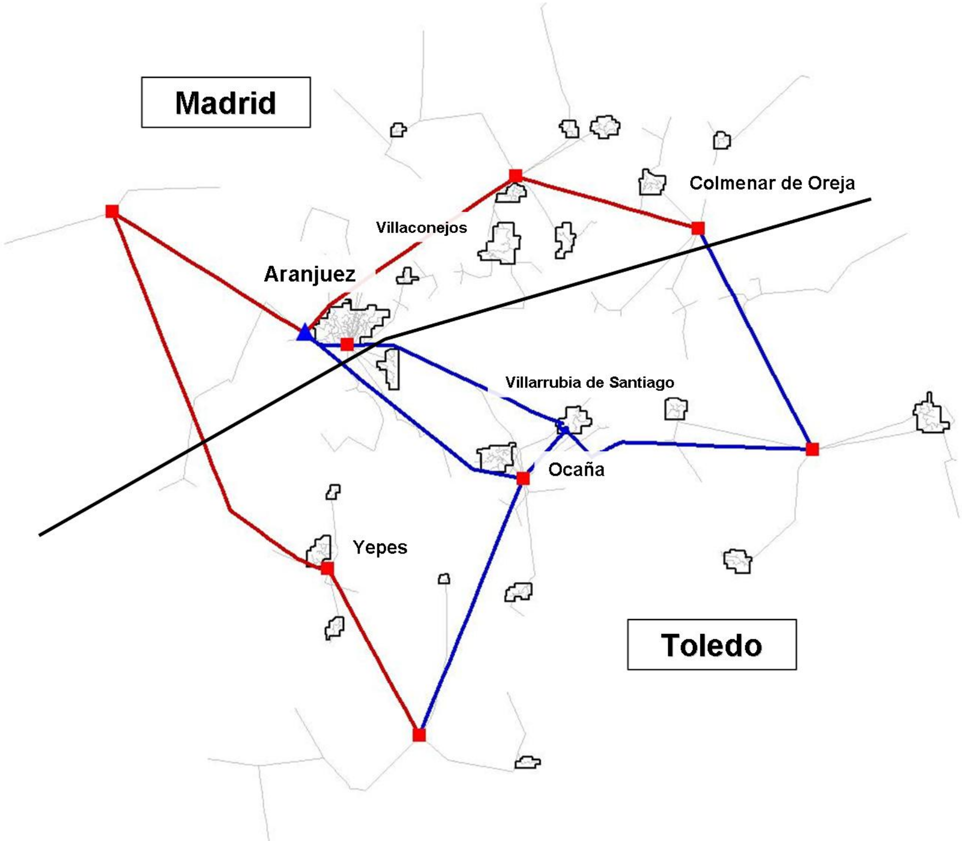

Figure 5: Aranjuez area distribution network indicating the grid structure (Source: Union Fenosa Distribucion, Spanish DSO)

The applicability of selected DG/RES technologies on case study level demands changes as well. As **Green*Net*** takes into consideration renewable energy sources according updates were performed for the case studies as well. These areas were chosen by the distribution system operators providing future estimations on DG/RES capacity development as well as existing generation and demand areas as indicated above.

With respect to the Dutch case study solely wind generation (onshore installations) is applicable for **Green*Net*** simulations. In detail, the DSOs estimated two scenarios on future wind development, starting with an already existing wind potential of 176 GWh (79 MW) for both scenarios. The first one, which is expected to evolve as a High wind penetration scenario, estimates future potentials of wind generation to about 1061 GWh or 491 MW installed capacity. A more moderate prognosis on wind development within the case study area – the so called Low scenario - forecasts approx. 525 GWh generation potential in 2020 or 243 MW of installed capacities as shown in Table 7.

Table 7: Performed database updates on case study level for the Netherlands

| **DG/RES cases updates: NL** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Wind energy - Wind onshore_high | 176 | 1061 | **1237** | 79 | 491 | **570** |
| Wind energy - Wind onshore_low | 176 | 525 | **701** | 79 | 243 | **322** |

With respect to the German case, which represents an urban region, solely photovoltaic generation potentials are expectable for the future renewable DG. As a starting value of already installed generation potentials, 0.66 GWh per year (0.82 MW capacity) are included in the case study database. Furthermore, possible future potential estimation were 18.7 GWh (20 MW) for the High and 9.7 GWh (10 MW) for the Low scenario. Again all database changes are summarised in the following table.

Table 8: Performed database updates on case study level for Germany

| **DG/RES CASE update: GER** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Solar electricity - Photovoltaics_high | 0.7 | 18.1 | **18.7** | 0.8 | 20.1 | **20.9** |
| Solar electricity - Photovoltaics_low | 0.7 | 9.0 | **9.7** | 0.8 | 10.0 | **10.9** |

For the case study in Spain a DG/RES mix of wind and PV is evaluated with a wind starting potential of 23 GWh (10 MW) and no PV installations. Future potentials were estimated at 80 GWh (40 MW) and 74 GWh (40 MW) for PV and wind at the High scenario and 22 GWh (11 MW) for PV as well as 37 GWh (20 MW) for wind in the Low one (compare Table 9).

Table 9: Performed database updates on case study level for Spain

| **DG/RES case update: ES** | Potential - Electricity generation [GWh] | | | Potential - Capacity [MW] | | |
|---|---|---|---|---|---|---|
| *Technologies* | Existing plant | New plant (up to 2020) | TOTAL | Existing plant | New plant (up to 2020) | **TOTAL** |
| Solar electricity - Photovoltaics_low | 0 | 22 | **22** | 0 | 11 | **11** |
| Solar electricity - Photovoltaics_high | 0 | 80 | **80** | 0 | 40 | **40** |
| Wind energy - Wind onshore_low | 23 | 37 | **60** | 10 | 20 | **30** |
| Wind energy - Wind onshore_high | 23 | 74 | **97** | 10 | 40 | **50** |

## 3.2 Scenario projection until 2030

Within the IMPROGRES project scenario projections until 2030 are performed based on **Green*Net*** simulation results. Therefore, inputs of recent EC reports including the PRIMES model (for a model description see [9]) scenarios (compare [4] and [5]) are used to identify a possible DG/RES development gradient in order to perform projections beginning from 2020 until 2030. Furthermore, a comparison of PRIMES (the green and the black line) and **Green*Net*** scenarios is indicated in Figure 6 for the European Business As Usual DG/RES development scenario. Even more, the PRIMES database is used for scenario updates on conventional CHP development described in chapter 3.3. The data used for those comparisons and updates is indicated in the green rows in Table 10.

Table 10: Exemplary data used from the PRIMES 2007 model enabling **Green*Net*** scenario projections until 2030 in the EU-27 Member States

| PRIMES 2007: EU | [Unit] | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| **Electricity generation by fuel type (in GWh)** | | | | | | | |
| Nuclear energy | GWh | 920.005 | 888.069 | 884.778 | 807.627 | 760.650 | 770.524 |
| Renewables | GWh | 450.028 | 578.740 | 647.163 | 772.299 | 865.443 | 943.007 |
| Hydro | GWh | 277.356 | 306.591 | 302.549 | 308.994 | 316.331 | 320.504 |
| Wind | GWh | 70.449 | 143.143 | 201.260 | 269.411 | 316.473 | 346.640 |
| Solar, tidal etc. | GWh | 1.489 | 3.730 | 6.699 | 11.803 | 16.732 | 21.422 |
| Biomass & waste | GWh | 93.209 | 117.456 | 128.714 | 173.916 | 207.307 | 245.506 |
| Geothermal heat | GWh | 7.525 | 7.820 | 7.942 | 8.175 | 8.600 | 8.935 |
| *Thermal power plants CHP* | GWh | *387.017* | *549.781* | *639.888* | *768.264* | *823.411* | *848.583* |

On European level it becomes evident that the difference between PRIMES 2007 and **Green*Net*** is relatively high. This difference is caused by the different modelling approach of **Green*Net***, following the least cost approach on a more disaggregated way than PRIMES as described in [3].

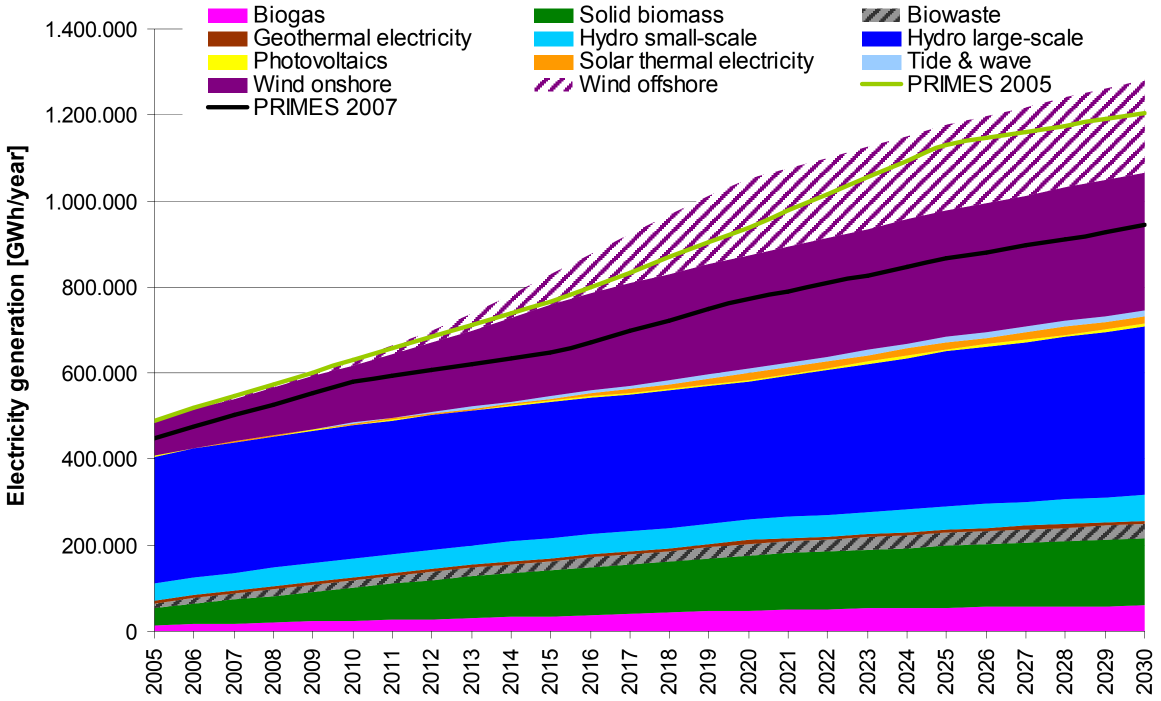

Figure 6: Electricity generation simulation results of the **Green*Net*** BAU scenario on European level including PRIMES 2005 and 2007 values (green and black line) scenarios as a comparison

Therefore, further comparison with national and international studies as e.g. in the Netherlands (see e.g. [5]) indicated in Figure 7 as green triangle development until 2020 are performed. As a result, deviations compared to national studies reduce significantly. The overall DG/RES share of electricity consumption rises to about 19% in 2020. Similar comparisons were performed for all countries analysed within the IMPROGRES project, deriving results in **Annex I**.

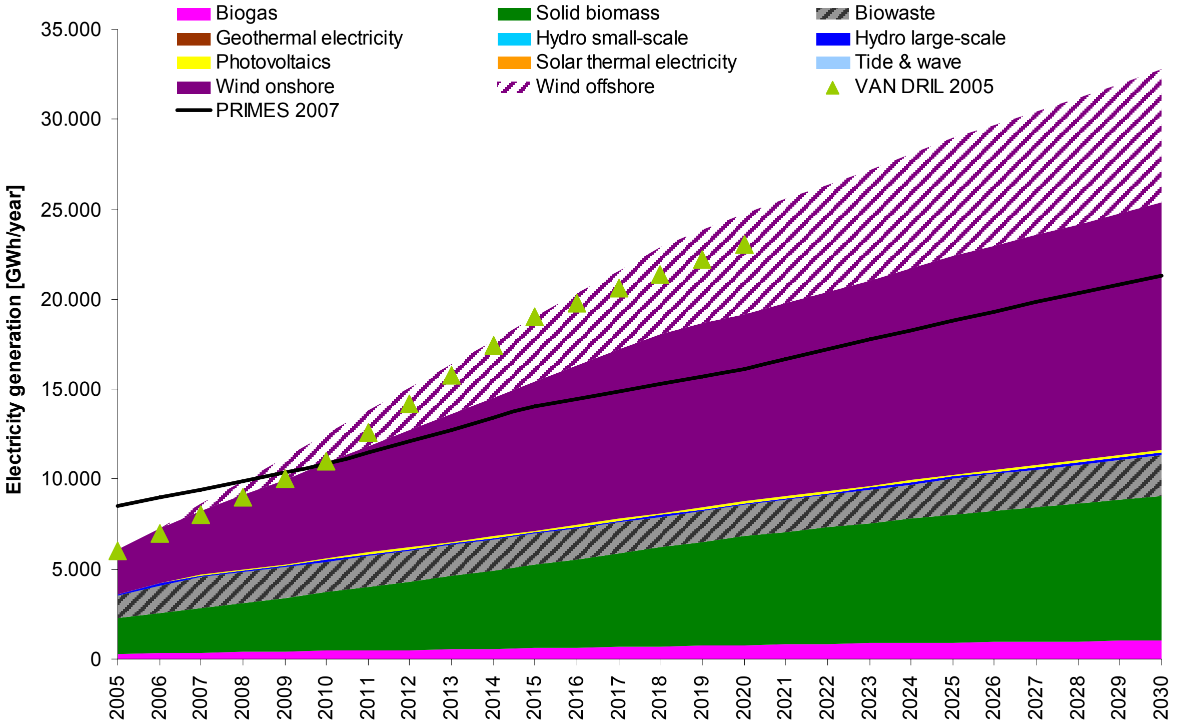

Figure 7: Dutch electricity generation simulation results of the **Green*Net*** BAU scenario including a comparison to PRIMES 2007 values (black line) as well as a national study (VAN DRIL 2005, indicated as green triangles; compare [6])

As it was decided to use BAU scenario and policy settings (2005) of **Green*Net***, it must be mentioned that policy changes of course influence future DG/RES scenario evolvement. As illustrated in Figure 8, such more recent policy implementations (as from 2008) within the project "EMPLOYRES" (see [15]) influence e.g. photovoltaic or solar thermal development due to better subsidiary conditions. But as these national policies may change from year to year, it was decided within the IMPROGRES project to keep originally implemented policies within the **Green*Net*** software focusing on DG/RES potential updates in order to provide concise scenarios for all countries and case studies analysed.

In general, these scenarios should provide a better understanding about which tendencies of DG/RES energy futures can be expected on country as well as specific case study level. Overall, these tendencies – even if they are not considering most recent policy updates – imply a significant growth of DG/RES on European as well as on national levels. As a result distribution grids are further charged and put to their limits by integration of renewable electricity generation (RES-E) and of course conventional generation technologies. Since combined heat and power (CHP) generation as one of these conventional technologies is also likely to be connected to distribution grids, the following chapters also analyse future conventional CHP developments which are added to **Green*Net*** scenarios.

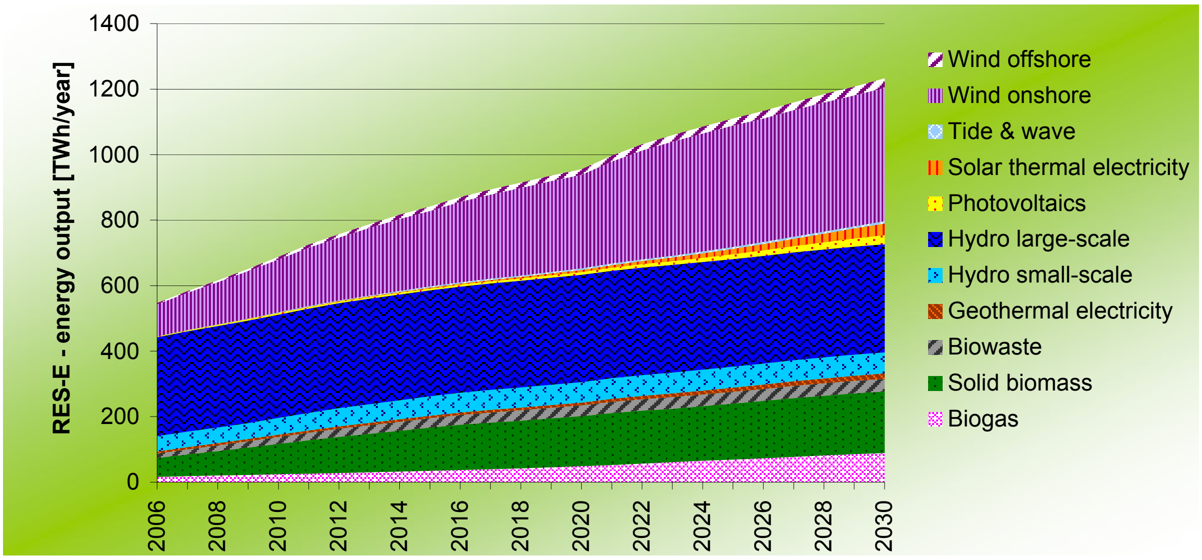

Figure 8: RES-E development for EU-27 until 2030 for a BAU scenario derived within the EU project “EMPLOYRES” incorporating policy settings of 2008 (compare [15]).

## 3.3 Integration of conventional CHP

In addition to the DG/RES simulation results and projections until 2030, a further update was performed taking into account conventional CHP developments. As already mentioned, PRIMES 2007 (see [4]) data on conventional CHP generation and capacity development is added to the derived **Green*Net*** scenarios. As an example Figure 9 shows the original BAU DG/RES scenario on EU level enhanced by conventional CHP generation indicated as grey areas. The same updates were performed for capacity developments illustrated in Figure 10.

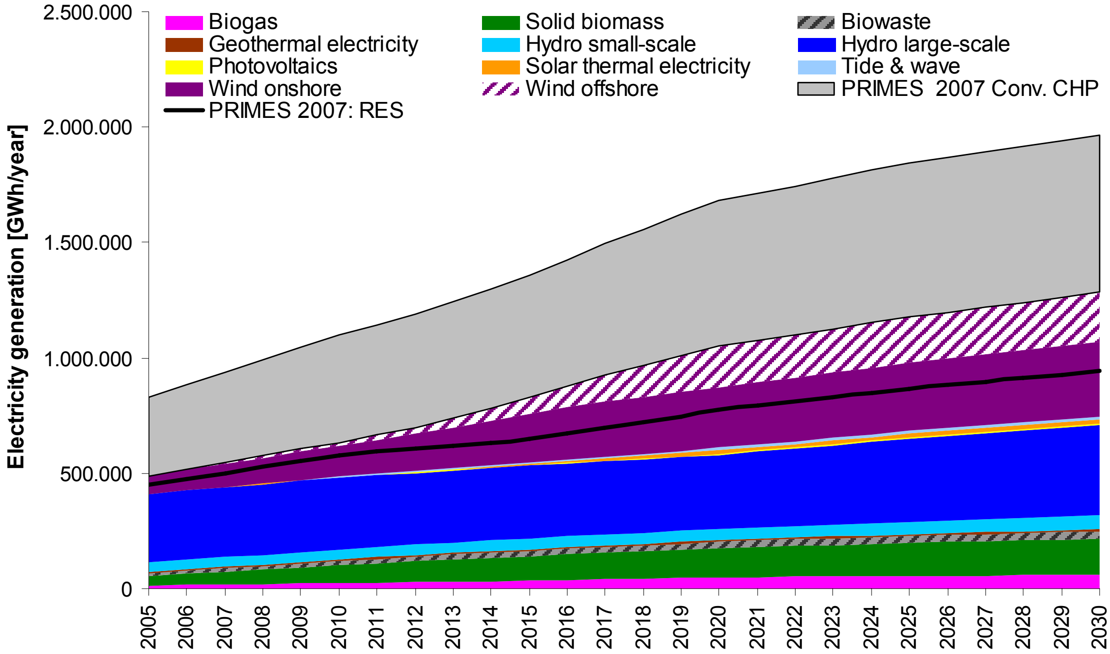

Figure 9: **Green*Net*** BAU simulation results including projections until 2030 and conventional CHP updates for electricity generation on European level

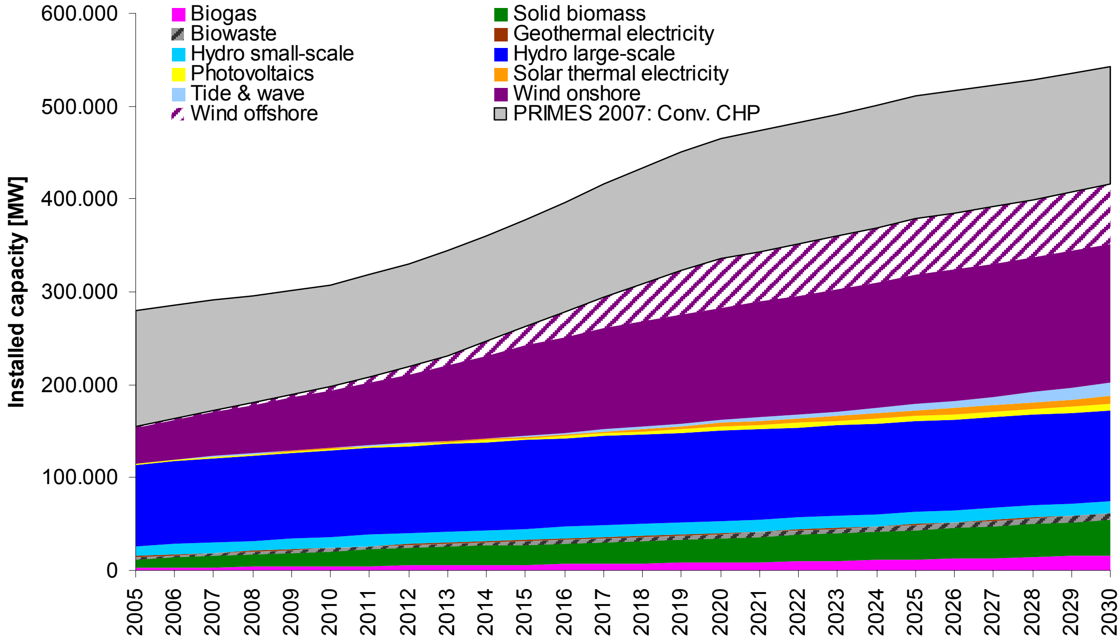

Figure 10: **Green*Net*** BAU simulation result including projections until 2030 and conventional CHP updates for generation capacities on European level

# 4 SIMULATION RESULTS: BUSINESS AS USUAL SCENARIO

## 4.1 **Green*Net*** Simulation results including projections until 2030

This chapter analyses the derived results of different **Green*Net*** simulation runs which are enhanced by projections until 2030 and by conventional CHP development as described in the previous chapter. The scenarios will be presented and discussed on a cumulated European, disaggregated country as well as on case study level.

### 4.1.1 EU level

Results of European simulation runs have already been presented by showing the model update methodology in chapter 3. In addition to that, further detailed interpretation of results is derived in this brief section.

According to a Business As Usual (BAU) scenario total DG/RES electricity generation within the EU Member States increases from 490 TWh/yr in 2005 to about 1280 TWh/yr in 2030. While generation from DG/RES technologies like hydro power and biowaste remains almost stable, especially for wind power, biomass and biogas a considerable increase up to 2030 can be observed (see Figure 6). The share of electricity generated from DG/RES regarding overall electricity demand increases from about 15% in 2005 to approximately 26% in 2020. According to the reference scenario wind power (onshore and offshore) is likely to be the dominant DG/RES technology up to 2030. Additionally, within this technology offshore installations are becoming increasingly important as from 2010. Besides that, future promising technologies like PV and solar thermal electricity also show increasing installations as from 2013.

### 4.1.2 Country level

On country level simulation results of the Netherlands, Germany and Spain are interpreted and compared to each other. With respect to the core objective of the IMPROGRES project, DG/RES capacity developments are presented in this chapter as they are most important for the analysis of the impact on distribution grids and future grid structures. Further simulation results for electricity generation by DG/RES technology as well as results for Denmark and UK can be found in **Annex II.**

To come to the country specific analysis, again the Netherlands is presented in the first stage. According to the reference (BAU) scenario total DG/RES capacities within the Netherlands increase from 1797 MW in 2005 to about 10600 MW in 2030. Conventional CHP development increases from approximately 9300 MW in 2005 to about 11100 MW in 2030. The Dutch DG/RES technology mix consist basically of wind power, biomass and biowaste with very little shares of hydro power and a growing photovoltaic development as from 2010 (see Figure 11). In the Netherlands the wind potential is significant, whereas there is limited potential at economically feasible prices expected for hydro power and photovoltaic technologies due to the geographic conditions in the country.

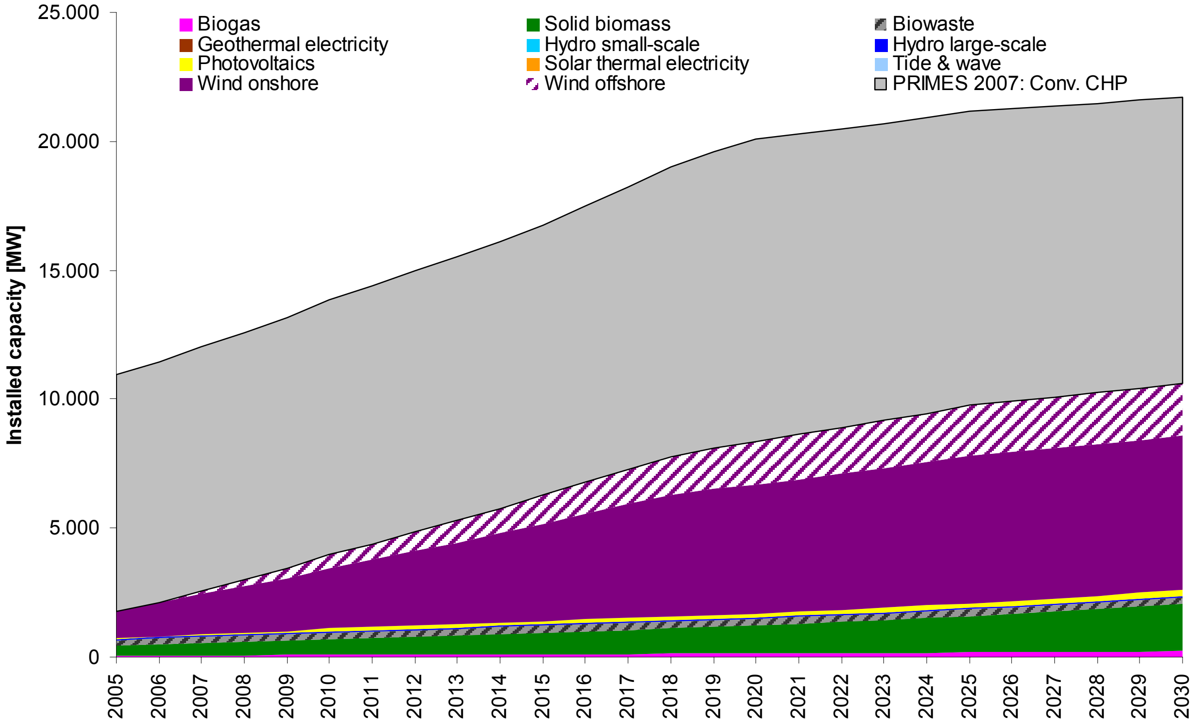

Figure 11: DG/RES and conventional CHP capacity development on disaggregated technology level in the Netherlands from 2005 to 2030 (including projections based on [4])

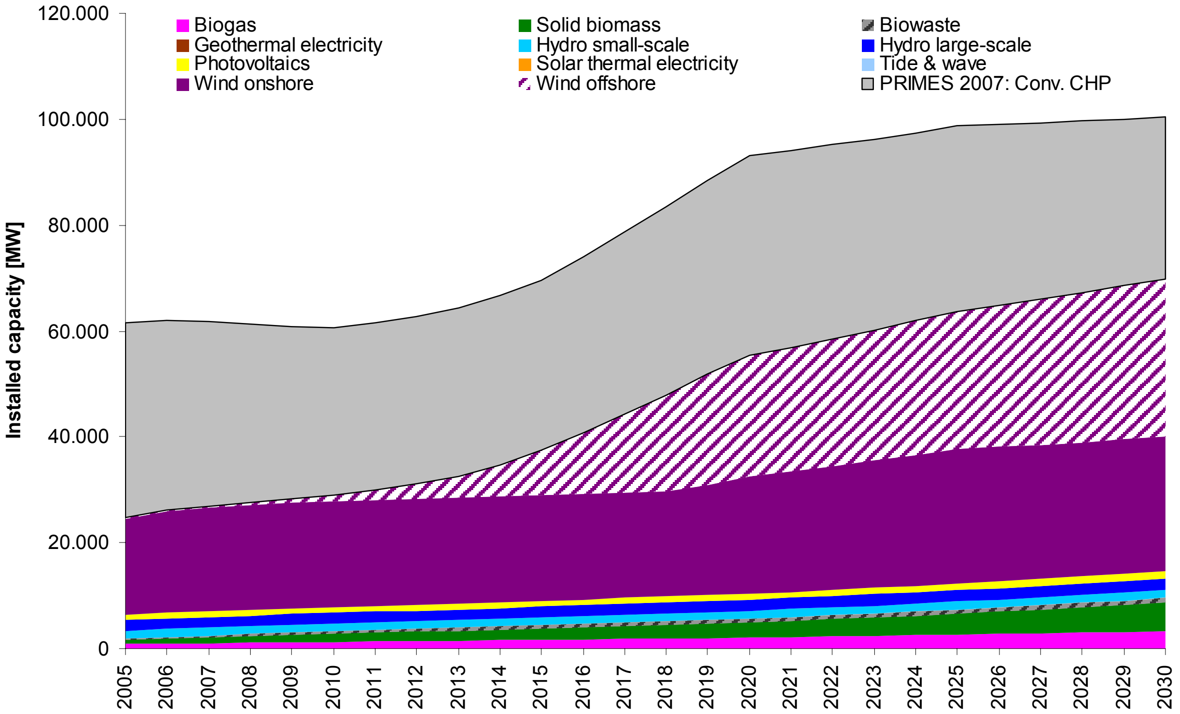

Figure 12: DG/RES and conventional CHP capacity development on disaggregated technology level in Germany from 2005 to 2030 (including projections based on [4])

With respect to Germany, the reference scenario indicates a total DG/RES capacity increase from 24600 MW in 2005 to about 75000 MW in 2030 (see Figure 12). Conventional CHP development decreases from 36900 MW in 2005 to about 30000 MW in 2030 according to performed projections (see [4]). As well as in the Netherlands, the German DG/RES technology mix consist basically of wind power with big offshore potentials, biomass, biogas and hydro power with very little shares of biowaste and a constantly growing photovoltaic potential as from 2005. On the other hand (and in comparison to Spain), the photovoltaic potential is limited because even high feed-in tariffs are not able to compensate the relatively low yearly full load hours in the least cost approach.

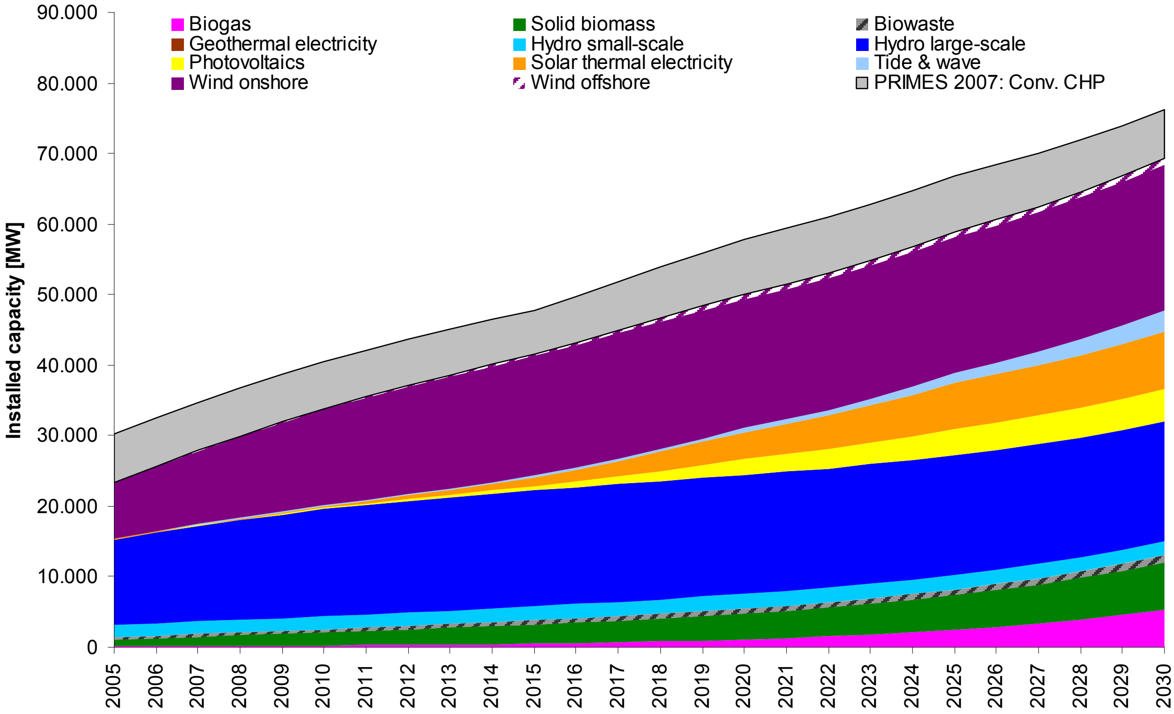

Figure 13: DG/RES and conventional CHP capacity development on disaggregated technology level in Spain from 2005 to 2030 (including projections based on PRIMES 2007)

Finally, in Spain the reference scenario (see Figure 13) derives a total DG/RES capacity increase from 23400 MW in 2005 to about 69400 MW in 2030. Conventional CHP development keeps constant at approximately 7000 MW according to projections in [4]. The DG/RES technology mix in Spain consists basically of hydro power followed by wind power with minor offshore potentials. Biomass, biogas, solar thermal, tidal as well as photovoltaic technologies also show significant and growing shares as from 2010.

### 4.1.3 Case study level

Similar to the analysis performed on country level, simulations for selected case study regions in the Netherlands, Germany and Spain are discussed. In the Dutch case total wind power capacities increase from 87 MW in 2005 (including already existing installations) to about 491 MW in 2030 within the High and from 86 to 331 MW in the Low scenario (see Figure 14) . It is worth mentioning, that the internal model scenario settings are chosen equal to country level in order to derive concise scenarios.

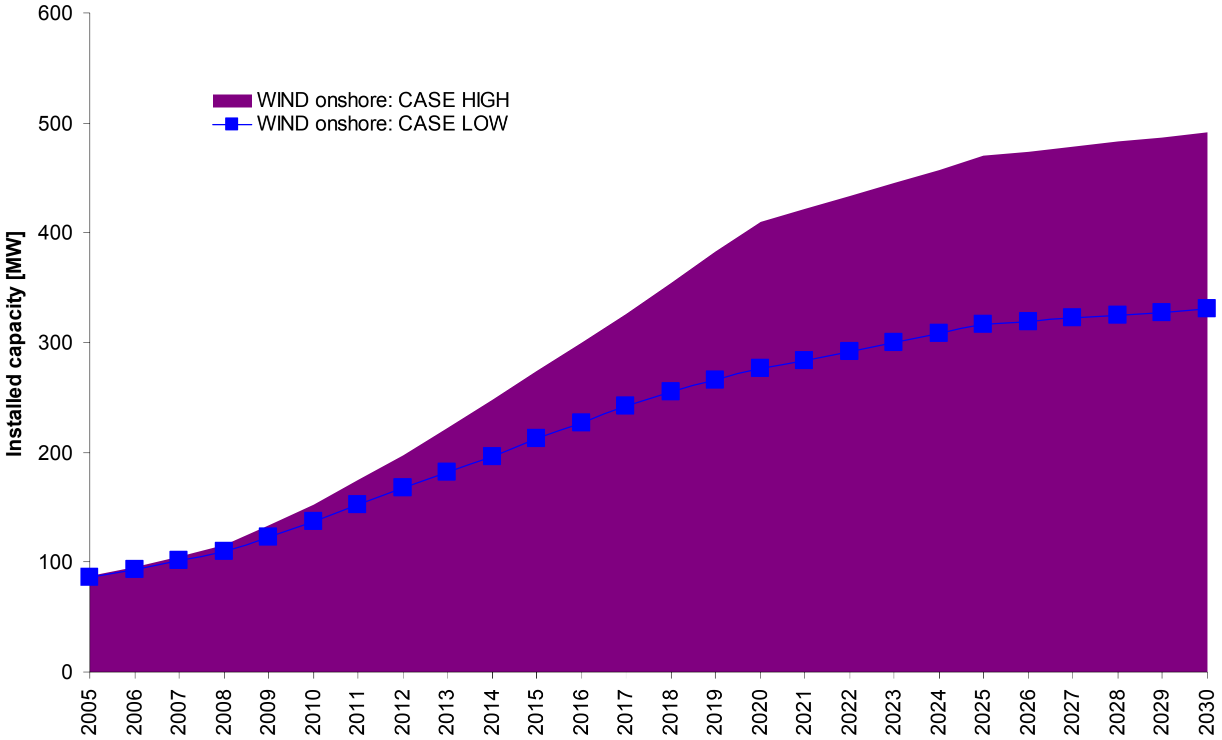

Figure 14: Wind development on case study level in the Netherlands from 2005 to 2030 (including projections based on PRIMES 2007)

In Germany photovoltaic capacity development within the case study area increases from 1 MW in 2005 (including already existing installations) to about 16 MW in 2030 within the High and from 1 to 10 MW in the Low scenario. As can be seen in Figure 15, as from 2015 there is no additional photovoltaic capacity installation any more. This is due to the currently implemented yearly decrease of the feed-in tariff for photovoltaic electricity generation in Germany. Costs for photovoltaic installations are too high and therefore not economically feasible in the least cost approach of **Green*Net***. The slight decrease of PV capacities after 2016 is due to old installations which reach their technical lifetime.

In the Spanish case study region there is capacity development for both wind and photovoltaic generators. Figure 16 shows that the capacity development of PV starts from about 0 MW in 2005 increasing to 80 MW in the High and to about 22 MW in 2030 in the Low scenario. Wind starts at 12 MW in 2005 and increases to 56 MW in the High and 34 MW in the Low scenario. Again the development after 2020 is projected using forecasts in [4].

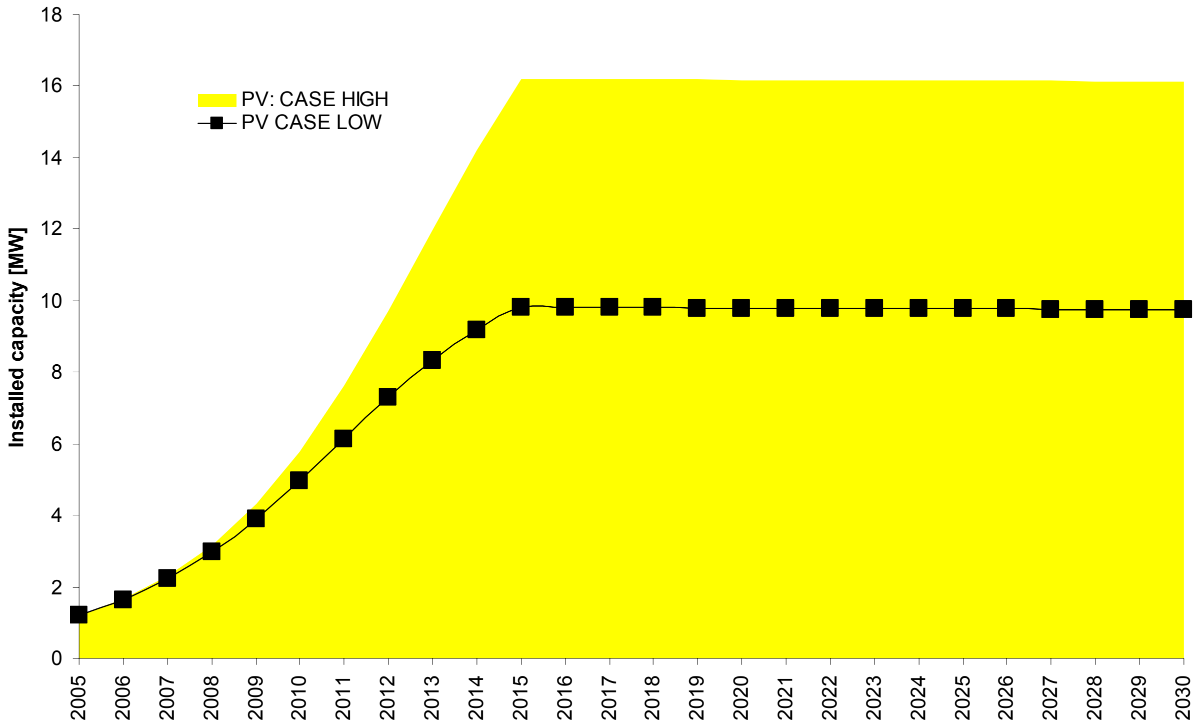

Figure 15: Photovoltaic capacity development for the case study in Germany from 2005 to 2030 (including projections based on [4])

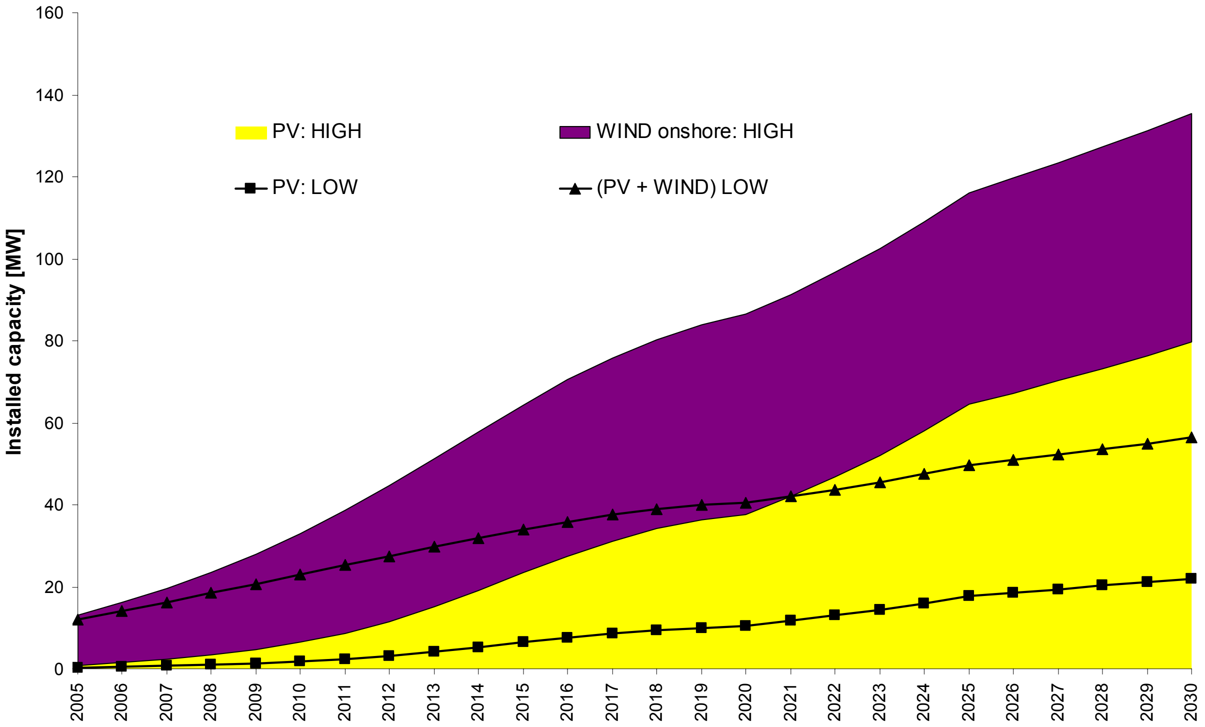

Figure 16: Photovoltaic and wind capacity development for the case study in Spain from 2005 to 2030 (including projections based on [4])

## 4.2 Separation between transmission and distribution level

As the IMPROGRES project analyses the impact of DG/RES mainly on distribution level, simulation results of **Green*Net*** were allocated to distribution areas as well. Thus, the following sections show derived figures of DG/RES development on country level for the Netherlands, Germany and Spain within distribution grids.

### 4.2.1 Netherlands

For the Netherlands the separation between transmission and distribution level (voltage level ≤ 150kV) was performed according to Table 11. Regarding the reference for separation of DSO/TSO level, the implemented values are based on 'expert judgements' using different databases. For CHP the distribution of existing CHP units over different size categories and linked particular size categories with connection at either distribution or transmission level was analysed. For DG/RES technologies the "Admire-Rebus"[3] models database was used to link specific size categories to connections at either the distribution or transmission level.

Furthermore, the **Green*Net*** simulation results presented in chapter 4.1.2 were recalculated illustrating results in Figure 17. In detail, generation capacities (incl. conventional CHP) increase from about 3.2 GW in 2005 to approximately 8.4 GW on distribution level. This implies an average yearly growth rate of DG/RES of about 5.5% between 2005 an 2020 followed by a lower average growth rate of about 1.5% between 2020 and 2030. Again it needs to be mentioned that this scenario is derived incorporating the Business As Usual policy setting as well as projections to 2030 according to [4].

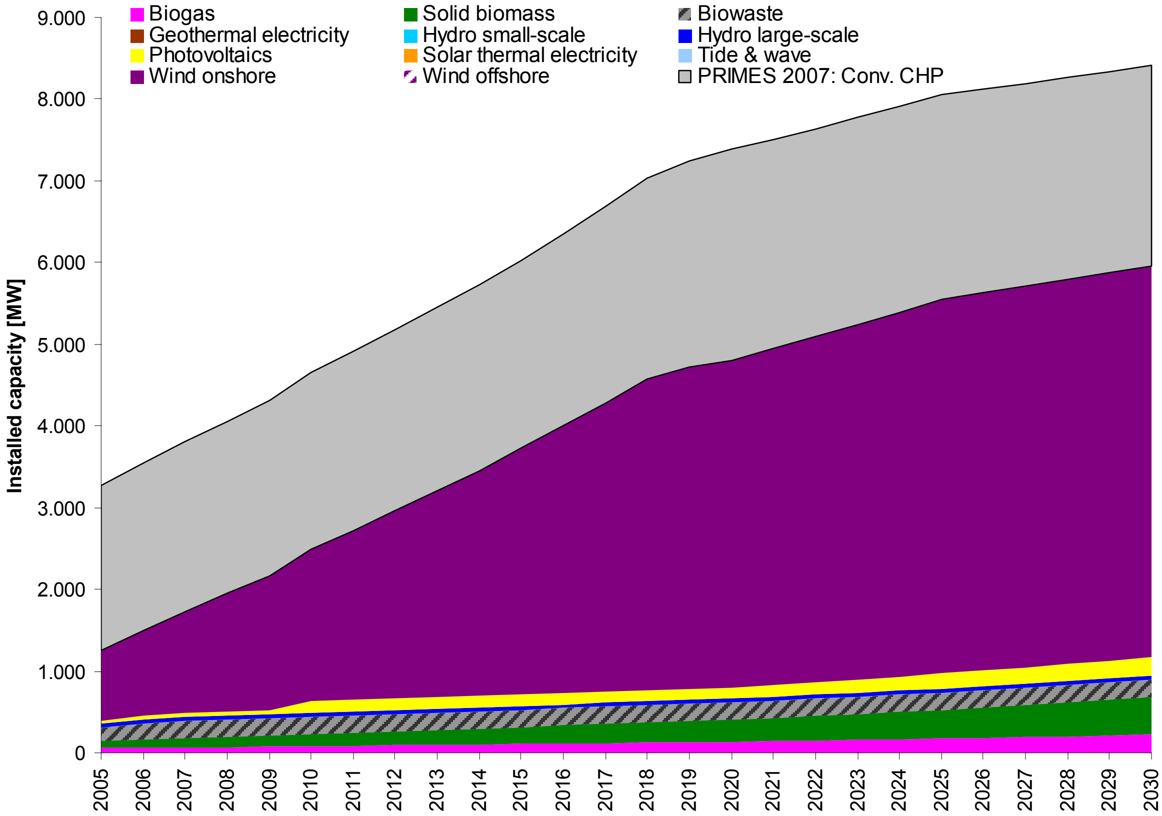

Figure 17: DG/RES and conventional CHP capacity development on distribution level in the Netherlands from 2005 to 2030

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[3] compare http://www.managenergy.net/products/R92.htm

Table 11: Separation of DG/RES electricity generation between distribution and transmission level in the Netherlands

| Technology | Distribution | Transmission |
|---|---|---|
| Biogas | 100% | 0% |
| Solid biomass | 25% | 75% |
| Biowaste | 80% | 20% |
| Geothermal | - | - |
| Hydro large-scale | 100% | 0% |
| Hydro small-scale | 100% | 0% |
| Photovoltaics | 100% | 0% |
| Solar thermal electricity | - | - |
| Tide | 100% | 0% |
| Wind onshore | 80% | 20% |
| Wind offshore | 0% | 100% |
| Conventional CHP | 22% | 88% |

In general, simulation results show that on distribution level a significant increase of wind and conventional CHP capacities can be expected in the Netherlands. Therefore, suitable solutions with respect to grid integration need to be implemented in the future.

### 4.2.2 Germany

In Germany the separation between transmission and distribution level (voltage level ≤ 110 kV) was performed similarly. Table 12 shows expected shares of DG/RES on transmission and distribution level on disaggregated technology level. Again **Green*Net*** simulation results were recalculated illustrating results in Figure 18. Generation capacities (incl. conventional CHP) increase from about 27 GW in 2005 to approximately 47 GW in 2030. This implies an average yearly growth rate of DG/RES of about 2.1% between 2005 an 2020 followed by an average growth rate of about 2.3% between 2020 and 2030.

Again a significant increase of wind onshore and conventional CHP capacities can be expected in distribution grids. Even significant capacity increases can be expected for biogas and solid biomass technologies.

Table 12: Separation of DG/RES electricity generation between distribution and transmission level in Germany (see [15])

| Technology | Distribution | Transmission |
|---|---|---|
| **Hydro** | 45% | 55% |
| **Wind** | 89% | 11% |
| **Biomass** | 98% | 2% |
| **Solar Energy** | 100% | 0% |
| **Other RE** | 78% | 22% |
| **CHP** | 19% | 81% |

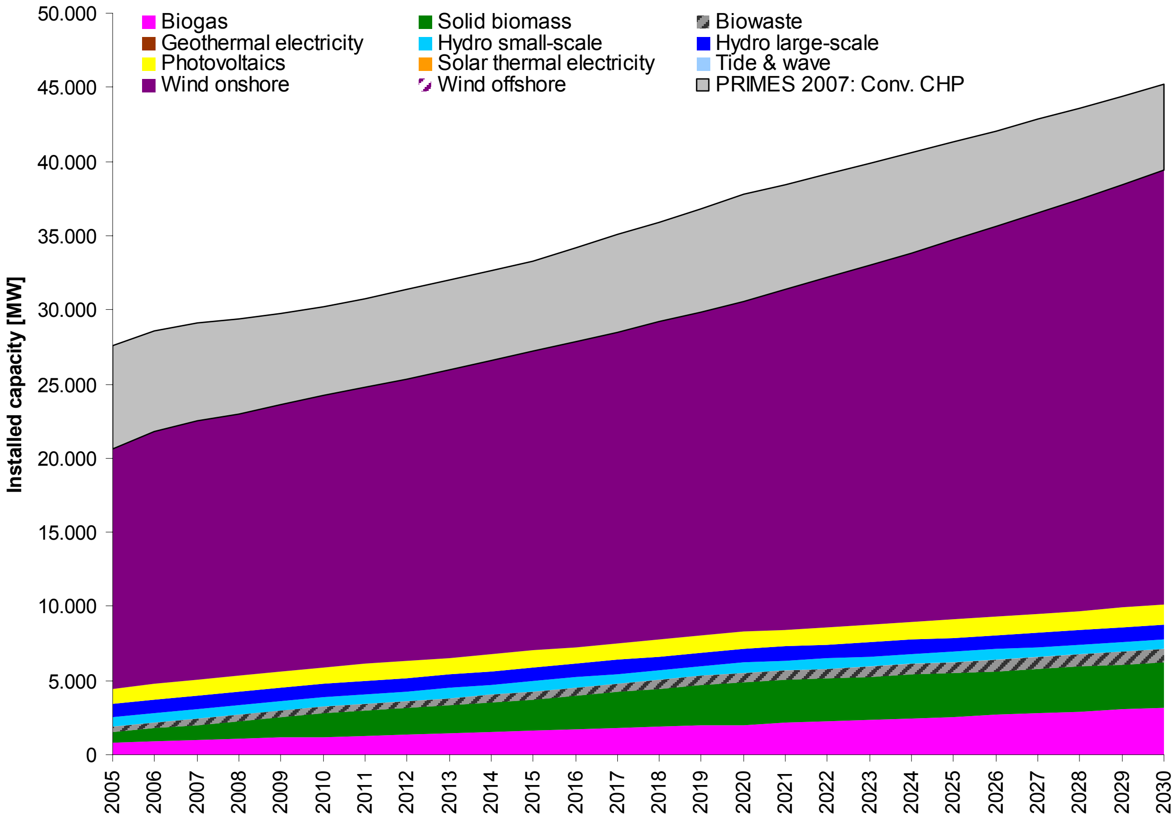

Figure 18: DG/RES and conventional CHP capacity development on distribution level in Germany from 2005 to 2030

### 4.2.3 Spain

Table 13 shows expected shares of DG/RES on transmission and distribution level (voltage level ≤ 145 kV) on disaggregated technology level in Spain. Generation capacities (incl. conventional CHP) on distribution level increase from about 22 GW in 2005 to approximately 56 GW. This implies an average yearly growth rate of DG/RES of about 4.3% between 2005 an 2020 followed by an average growth rate of about 3% between 2020 and 2030.

Significant capacity increases (compare Figure 19) can be expected in conventional CHP, photovoltaic, solar thermal, as well as biogas and biomass installations. This mix of partly intermittent and non-intermittent generation capacities might drive distribution capacities to its limits resulting in increased balancing and backup power upgrades as well as grid reinforcements.

Table 13: Separation of DG/RES electricity generation between distribution and transmission level in Spain (see [17])

| Technology | Distribution (≤145kV) | Transmission (>145kV) |
|---|---|---|
| Biogas | 99% | 1% |
| Solid biomass | 89% | 11% |
| Biowaste | 82% | 18% |
| Geothermal | 0% | 0% |
| Hydro large-scale | 74% | 0% |
| Hydro small-scale | 100% | 0% |
| Photovoltaics | 100% | 0% |
| Solar thermal electricity | 100% | 0% |
| Tide | 0% | 0% |
| Wind onshore | 80% | 20% |
| Wind offshore | 0% | 100% |
| CHP | 89% | 11% |

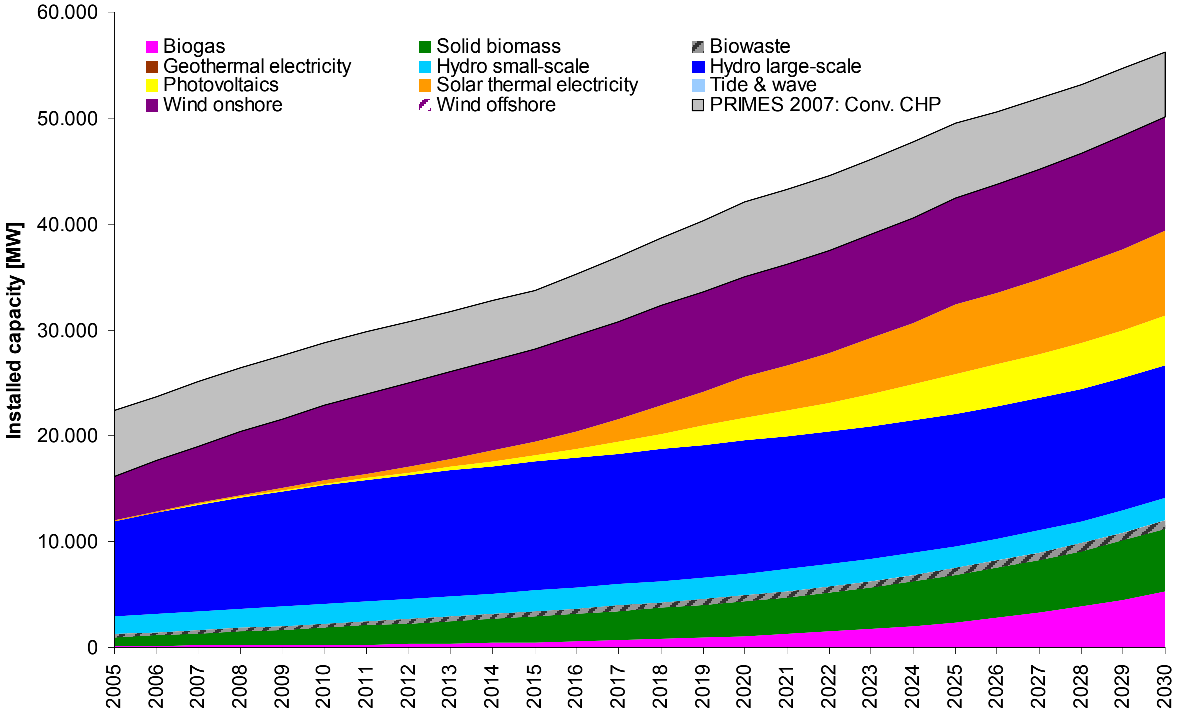

Figure 19: DG/RES and conventional CHP capacity development on distribution level in Spain from 2005 to 2030

# 5 INCREMENTAL CHANGES FOR A HIGH PRICE SCENARIO

Within the IMPROGRES project the derivation of different future DG/RES scenarios is considered. Thus, an alternative electricity price scenario for the Netherlands, Germany and Spain is implemented in the **Green*Net*** model as illustrated in Figure 20.

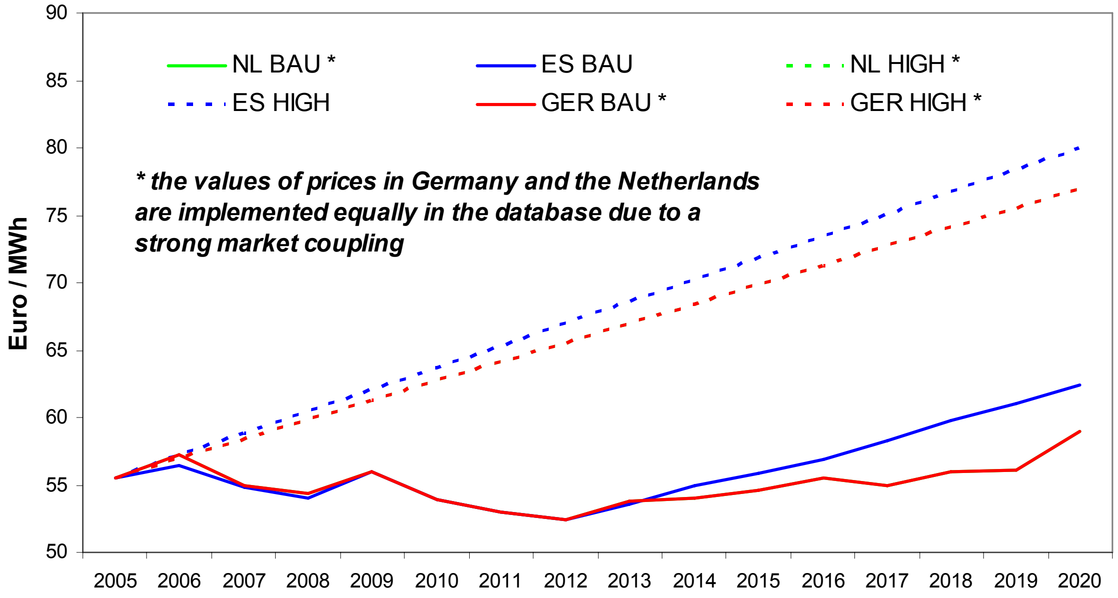

Figure 20: Chosen High price scenario (electricity prices) for the Netherlands, Germany and Spain (the values of prices in Germany and the Netherlands are implemented equally in the database due to a strong market coupling); the corresponding price values were adopted in the **Green*Net*** model accordingly

## 5.1 Netherlands

Simulations for the High price scenario were performed similar as for the BAU scenario (including all existing and future DG/RES potential changes) on country level analysing the incremental changes as shown in Table 14. It is evident that simulation results for biomass and wind offshore capacities increase by 22 and 237 MW at maximum in 2020 (145 and 800 GWh with respect to electricity generation). Compared to the BAU scenario this is a capacity increase of about 3.1%. Other technologies show no electricity price sensitivity as their generation cost might be too high compared to the price increases. Furthermore, Figure 21 illustrates capacity increases for wind and solid biomass technologies within the Netherlands. The slight variations are due to varying price differences between the BAU and High price scenario (compare Figure 20).

Table 14: Incremental changes of the simulation results of the High price scenario compared to the BAU scenario for electricity generation and capacities in the Netherlands

| Electricity generation [GWh] | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Netherlands** | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Solid biomass | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 19 | 35 | 55 | 78 | 106 | 138 | 145 |
| Wind offshore | 400 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 | 800 |
| Electricity capacity [MW] | | | | | | | | | | | | | | | | |
| **Netherlands** | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Solid biomass | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 5 | 9 | 12 | 16 | 21 | 22 |
| Wind offshore | 126 | 256 | 265 | 261 | 248 | 244 | 244 | 245 | 249 | 252 | 252 | 252 | 252 | 247 | 240 | 237 |

Figure 21: DG/RES capacity increase within simulation results in the Netherlands due to a High price scenario compared to the BAU scenario until 2020

## 5.2 Germany

For the German High price scenario deviations to the BAU scenario are caused by several DG/RES technologies as can be seen in detail in Table 15. The overall DG/RES capacity increase can be quantified by approximately 7930 MW or 14809 GWh in 2020. Compared to the BAU scenario this is a capacity increase of about 14.4%. In addition, Figure 22 illustrates capacity increases for several DG/RES technologies within Germany.

Table 15: Incremental changes of the simulation results of the High price scenario compared to the BAU scenario for electricity generation and capacities in Germany

**Electricity generation [GWh]**

| **Germany** | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biogas | 0 | 0 | 48 | 81 | 81 | 81 | 81 | 125 | 166 | 186 | 186 | 186 | 172 |
| Solid biomass | 0 | 0 | 0 | 0 | 0 | 0 | 99 | 99 | 137 | 141 | 137 | 651 | 1.140 |
| Hydro large-scale | 424 | 424 | 550 | 809 | 809 | 923 | 1.018 | 732 | 1.066 | 1.066 | 1.066 | 1.232 | 983 |
| Hydro small-scale | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 77 | 152 | 225 | 297 | 366 |
| Photovoltaics | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 |
| Tide & wave | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39 | 77 | 116 |
| Wind onshore | 0 | 0 | 0 | 35 | 1.561 | 3.973 | 5.186 | 7.575 | 9.657 | 11.416 | 13.006 | 13.026 | 12.030 |

**Electricity capacity [MW]**

| **Germany** | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biogas | 0 | 0 | 9 | 15 | 15 | 15 | 15 | 22 | 28 | 32 | 32 | 32 | 29 |
| Solid biomass | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 15 | 21 | 22 | 21 | 99 | 174 |
| Hydro large-scale | 61 | 61 | 81 | 123 | 123 | 143 | 164 | 123 | 171 | 171 | 171 | 197 | 158 |
| Hydro small-scale | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 28 | 41 | 54 | 67 |
| Photovoltaics | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 |
| Tide & wave | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 28 | 42 |
| Wind onshore | 0 | 0 | 0 | 18 | 860 | 2.238 | 2.928 | 4.367 | 5.625 | 6.707 | 7.705 | 7.880 | 7.459 |

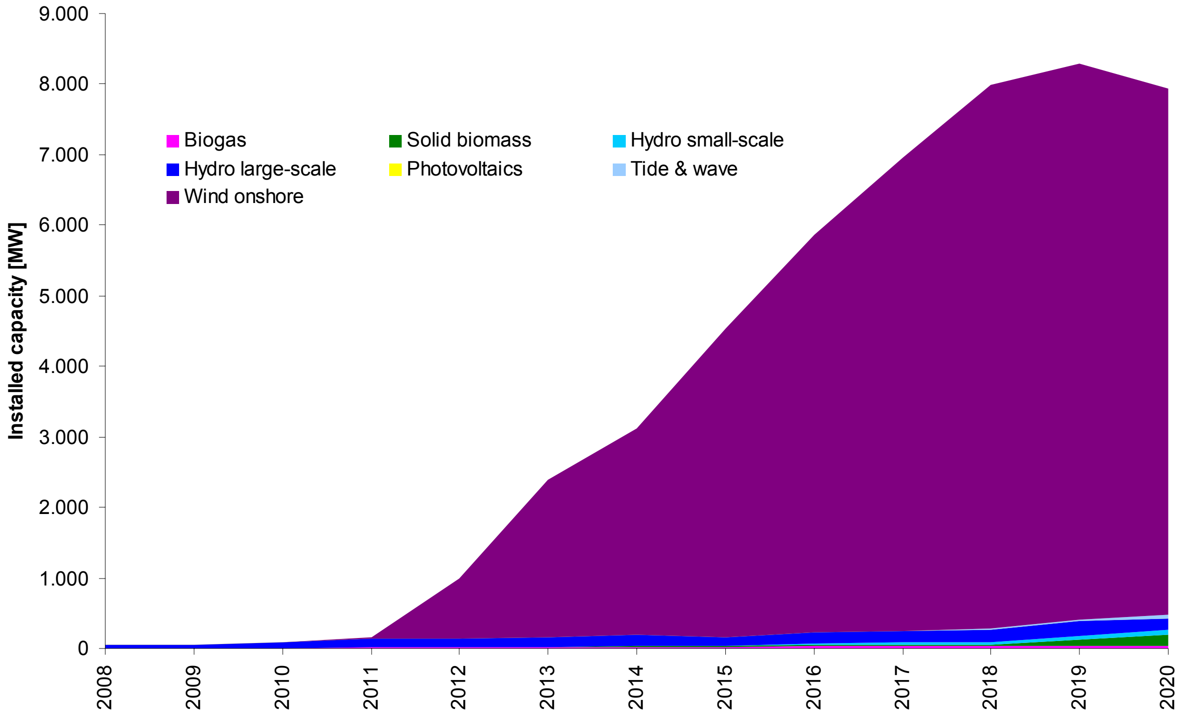

Figure 22: DG/RES capacity increase within simulation results in Germany due to a High price scenario compared to the BAU scenario until 2020

## 5.3 Spain

In Spain incremental changes are evident only for biomass technologies, which amount to about 53 MW or 351 GWh in 2020. This is a change of only 0.1%. Within the simulation results it can be seen that the incremental changes only occur as from 2020. This indicates that the currently implemented policy supports DG/RES even in a better way than the increased market price would do. Therefore it is not likely that more DG/RES is installed until 2020 in the High price scenario.

Table 16: Incremental changes of the simulation results of the High price scenario compared to the BAU scenario for electricity generation and capacities in Spain

| **Electricity generation [GWh]** | |
|---|---|
| **Spain** | 2020 |
| Solid biomass | 351 |
| **Electricity capacity [MW]** | |
| **Spain** | 2020 |
| Solid biomass | 53 |

# 6 GRID INTEGRATION COST ON COUNTRY LEVEL

This chapter gives an overview on the methodologies applied with respect to the implementation of grid related cost due to DG/RES integration. When taking into account grid integration the grid infrastructure (connection of RES-E generation technologies to the existing grid, reinforcement of the existing grid due to RES-E integration) has to be analyzed in detail.

Within the analytical framework of the software tool **Green*Net*** the cost elements are cost for grid connection and grid reinforcements and are added to the long-run marginal cost of DG/RES generation and therefore influence the investment decision for new capacities.

The basic principle of the allocation of grid and system related cost due to RES-E generation in the supply curve is shown in Figure 23 below. With respect to system operation cost detailed analysis is performed within Deliverable 5 of the IMPROGRES project for specific case studies.

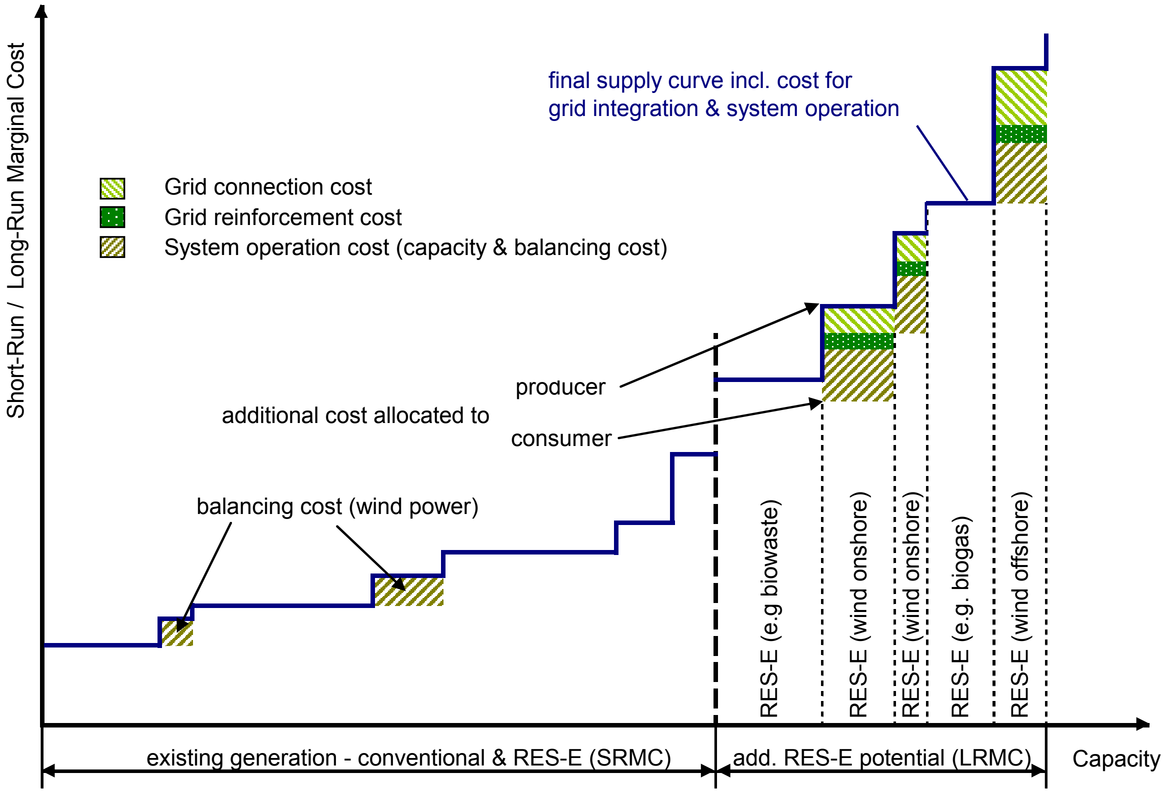

Figure 23: Implementation of the additional system operation costs (not analysed within this report) as well as corresponding grid connection and reinforcement costs in the formal framework of the simulation software **Green*Net*** (see [18])

RES-E generation having no intermittent nature as well as conventional generation is modeled without any additional system operation requirements and cost.

In the existing version of the software tool **Green*Net*** cost for grid connection and grid reinforcement are only taken into account for wind power. For several other DG/RES technologies the cost for grid connection are implemented as a part of the investment cost (and are therefore always allocated to the RES-E generator according to the current practice) and cost for reinforcement are neglected.

As the results of several case studies on DG/RES grid integration carried out in the **Green*Net*** projects (compare e.g. [19]) show, cost for grid connection are in the range of up to 3% for technologies for which sites are not constraint by the primary energy source (e.g. biomass) and therefore the allocation practice only has a minor effect on the investment decision.

## 6.1 Grid infrastructure costs

In general the integration of any power generation technology into the existing power grid is connected with investments in grid infrastructure. This is also the case for the grid integration of DG/RES power plants. In this context two different aspects have to be considered:

i) The connection of RES-E power plants to the existing power grid – the corresponding investments are indicated as **grid connection costs (GC)**.

ii) Reinforcements of the existing power grid due to RES-E grid integration – the corresponding investments are indicated as **grid reinforcement costs (GR)**.

As already mentioned in the current version of the software tool **Green*Net*** these investments are considered separately only for wind power; for several other conventional as well as DG/RES power generation technologies the grid connection cost is treated as a part of the overall investments and grid reinforcement cost is neglected.

In order to avoid any misinterpretation of the results presented in this report, a detailed definition of terms and system bounds used within **Green*Net*** is given in the following chapter.

### 6.1.1 Grid connection costs

The term *grid connection* indicates the physical connection of a DG/RES power plant or a number of power plants (e.g. a wind farm) to the nearest connection point of the existing grid being technically and economically feasible, i.e. the so called external grid. **It does not comprise the so called internal grid,** connecting e.g. the turbines of a wind farm with the common connection point of the site.

The grid connection usually comprises the power line/cable connecting the common connection point of the site with the connection point of the existing grid (in general the substation) as well as modifications and extensions of the corresponding substation.

For offshore wind farms the connection point of the existing grid in any case is located onshore independent of the underlying connection concept. I.e. even if the high voltage power grid is extended to the sea in the sense of a coordinated (and least cost) grid connection of offshore wind farms, the grid connection comprises even this high voltage power line. Figure 24 illustrates the system bounds used in **Green*Net*** for both connection concepts – the individual connection of single wind farms to the existing onshore power grid and the coordinated connection of a number of wind farms located in a certain area.

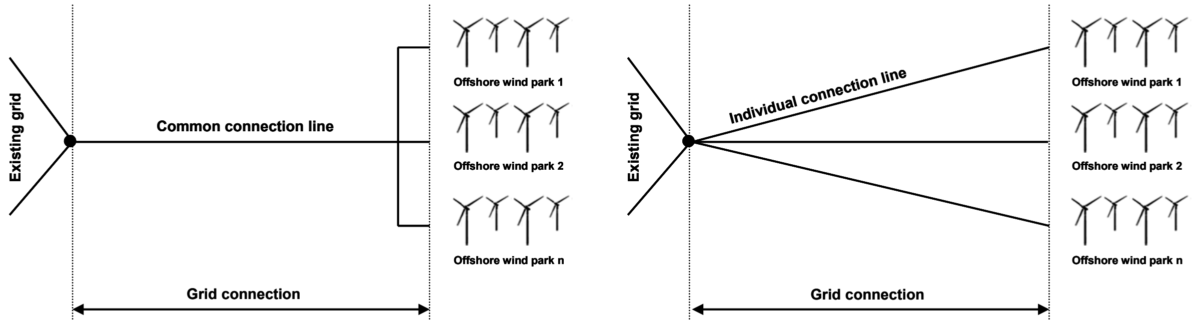

Figure 24: Illustration of the term grid connection as used in **Green*Net*** for the case of an individual connection of offshore wind farms to the existing onshore power grid (right) and coordinated connection of offshore wind farms via a common link (left)

The term *grid connection costs* indicates several costs for connecting a RES-E power plant or a number of RES-E power plants (e.g. a wind farm) to the existing grid (i.e. the cost of the external grid).

In general, grid connection costs of RES-E generation technologies are determined by a variety of factors. Most important ones are:

- The distance of the RES-E plant to the point of common coupling to the grid;
- The possibility to apply standardized equipment (for substations, cables, etc.);
- The necessity to extend the local grid and/or to switch to a higher voltage level.

In the past, grid connection costs have been comprehensively discussed for wind energy. But also for traditional DG/RES technologies – such as small hydropower – grid connection often appears to be a significant barrier. In general, grid connection is an important economic constraint for those generation technologies being mainly determined by the local availability of resources. Therefore, often a compromise between best sites and proper grid conditions appears. On the contrary, for biomass grid connection (in general) there is no crucial barrier as the particular location of the plant is even more independent from resource conditions.

Model implementation

In practice grid connection costs are – independent of the power generation technology – considered as part of the total investments and are therefore paid by the DG/RES generator. An alternative way might be the allocation of grid connection cost to the grid operator in order to minimize barriers for the grid access of (new) generators. Therefore the software tool **Green*Net*** simulates both cases – the allocation of grid connection cost to the DG/RES generator and to the grid operator. In the latter case the grid operator socializes cost, i.e. the end user finally pays for grid connection in form of a higher grid tariff.

So far in **Green*Net*** a separate allocation of grid connection cost is only implemented for wind power. However, it is planned to extend this approach to other RES-E technologies for which the grid connection issue is of relevance, like for small hydro, wave and tidal energy, within future research projects.

Costs for connecting wind power are implemented in the **Green*Net*** model based on empirical data collected:

- For wind onshore grid connection cost are assumed to be 8% of specific investment cost for all categories;
- For wind offshore capacities with similar distances to shore are clustered and allocated to four different cost levels ranging from 10 to 25% of the corresponding total specific investment cost.

### 6.1.2 Modeling grid reinforcement cost

The term *grid reinforcement* indicates several reinforcements of the existing transmission grids necessary to integrate DG/RES power plants into the power grid. Reinforcements of the distribution grid are for now not taken into account in **Green*Net*** since empirical data is very rare. Whilst reinforcements of the distribution grids usually can be clearly allocated to the originator, reinforcements of the transmission grid may on the one hand become necessary for a number of reasons (increased power trade, modification of spatial distribution of power demand and/or supply) and on the other hand imply advantages for a number of players in the power market (traders, consumers, utilities, DG/RES generators, etc.). This makes it difficult to allocate reinforcement measures in the transmission grid to a certain power generation technology (e.g. wind power or even nuclear power).

Grid reinforcement measures include the upgrade of existing power lines and/or the installation of additional power lines both resulting in an increased capacity.

The term *grid reinforcement cost* indicates several costs for reinforcements of the existing transmission power grids that can be allocated to DG/RES, i.e. only part of investments for reinforcements of the transmission grid are allocated to the specific DG/RES generation technologies for reasons mentioned above. The methodology used for modeling these cost is described in detail in the following sections.

Empirical data

Within the last years several studies were carried out addressing needs for grid reinforcements due to the grid integration of wind power. To derive comparable numbers for reinforcement cost based on the empirical data available, costs were derived according to a common methodology described in the following:

- On the one hand specific cost data determined in country specific studies are used to assess grid related reinforcement expenditures,
- on the other hand reinforcement costs are calculated resting upon common prices for transmission or distribution lines (€/km) and, furthermore,
- different scenarios of wind deployment are taken into account resulting in several shares of wind generation (related to the total generation).

As already indicated above, only part of the reinforcement costs for the transmission grid are taken into account, as the fed in wind power generation only requires part of the additional power line capacity on average. Hence, there are other market players profiting from additional transmission capacity, too. The additional capacity remaining for other market actors is depending on the wind power production as well as on the distribution of generation and loads for each moment and therefore changing over time, which makes it difficult to define a share of “non-utilized” capacity that may be allocated to other market players.

Finally, the capacity factor of wind power was found to be a suitable measure indicating the utilization of the grid[4]. This simplification allows the definition of the reinforcement cost of wind power as

$C_{GR,\ Wind} = CF_{Wind} * C_{GR,\ total}$

where

| | |
|---|---|
| $C_{GR,\ Wind}$............... | Cost of grid reinforcement allocated due to wind power |
| $CF_{Wind}$ ............... | Capacity factor of wind power |
| $C_{GR,\ total}$.............. | Total cost of grid reinforcement |

The application of the method described above on the empirical data available leads to the resulting numbers given in the table below. The corresponding graph shows that there is a correlation between reinforcement costs for the transmission grid and the wind power penetration. Furthermore, it can be seen that numbers are varying in a relatively wide range due to varying structural conditions in the different countries investigated.

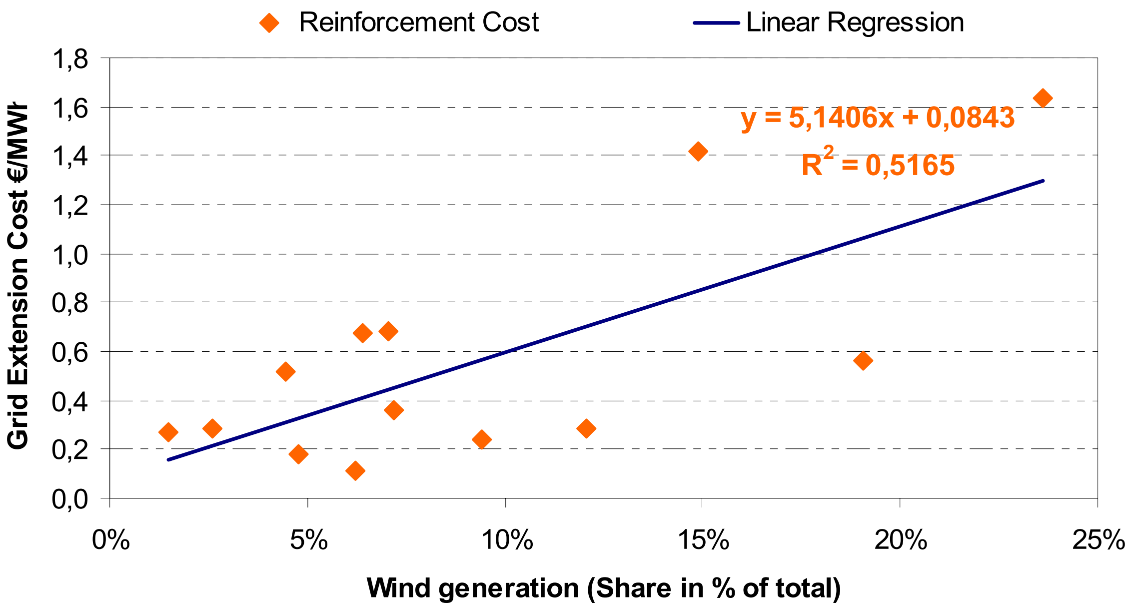

Figure 25: Cost for reinforcements of the transmission grid due to integration of wind power as a function of wind power penetration implemented in the **Green*Net*** model (see [18])

In order to represent the overall bandwidth of grid reinforcement cost, three scenarios are implemented in the software tool **Green*Net***. It is assumed that reinforcement costs of the transmission grid are increasing linearly with wind power penetration.

As already mentioned above, costs for grid reinforcements due to wind power are only allocated (if selected) to the long run marginal cost of new plants. In order to be able to reflect country-specific conditions within model runs, the scenario selection is implemented on country level.

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[4] Please note that this approach tends to overestimate grid reinforcement cost of a certain technology as it implies the assumption that the fed-in power utilizes the reinforced line(s) only, which is usually not the case for an intermeshed transmission grid.

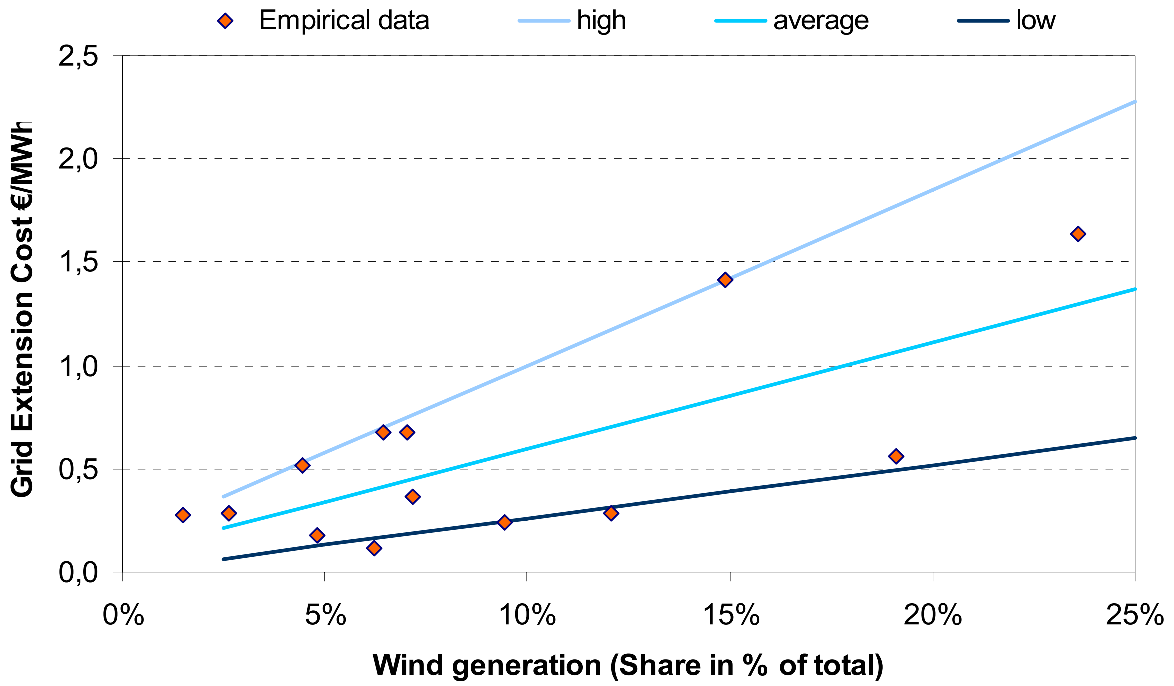

Figure 26: Model implementation of grid reinforcement costs of wind power in **Green*Net*** based on empirical data available (see [18])

## 6.2 Simulation results on country level

Within the IMPROGRES project the **Green*Net*** simulation software is used to derive country specific grid reinforcement needs as well as grid connection cost of wind technology. Grid reinforcement cost as described in previous chapters are applicable for transmission levels in each country analysed. In addition to that, Deliverable 5 of the IMPROGRES project analyses grid related cost in more detail for the specific case studies already mentioned above deriving cost for grid reinforcements on distribution level.

With respect to grid connection the overall costs (simulations were performed implementing average cost in Figure 26) occur on both transmission as well as on distribution level depending on the cumulated wind farm size. In general, it can be said that wind offshore installations are much more likely to be connected to transmission grids as their capacities are very high. As a result grid connection cost of wind onshore installations are more likely to be applicable for distribution level.

The following sections will provide simulation results of **Green*Net*** according to total grid reinforcement and connection cost again for the Netherlands, Germany and Spain on a yearly basis.

### 6.2.1 Grid reinforcement cost

In the Netherlands, overall grid reinforcement costs increase to about 12 million € per year due to installed wind capacities (onshore and offshore; compare Figure 27). With respect to about 6.3 GW of newly installed wind capacities in 2020 (compare Figure 11), this results in approximately 1.9 €/kW of yearly grid reinforcement cost.

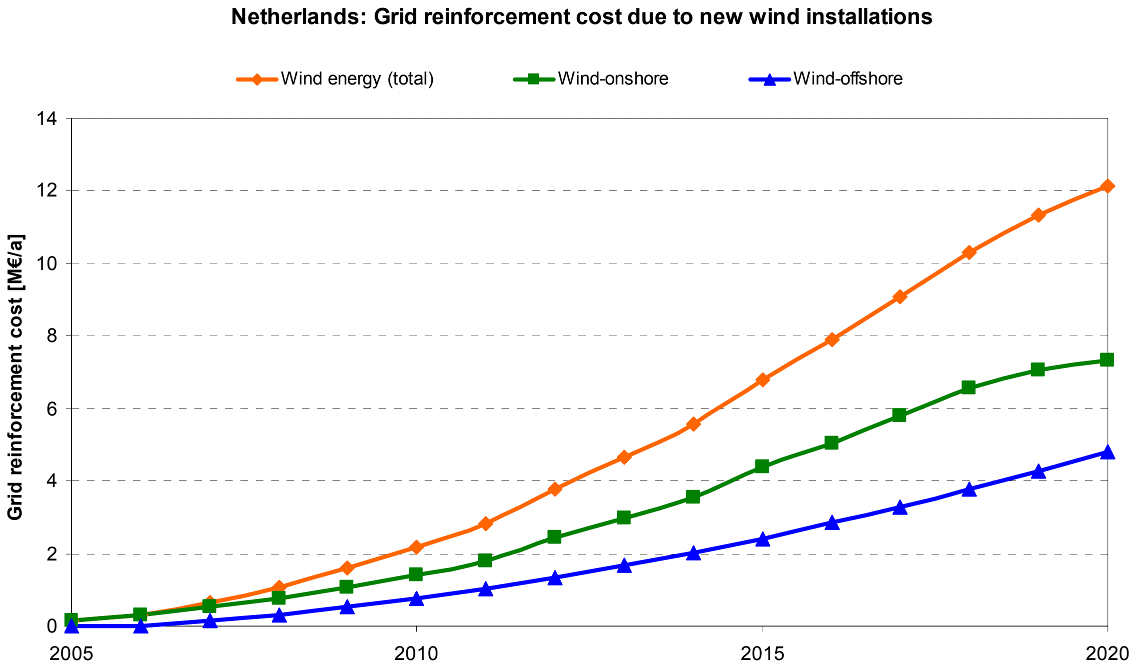

Figure 27: Total yearly grid reinforcement cost development for the Netherlands due to new wind (onshore and offshore) installations until 2020

In Germany, overall grid reinforcement cost increase to about 117 million € per year for new wind onshore and offshore installations. As from 2013 network reinforcement costs due to wind offshore installations get higher than for onshore technologies. This results in about 3.4 €/kW of yearly grid reinforcement cost if total wind capacities are ~34.4 GW in 2020.

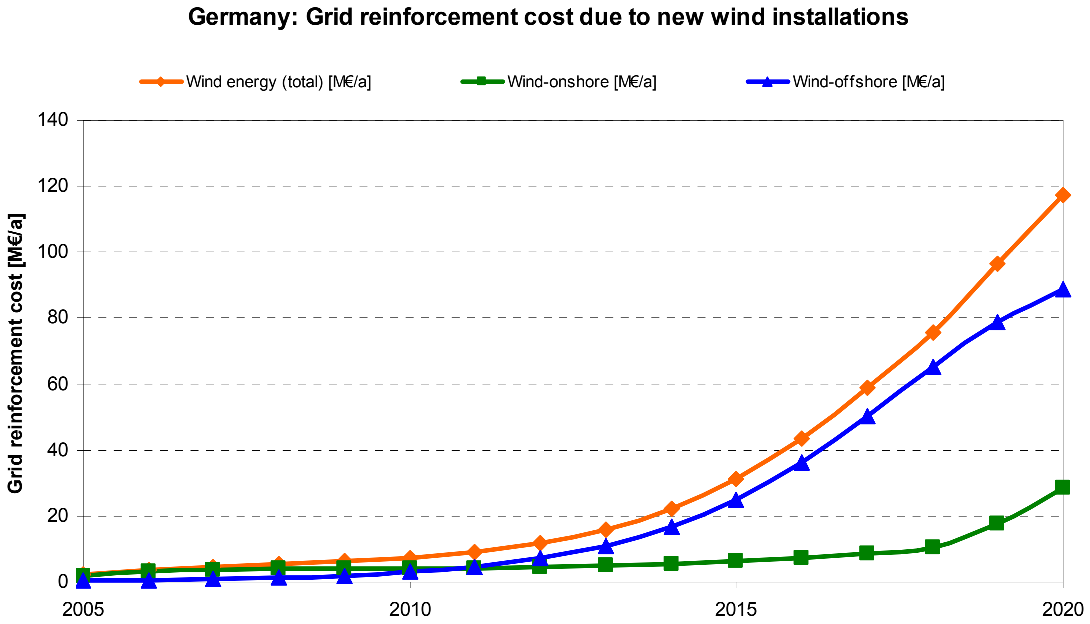

Figure 28: Total yearly grid reinforcement cost development in Germany due to wind (onshore and offshore) installations until 2020

In Spain (compare Figure 29) new wind onshore installations achieve the highest shares of overall grid reinforcement costs, which cumulate to ~30 million € per year in 2020. Compared to a newly built wind capacity of ~14.3 GW this results in yearly cost of ~2 €/kW.

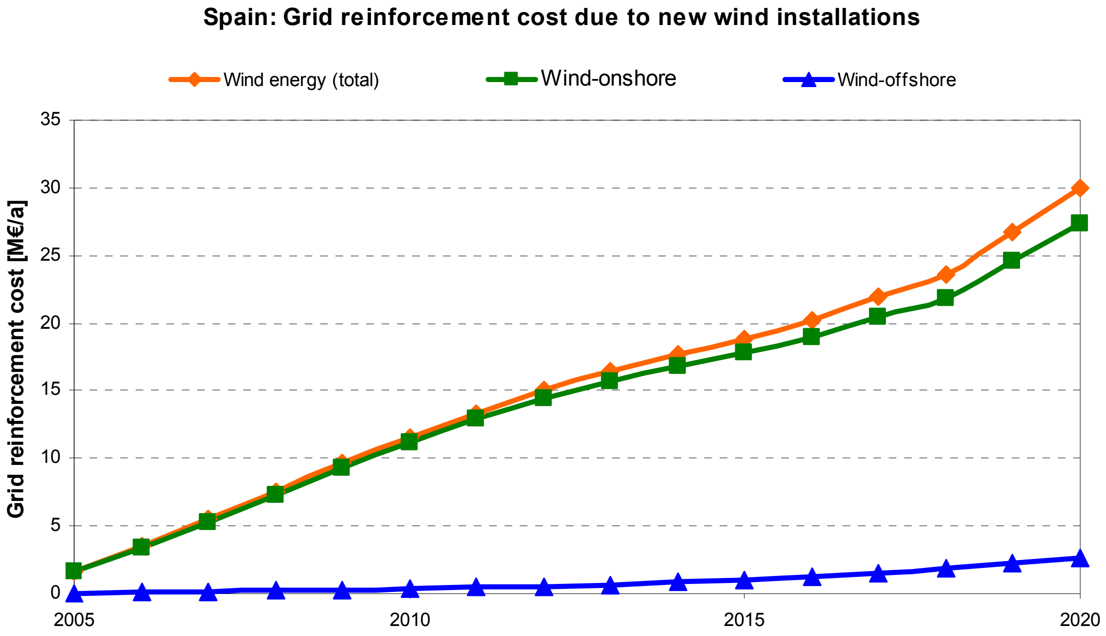

Figure 29: Total yearly grid reinforcement cost development in Spain due to wind (onshore and offshore) installations until 2020

### 6.2.2 Grid connection cost

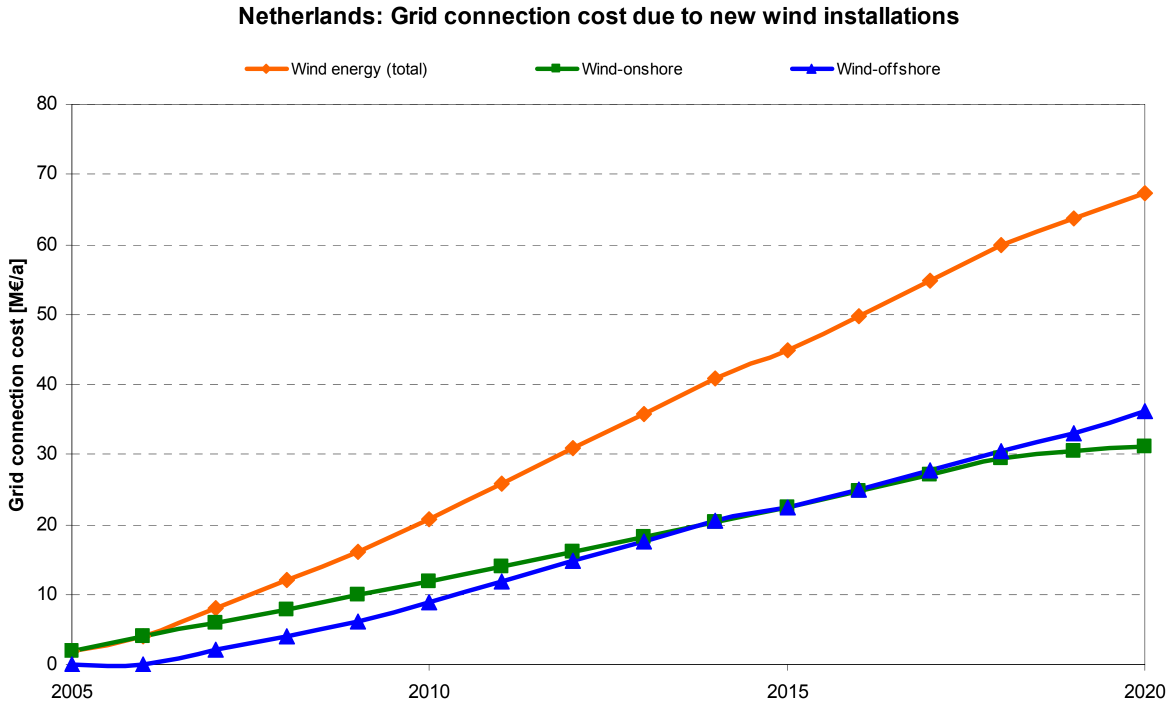

Figure 30: Total yearly grid connection cost development for the Netherlands due to new wind (onshore and offshore) installations until 2020

Regarding grid connection cost new wind installations in the Netherlands (compare Figure 30) illustrates approximately 67 million € per year up to 2020. Starting from 2014 until 2017 cost shares for wind onshore and offshore installations are more or less equal. After 2018 cost for wind onshore technology slightly stagnates due to fewer installations. Per kilowatt installed this implies yearly average cost of about 10.6 €.

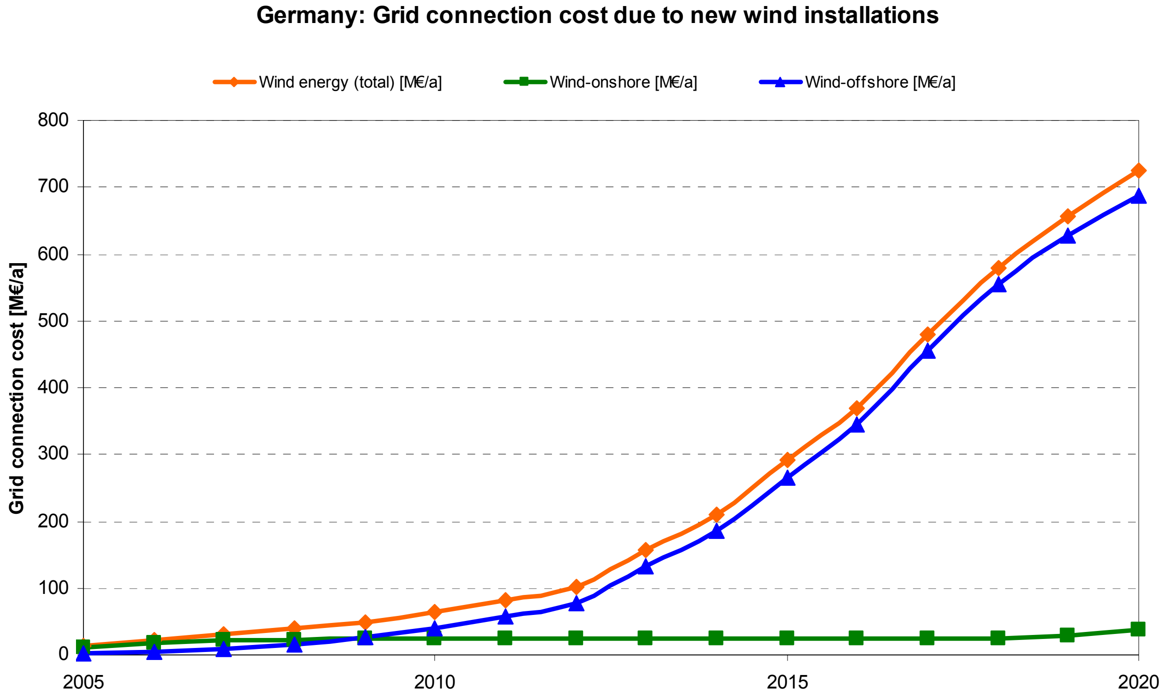

Figure 31: Total yearly grid connection cost development in Germany due to wind (onshore and offshore) installations until 2020

With respect to Germany overall cost of grid connection for wind onshore and wind offshore installations become more than 700 million € per year up to 2020 (compare Figure 31). Wind offshore related cost get higher than wind onshore related due to bigger yearly installations as from 2011. Average cost for grid connection are about 20.3 €/kW. Compared to the Netherlands these average cost are 100% higher due to higher offshore installations, which are very expensive.

In Spain cost for grid connection evolve up to 96 million € per year until 2020, whereas wind onshore holds the biggest share as wind offshore installations are very limited (compare Figure 32). Calculations show that in 2020 average yearly grid connection costs per kilowatt of wind installed are approximately 6.7 €.

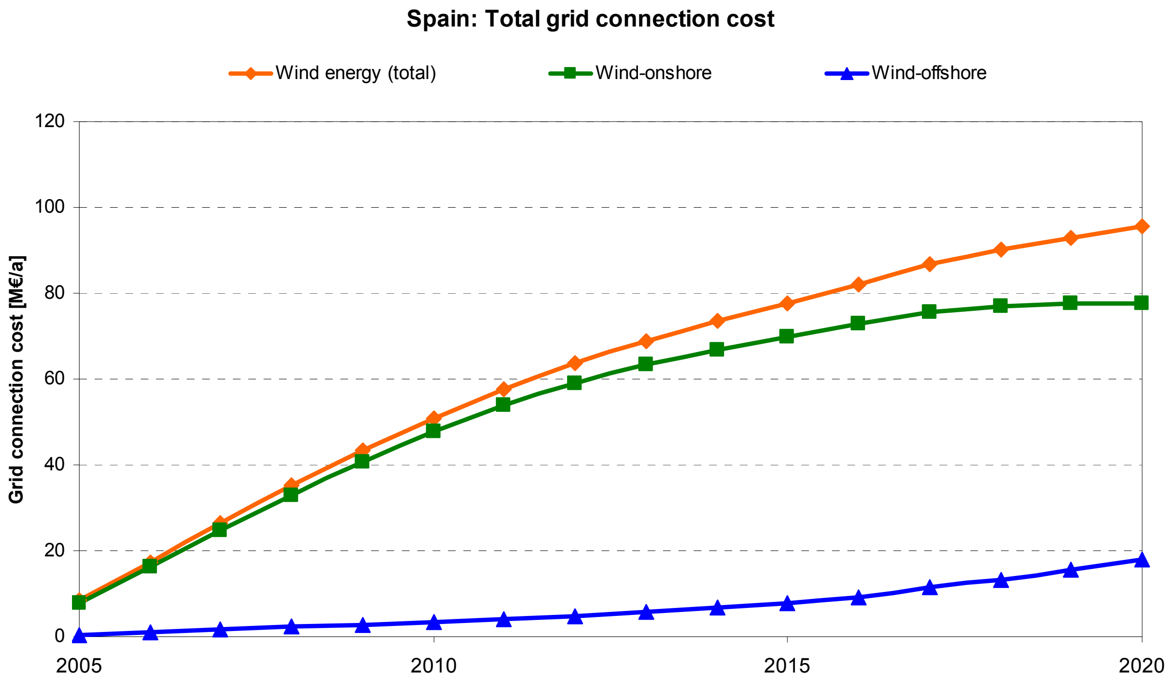

Figure 32: Total yearly grid connection cost development in Spain due to wind (onshore and offshore) installations until 2020

## 6.3 Differences between country and case study level

As **Green*Net*** derives grid related cost calculations solely on country level, it is not possible to derive cost components for grid connection and grid reinforcement for case studies as the modelling approach cannot be applied for specific network areas. Each grid segment has its specific historical development and geographically caused design. Even loads and generation in the areas may highly deviate from average country values. This is why it is not possible to perform a breakdown of country specific grid integration to case study levels.

On the contrary, the IMPROGRES project intends to evaluate specific cost parameters of DG/RES even on case study level in order to derive overall system cost. Thus, as the necessary steps to perform such analysis is far beyond the scope of this report, detailed calculations on case study level is presented within Deliverable 5 of the IMPROGRES project.

As previously mentioned, it is neither possible to allocate country related cost elements to case study level due to many differences of locally organised grid structures nor it is possible to perform the other way around. Detailed case study results are not eligible to perform projections on country or even European level. Therefore, the IMPROGRES project should provide a better understanding of DG/RES cost impacts from the energy systems and societies point of view. As a substantial contribution to that, this report delivers possible scenarios of DG/RES deployment in different countries and case studies analysed as well as cost calculations for grid reinforcement and grid connection on country level.

# 7 CONCLUSIONS AND RECOMMENDATIONS

In general, all **Green*Net*** simulation results show a significant growth in DG/RES capacities on European, country as well as on case study level. This implies that on European level according to a Business As Usual scenario total DG/RES electricity generation within the EU Member States (EU-27) increases from 490 TWh/yr in 2005 to about 1280 TWh/yr in 2030. The share of electricity generated from DG/RES regarding overall electricity demand increases from about 15% in 2005 to approximately 26% in 2020.

In addition to DG/RES development also conventional CHP capacity development is expected to increase in most countries analysed. With respect to wind capacities, significant grid related cost increases due to grid connection and grid reinforcement measures can be expected. Furthermore, calculation results show that on average, ~60% (average value for the three countries) of DG/RES are to be connected to distribution levels. Overall, according to the results shown in this report, wind power is likely to represent the dominant DG/RES technology in terms of installations. This trend supports the special emphasis given to the issues of grid integration of this technology within this work package.

To draw some recommendations for large-scale DG/RES grid integration clear definitions of adequate cost allocation of grid connection and grid reinforcements need to be found in order to guarantee investment security. Contrarily, DG/RES grid integration cannot take place on the expense of other market actors like grid operators. Grid operators increasingly have to compensate negative effects on transmission and distribution networks caused by DG/RES power plant location and technology choice. Therefore, it is suggested that explicit mechanisms are created also in grid regulation policies, being able to identify and remunerate the increase in investment requirements and possible asset stranding caused by large-scale DG/RES grid integration. Only then, economic disincentives for grid operators for absorbing DG/RES generation will disappear.

Furthermore, decentralised RES-E grid integration shall be exposed to locational signals to ensure the efficient choice of location, regardless of the cost allocation and charging policy. The calculation of charges should include both costs and benefits attributed to new locations. In principle, the present value of correct and fully cost reflective “deep” or “shallow” connection charges that recover the capital expenditures over the project lifetime are equivalent. Shallow charges might be preferred because they reduce risks and the financing costs of the DG/RES generator to be connected.

# BIBLIOGRAPHY

[1] Huber C., T. Faber, G. Resch, H. Auer: "The Integrated Dynamic Formal Framework of Green*Net*", Project Report, WP8, available on www.greennet.at, December 2004.

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

[3] Resch G.: "Dynamic cost-resource curves for electricity from renewable energy sources and their application in energy policy assessment", PhD-thesis conducted at Energy Economics Group (EEG), Vienna University of Technology, Austria, 2005.

[4] European Commission, "European Energy and Transport - Trends to 2030 - update 2007" European Commission, ISBN 978-92-79-07620-6, Luxembourg, 2008.

[5] European Commission, "European Energy and Transport – Scenarios on high oil and gas prices", European Commission, ISBN 92-79-02798-0, Luxembourg, 2006.

[6] A.W.N. van Dril, H.E. Elzenga: "Reference Projections energy and emissions 2005-2020", Project: Reference Projection energy, climate and acidifying emissions, Amsterdam, 2005.

[7] Auer H., Stadler M., Resch G., Huber C., Schuster T., Taus H., Nielsen L.H., Twidell J., Swider D.J.: "Cost and Technical Constraints of RES-E Grid Integration", WP2-report, August 2004, available for download from the project website www.greennet.at.

[8] Red electrica de Espana: "El sistema electrico 2006", National report, Madrid, 2007

[9] Capros P.: "The PRIMES Energy System Model Summary Description", model description; NATIONAL TECHNICAL UNIVERSITY OF ATHENS; European Commission Joule-III Programme, Athens, 2005

[10] M. de Noord, L.W.M. Beurskens, H.J. de Vries: "Potentials and costs for renewable Electricity generation", ECN, Petten, February 2004

[11] DIRECTIVE 2001/77/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of electricity produced from renewable energy sources in the internal electricity market; Official Journal the European Communities, September 2001

[12] Energistyrelsen: "Fremskrivning af Danmarks energiforbrug og udledning af drivhusgasser frem til 2025"; national report; ISBNwww: 978-87-7844-740-1; Juli 2008

[13] Nitsch J.: „Leitstudie 2007: Ausbaustrategie Erneuerbare Energien - Aktualisierung und Neubewertung bis zu den Jahren 2020 und 2030 mit Ausblick bis 2050"; Untersuchung im Auftrag des Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit; Stuttgart, 2007

[14] Redpoint Energy Limited „Implementation of EU 2020 Renewable Target in the UK Electricity Sector: Renewable Support Schemes"; A report for the Department of Business, Enterprise and Regulatory Reform, June 2008

[15] Ragwitz et al.: "EmployRES - The impact of renewable energy policy on economic growth and employment in the European Union"; Final report, Karlsruhe, 2009

[16] Bundesnetzagentur: "Monitoringbericht 2008"; Monitoringbericht gemäß §63 Abs. 4 EnWG i.V.m. § 35 EnWG, Bonn, July 2008

[17] Spanish regulator: "Información estadística sobre las ventas de energía del régimen especial", 2009

[18] Auer H., Obersteiner C., Faber T., Resch G., Prüggler W.: „Least cost RES-E grid integration strategies under different regulatory conditions", Deliverable D7 of the project **Green*Net*-EU27,** www.greennet-europe.org , Vienna, 2006

[19] Swider D., Beurskens L., Davidson S., Twidell J., Pyrko J., Prüggler W, Auer H., Vertin K., Skema R.: "Conditions and costs for renewables electricity grid connection: Examples in Europe"; Renewable Energy Vol 33/8 pp 1832-1842; DOI: 10.1016/j.renene.2007.11.005

# ANNEX I

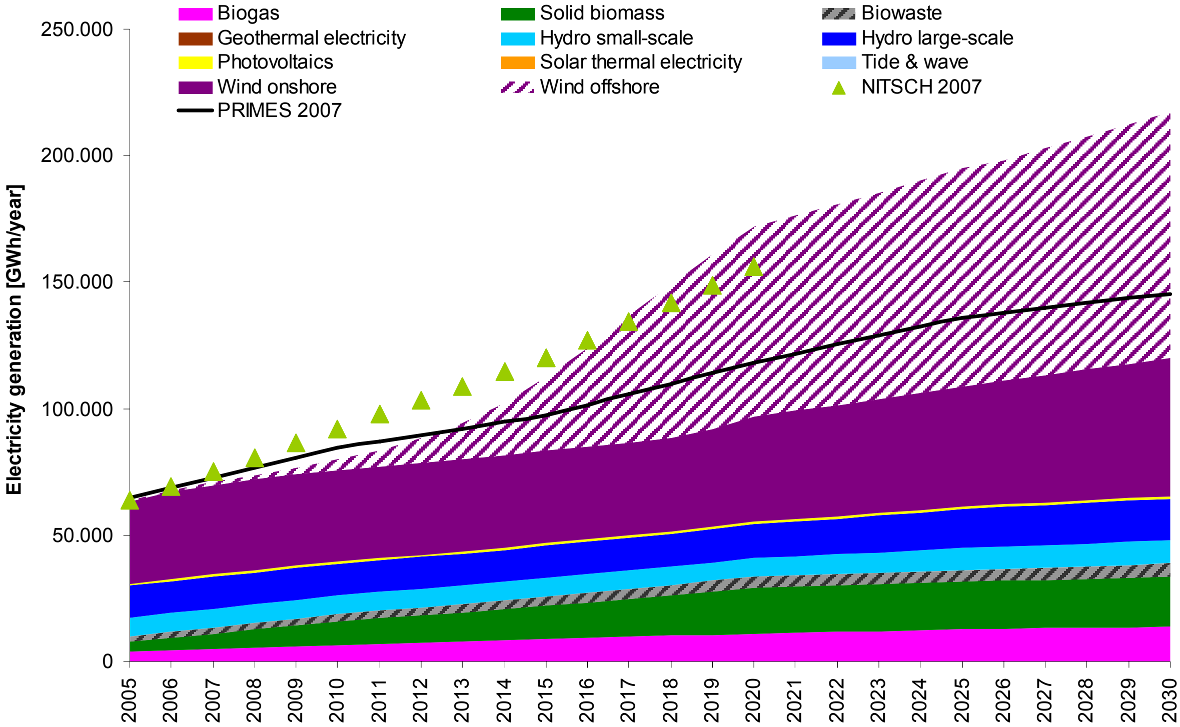

Figure 33: German electricity generation BAU scenario including a comparison to PRIMES 2007 values (black line, see [4]) as well as a national study (indicated as green triangles; compare [13]); Overall DG/RES electricity share is about 25.3% in 2020

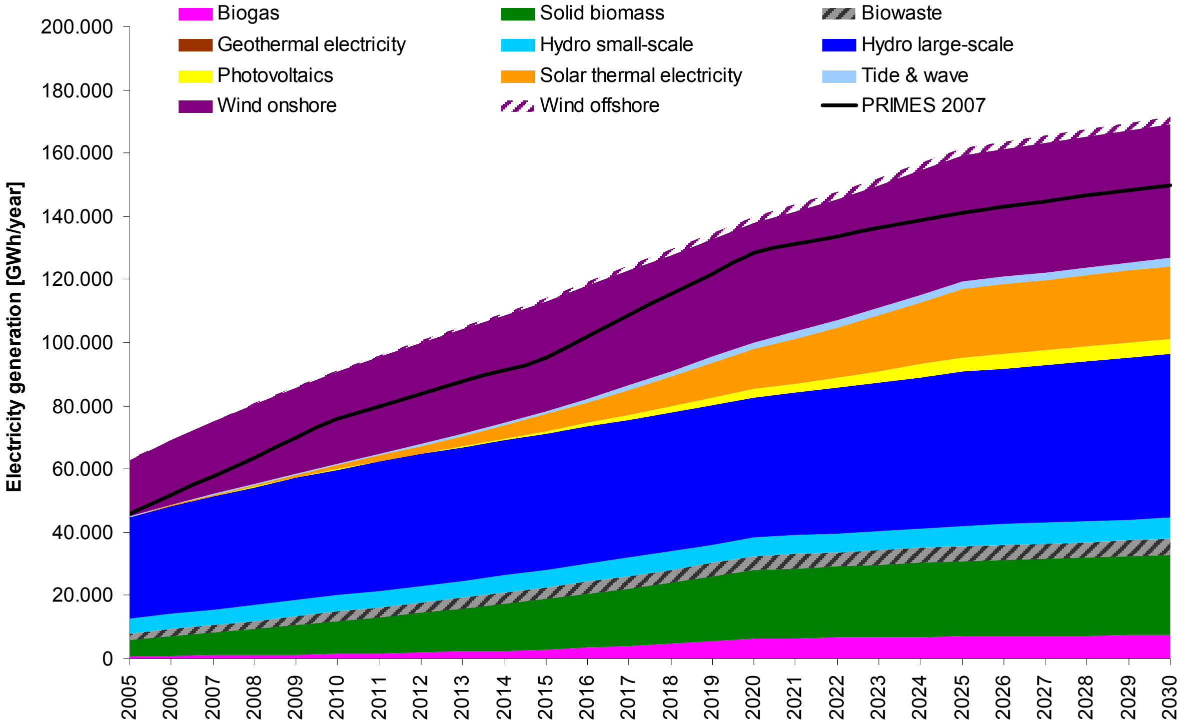

Figure 34: Spanish BAU scenario including a comparison to PRIMES 2007 values (black line, see [4]); Overall DG/RES electricity share is about 40% in 2020

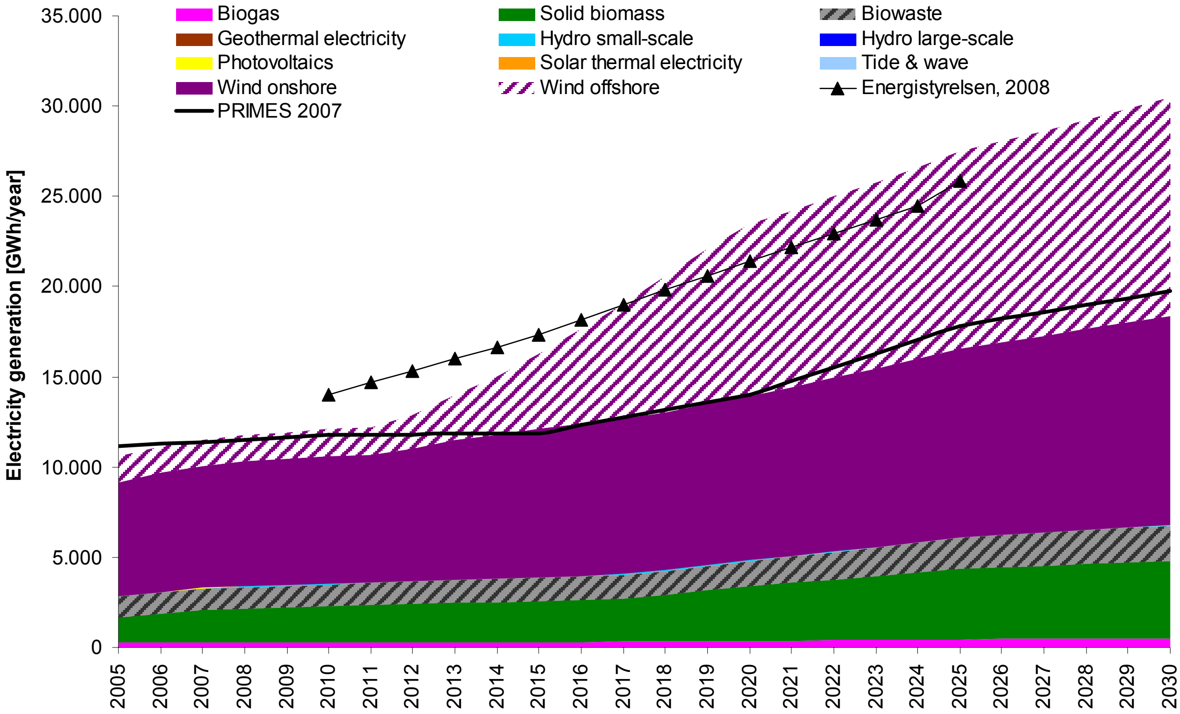

Figure 35: Danish BAU scenario including a comparison to PRIMES 2007 values (black line, see [4]) as well as a national study (Energistyrelsen, 2008, indicated as black triangles; compare [12]); Overall DG/RES electricity share is about 56% in 2020

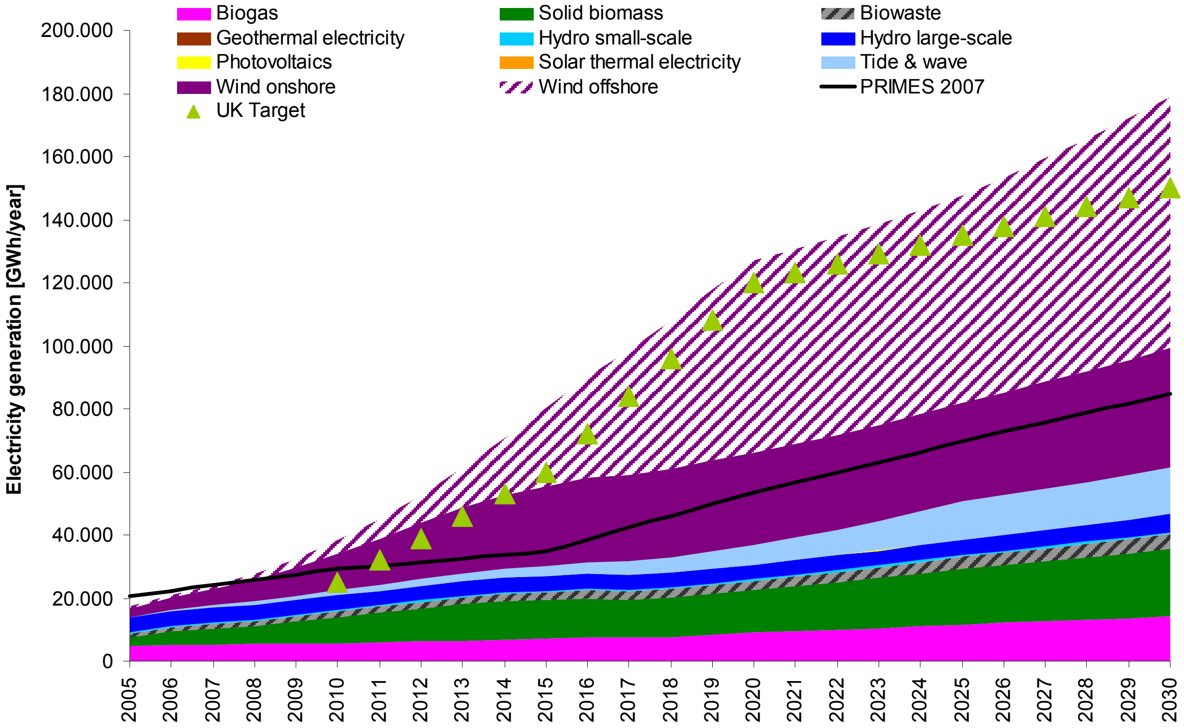

Figure 36: UK electricity generation BAU scenario including a comparison to PRIMES 2007 values (black line, see [4]) as well as a national study (indicated as green triangles; compare [14]); Overall DG/RES electricity share is about 25.5% in 2020

# ANNEX II

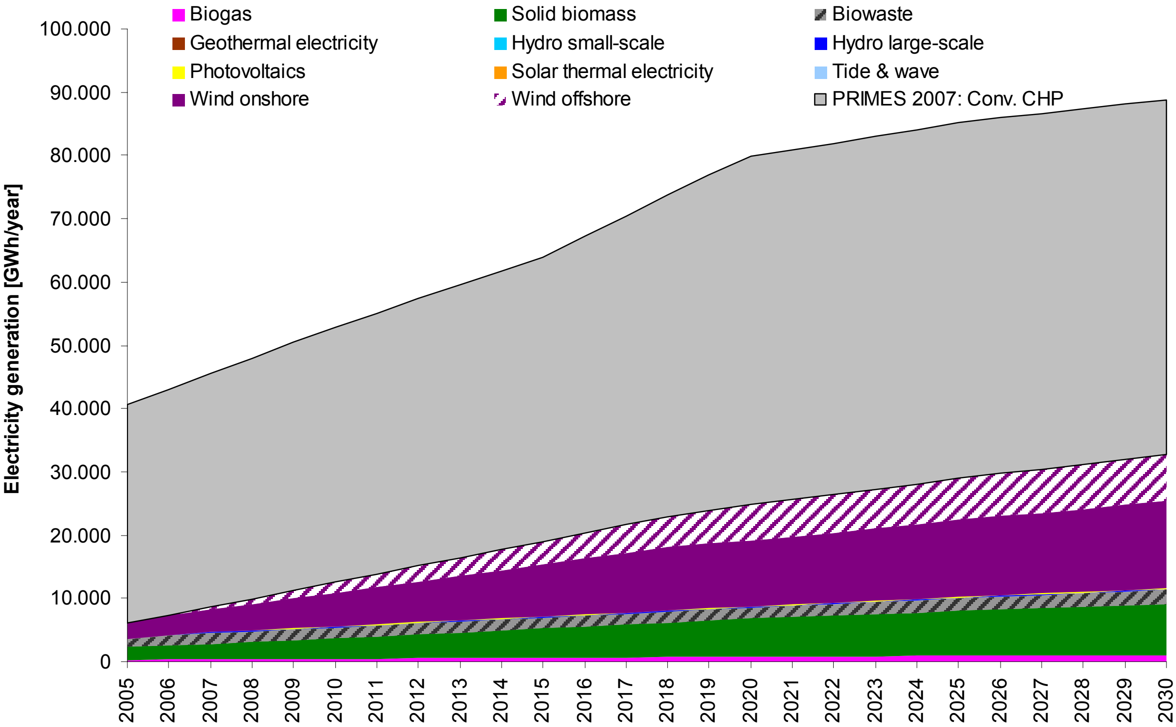

Figure 37: DG/RES and conventional CHP generation development in the Netherlands from 2005 to 2030 (including projections based on [4])

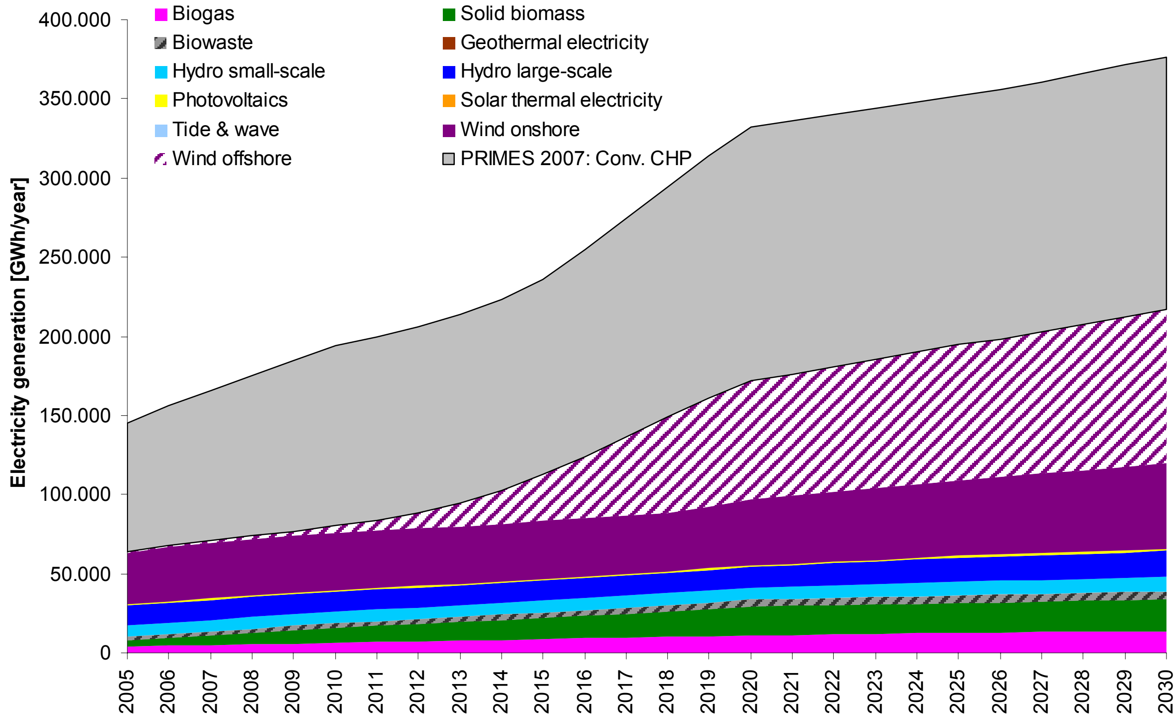

Figure 38: DG/RES and conventional CHP generation development in Germany from 2005 to 2030 (including projections based on [4])

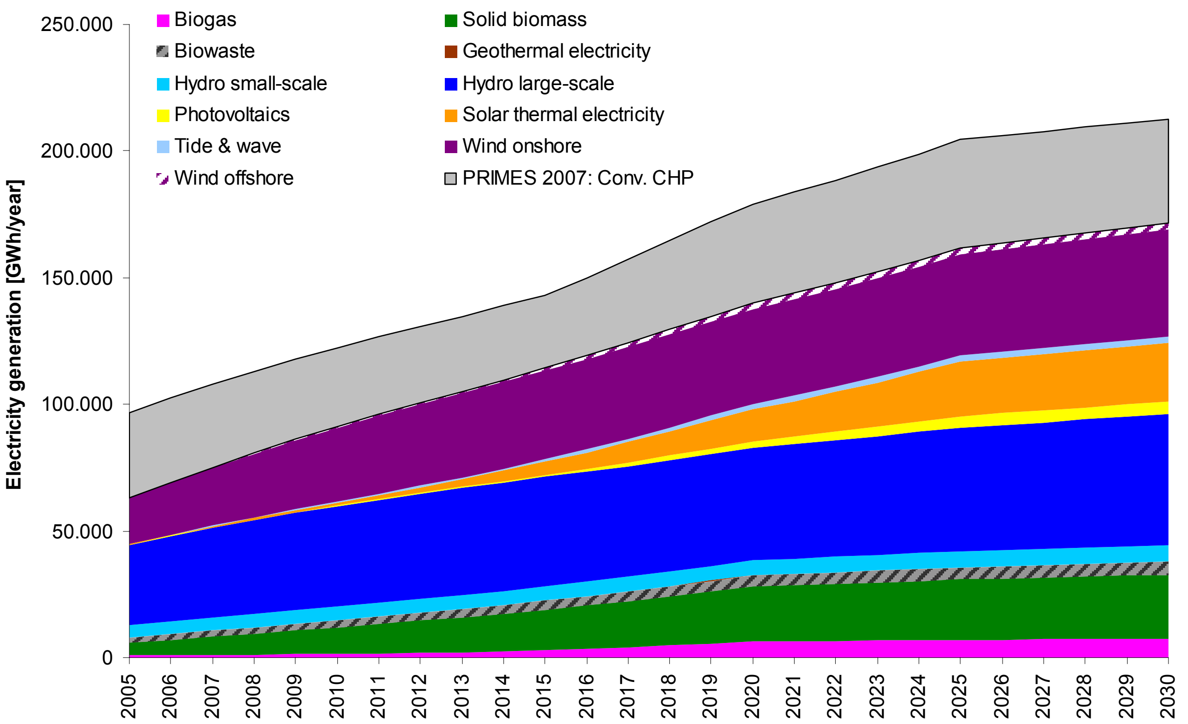

Figure 39: DG/RES and conventional CHP generation development in Spain from 2005 to 2030 (including projections based on [4])

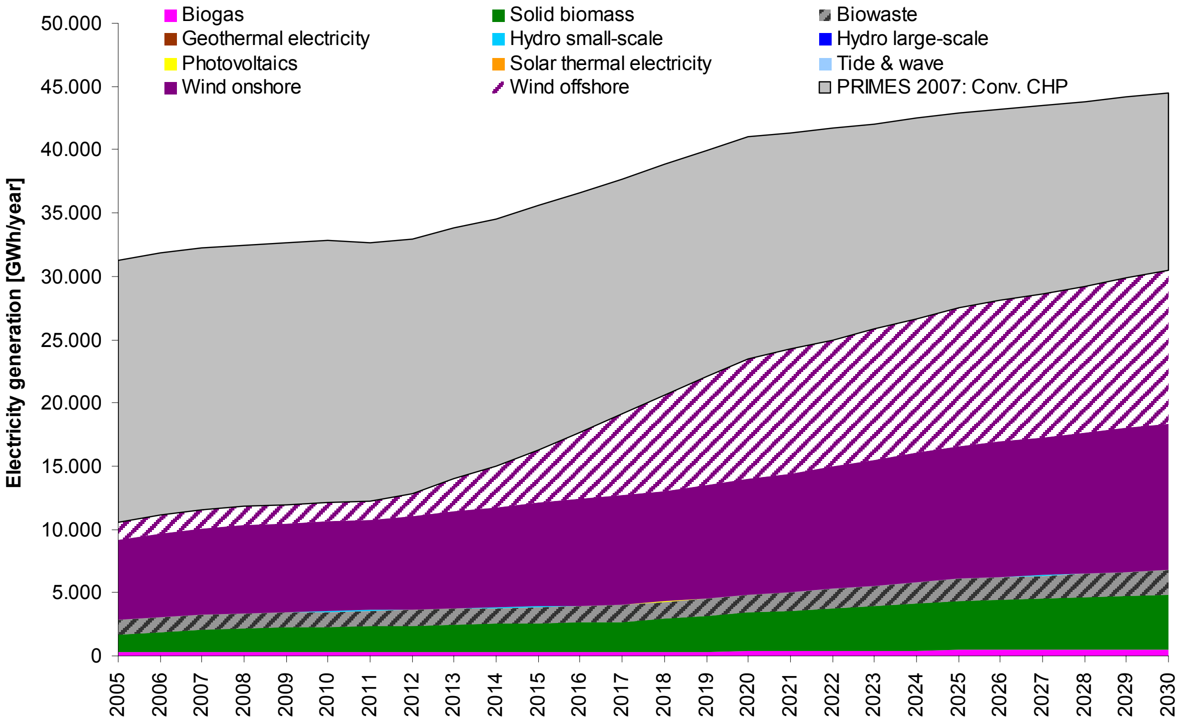

Figure 40: DG/RES and conventional CHP generation development in Denmark from 2005 to 2030 (including projections based on [4])

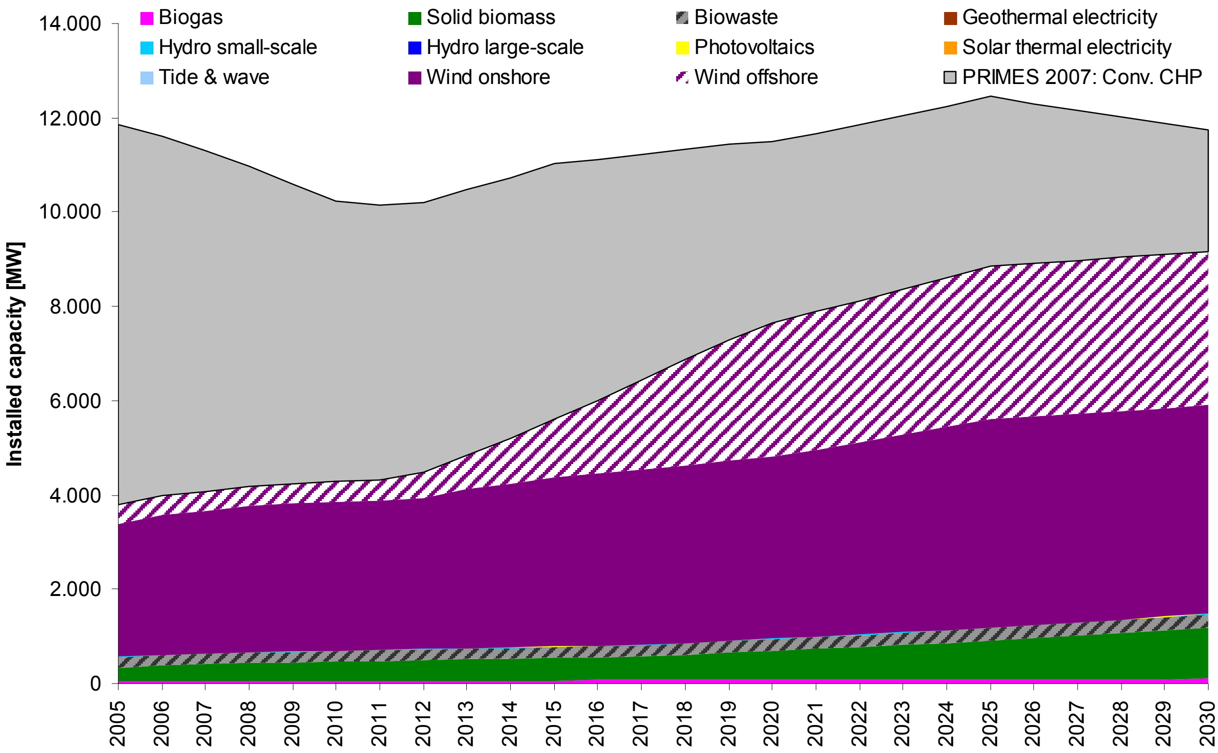

Figure 41: DG/RES and conventional CHP capacity development in Denmark from 2005 to 2030 (including projections based on [4])

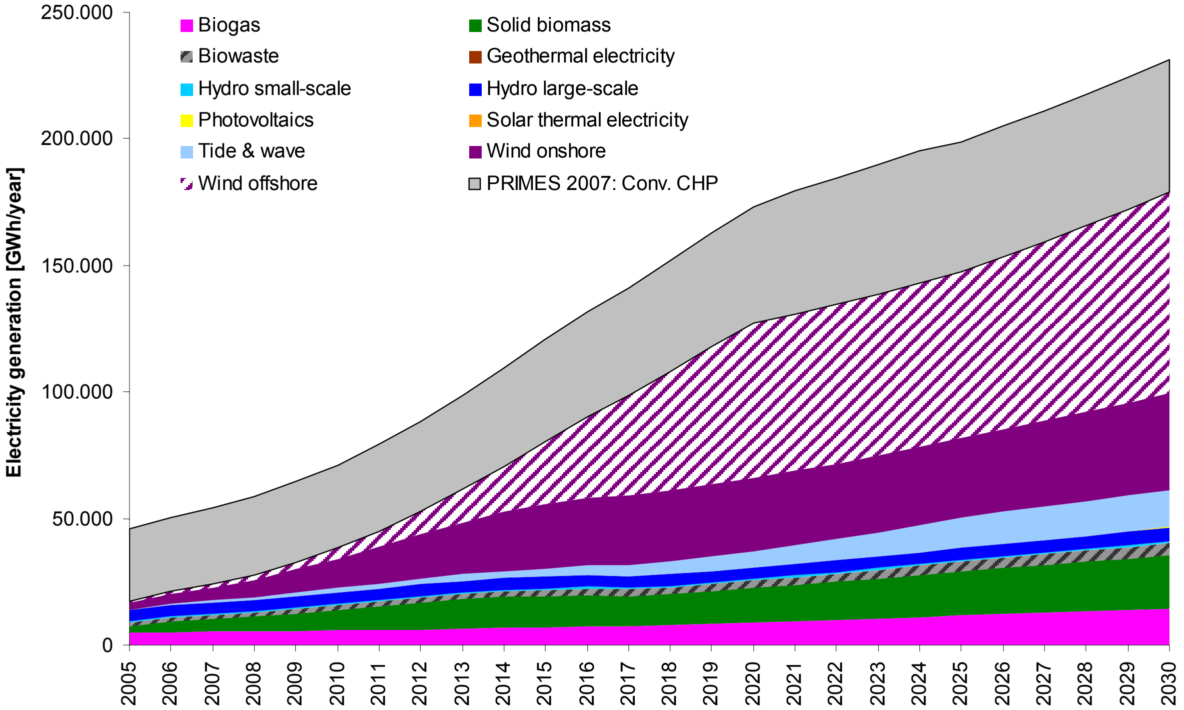

Figure 42: DG/RES and conventional CHP generation development in UK from 2005 to 2030 (including projections based on [4])

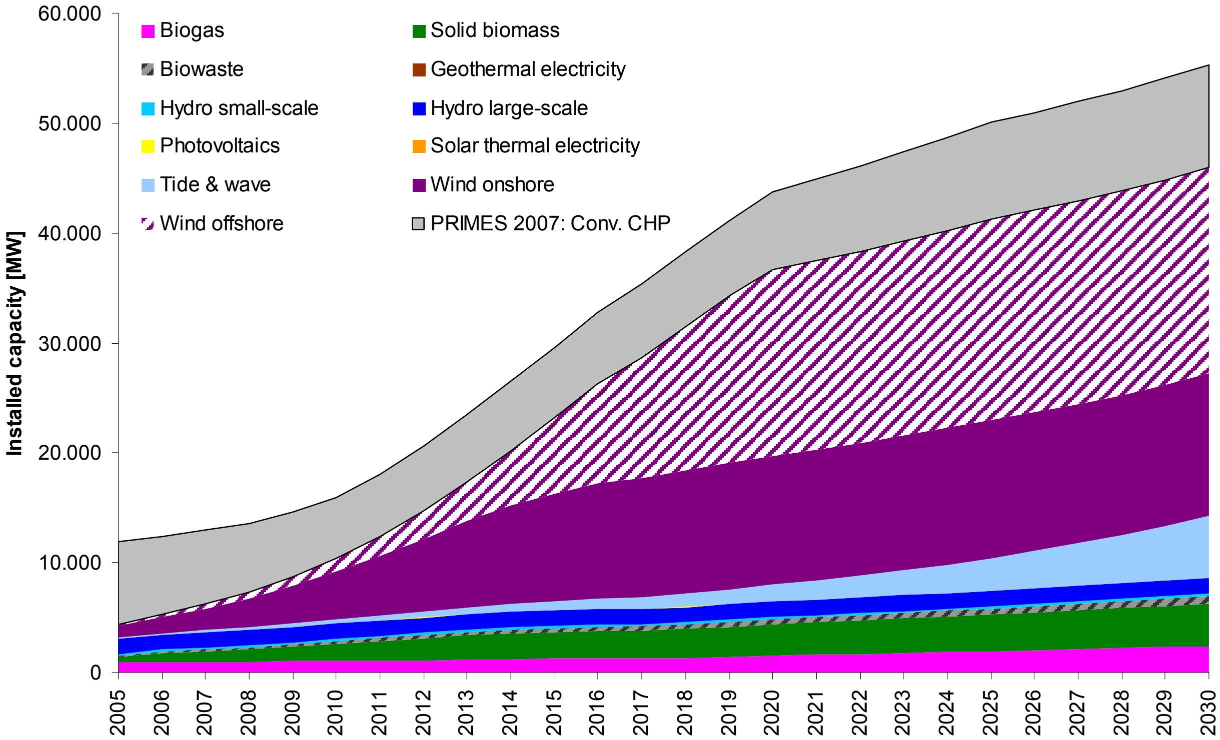

Figure 43: DG/RES and conventional CHP capacity development in UK from 2005 to 2030 (including projections based on [4])