View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Apollo

Integrating Distributed Generation: Regulation and Trends in three leading countries

By

Karim L. Anaya[1,2] and Michael G. Pollitt[2]

Abstract

This paper explores the trends in the deployment and integration of distributed generation in Germany, Denmark and Sweden. The study concentrates on the regulation of renewable energy generation with a focus on grid access and connection mechanisms. The high rate of distributed generation penetration is mainly based on the early support that these countries gave to the expansion of renewable energy generation – mainly wind and solar - within their respective national policies. Germany and Denmark are the ones with the most sophisticated support schemes, which have shown a dynamic design over time. In terms of connections, Germany has the most favourable connection regime which provides not only priority connection but also priority grid access for generation units that produce electricity from renewable energy sources. Sweden guarantees equal treatment among different technologies (i.e. a non-discrimination principle). High connection costs have been observed specially in Germany and Denmark. The costs of network upgrades are usually socialised across demand customers. However, integration issues should be taken into consideration in order to avoid expansion of distributed generation in a way which unnecessarily raises total system costs, via high connection costs.

Key words: distributed generation, renewable energy, support schemes, connection arrangements

[1] Corresponding author.
[2] The authors are with the Energy Policy Research Group (EPRG), University of Cambridge, Trumpington Street, Cambridge, CB2 1AG, England. E-mail: k.anaya@jbs.cam.ac.uk, m.pollitt@jbs.cam.ac.uk; phone: +44 1527 759858, +44 1223 339615.

1. Introduction

The EU 2020 target of 20% of EU energy consumption produced from renewable resources, and the associated national renewable energy targets, are the main drivers for the expansion of distributed generation (DG)[3]. The empirical evidence suggests that there has been a substantial increase in the rate of DG penetration over total installed capacity (Ferreira et al., 2010). The connection of more DG units to the distribution grid poses a number of key challenges for electricity distribution utilities. First, there are the technical issues associated with the operation of the network in the face of intermittent generation embedded in a network built to serve loads. Second, there is the question of how to set up the right economic incentives for connection and operation especially given that there are multiple parties involved. Third, there is the issue of how to set up the regulatory framework to facilitate – rather than impede – the connection of more DG connecting in a cost efficient way.[4]

Different studies have evaluated the implications and risks of integrating more DG into the electric systems of Europe and the US; including the different support policies focussed on renewable DG and decentralised CHP (that encourage their expansion) and the effect of types of ownership (Van der Vleuten and Raven, 2006; Lund, 2005; Klessmann *et al*., 2008; Lopes *et al*., 2007; Carley, 2009). However, the comparison of different connections and access grid charges for DG and the most recent associated regulation is a work in progress.

The aim of this paper is to explore and analyse the experience of three leading countries in the deployment and integration of DG within the distribution grid. We want to know about the influence that regulation and other factors have had on the deployment of DG. The paper also analyses the

[3] Renewable energy and emission targets have been set through different European Directives and followed by EU members in their national energy policies. However, we acknowledge that strong assumptions have been made and that the success or failure to reach them is subject to judgement (e.g. deployment of future technologies, market investments).

[4] In critiquing current connection arrangements, we acknowledge that many countries may have deliberately promoted DG with policies not designed to connect DG in the most cost efficient way. However, this does not mean that there are not important negative welfare consequences from a policy stimulus to DG which does not pay sufficient attention to efficient connection arrangements.

different grid access policies[5], connection charging methods[6] (and their associated charges) for connecting DG facilities and explores the existence of smart connections[7] that make possible quicker and cheaper DG integration. Following Klessmann et *al.* (2008), connection charging methods may influence the project profitability and the spatial allocation of generators. Lopes et *al.* (2007) point out the importance of active management techniques (smart solutions) that help distribution network operators to manage more efficiently the existing distribution network infrastructure. The case studies we look at are Germany, Denmark and Sweden due to the high rate of DG penetration and the maturity of the regulatory framework with a focus on renewable generation.

This paper is structured as follows. Section 2 summarises the challenges and opportunities of DG and its development. Section 3 explains and introduces our case studies from Germany, Denmark and Sweden. Section 4 discusses the case studies and main findings. Section 5 concludes.

2. Background on Distributed Generation

2.1 Challenges and Opportunities

DG may produce a negative impact on distribution network operation. Among the main issues are voltage fluctuation, thermal capacity congestion, fault-level contributions, frequency variation, regulation and harmonics (Currie *et al.* 2006; Lai and Chan, 2007; Passey *et al*., 2011; Wojszczyk and Brandao, 2011). Some benefits are also associated with the integration of DG to the distribution grid. Among the main benefits are the reduction of power losses (subject to the level of DG penetration), provision of ancillary services (e.g. reactive power control and energy balancing)[8], the deferral of distribution and transmission system upgrades (especially in constrained areas), improvements in the security of energy supply (via reduction of the dependency on imported fossil fuels), customer

[5] Grid access refers to the rights that generators have to export electricity to the grid (i.e. in some cases electricity produced by renewable energy sources has priority over the one produced by conventional energy sources).
[6] Connection charging methods refer to the different charging schemes applicable to DG owners for connecting to the distribution grid (e.g. deep, shallow, shallowish).
[7] In the presence of network constraints, smart connections allow the curtailment of DG export capacity using smart solutions (e.g. Active Network Management). This allows the avoidance of network reinforcement. Smart connections are also known as non-firm connections or interruptible connections.
[8] However, following Cossent *et al*. (2009) the contribution of DG to the provision of ancillary services in Europe is still low.

bill savings (net metering) and quick construction (in comparison with conventional centralised generating plants) (Gil and Joos, 2006; Mendez *et al.,* 2006; Harrison *et al.*, 2007; Lai and Chan, 2007; Passey *et al.,* 2011; Wang *et al.*, 2009; Hung and Mithulananthan, 2012). For an extended discussion of challenges and opportunities of DG integration see Lopes et al. (2007). IEEE (2012) indicates that the top three benefits for DG (based on frequency of response to a survey of 460 global smart grid executives) are related to (1) supply issues (supply can be added when needed, 47%), (2) cost reduction (for larger-scale generation facilities, 37%) and (3) improvement reliability (36%).

2.2 Distributed Generation Development

Based on the number of respondents in the IEEE (2012) survey, the region that is expected to see the most growth in DG over the next five years is Europe (32%) followed by North America and Asia-Pacific (26% both). Solar and wind technologies are likely to see the most significant growth in the next five years, see Figure 1.

[Insert Figure 1 about here]

This is in agreement with the trends in the solar and wind energy primary production over the last years in the 27 European Union Member States (EU-27 MS). Solar technology and wind technologies are among those with the highest growth across the EU-27 MS (see Figure 2).

[Insert Figure 2 about here]

Even though biomass and waste, and hydro technologies are among those with the largest share of renewable energy, around 67% and 16% respectively, their respective growth rate over the last five years is relatively low, in comparison with solar and wind technologies.

3. Case Studies

Three country case studies have been selected based on the maturity of their national regulatory framework in terms of support for renewable energy sources (RES) in those countries. The implementation of early subsidies and support schemes to electricity generation from renewable energy sources is closely related to the expansion of DG.

Germany and Denmark are among the first movers in implementing substantial support schemes for promoting the use of green technologies through the Feed-in Tariff approach, starting in 1990 and 1993 respectively. Currently both countries apply sophisticated subsidies schemes and incentives. For instance, in Germany before the recent modification of the Renewable Energy Sources Act (EEG 2014), it was possible to make a selection between different methods. In Denmark, premium Feed-in Tariff is the methodology selected. In both cases, specific bonuses (i.e. balancing costs, ancillary services, repowering)[9], digression rates (fixed and flexible)[10] and stepped tariff schemes apply depending on the technology. The early implementation of support mechanisms is reflected in the highest penetration of DG in both countries.[11]

Sweden is also an interesting case, with a very high level of renewable generation electricity, mainly from hydro resources, however wind and solar generation are becoming increasingly utilised over recent years. Sweden has had the same subsidy scheme as Great Britain, a tradable green electricity certificate scheme, where green certificates can also be traded with Norway.

A brief description of the country's electricity market and key energy policies is given first, followed by a discussion of the trend in DG and the related connection methods and charging.

3.1 Germany

3.1.1 Background on Electricity Market

Germany is the largest electricity market in Europe and was fully opened to competition in 1998. It has a decentralised structure with a large number of private and publicly owned utilities. In contrast

[9] Some of the bonuses applied in Germany have been recently abolished under EEG 2014.
[10] Flexible rates depend on the expansion of the renewable generation capacity.
[11] There is a question of what happens to individual DG projects once they are no longer supported (i.e. after the end of the subsidy period), however given the low running costs of DG this should not significantly affect its operation.

with many other countries, there is not a single system operator or a separate energy regulator. The Federal Network Agency (BNetzA) and the state authorities (Landesregulierungsbehörden) are in charge of regulating the electricity and gas utilities in Germany. The state authorities oversee distribution networks with less than 100,000 customers which operate within their geographic boundaries. The German transmission system is the most important electricity-transit country and hub in the mainland European electricity market (IEA, 2013b). Table 1 summarises the German electricity market.

[Insert Table 1 about here]

Four utilities dominate the electricity market: RWE AG, E.ON Energy AG, Vattenfall Europe AG and EnBW AG. They are known as supra-regional utilities or the Big 4 utilities. Based on IEA (2013b) the continuation of their expansion is in response to the closure of eight nuclear plants and the expansion of renewable energy capacity. The four utilities are involved in the generation activity (together generate around 73% of the total electricity generated in 2012) and supply activity (with a retail market share of 45.5% in 2012). The rest of the suppliers are comprised of approximately 900 regional and local vertically integrated utilities that own generation assets, and are involved in the distribution and supply business (BNetzA, 2014; IEA, 2013b).

In terms of generation installed capacity, the share of generation facilities using renewable energy sources amounts to 43% of total installed capacity. Coal and nuclear remain the major sources for electricity generation with a share of 45.1% and 18% respectively. The share of renewable energy sources in gross final energy consumption has risen from 5.8% (2004) to 12.4% (2012). Even with this important increase, the average share in Germany over the period 2004-2012 is still below the average of the 28 EU MS. Germany is among the 16 of the EU MS that expect to exceed its national 2020 target (18%) for the share of renewable energy sources in gross final energy consumption (EREC, 2011), see Figure 3.

[Insert Figure 3 about here]

In terms of policies, the decisions made under the Energy Concept of 2010 and the Transformations of the Energy System of 2011 (Energiewende) constitute the current (late 2014) federal Government's energy policy. The Energy Concept 2010 represents a long term strategy for the implementation of a reliable, affordable and environmentally sound energy supply system by 2050 and at the same time constitutes the roadmap to the age of renewable energy (BMU, 2011). Energiewende is associated with the move towards an energy portfolio focus on renewable generation and the phase out of nuclear power[12]. In addition, the EEG is a key element in the success of the renewable energy expansion. The Act entered into force in 2000 and has been amended several times. For instance, with the latest implementation of the modified Act (EEG 2014), generators with an installed capacity of at least 500 KW that operate new plants are required to sell their electricity in the power market thus the option of a Feed-in Tariff is not applicable anymore, however some exceptions may apply. The threshold is reduced to 100 KW from 2016 onwards. In addition, from 2017 onwards, a tendering process will be implemented and will replace both the Feed-in Tariff and the market premium[13].

Specific renewable energy, energy efficiency and climate targets have been also set. Table 2 summarises them. Its implementation requires the increase of energy efficiency, expansion of renewable energy sources, reduction of the greenhouse emissions and additional investment in the electricity grid.

[Insert Table 2 about here]

3.1.2 Distributed Generation

[12] In 2011 the role assigned to nuclear power in the Energy Concept was reassessed due to the nuclear meltdown at Fukushima in March 2011. As a result the seven oldest nuclear plants and the one at Krummel were shut down permanently. In addition, it was proposed to phase out the operation of the remaining nine nuclear power plants by 2022 (instead of 2036)

[13] Also known as premium Feed-in Tariff, where generators are entitled to a market premium in addition to the sale of electricity in the spot market.

3.1.2.1 Distributed Generation Figures

In 2010, the installed capacity allocated to DG was 83 GW and represented 51.7% of the total. In addition, around 97% of renewable energy sources were connected to the distribution grid (BMU, 2012). Figure 4 illustrates the trend in DG with a focus on renewable energy sources for the period 1990-2012.

[Insert Figure 4 about here]

Wind power and solar PV are those with the highest share of DG. By the end of 2012, wind power and solar PV accounts to 83% of the total renewable installed capacity. In terms of solar PV, the majority of customers are connected to low voltage (LV) level (230/400V) and medium voltage (MV) level (11-60 kV). 65% of generators are connected to LV level and 35% to MV level. Only a few plants are connected to high voltage (HV) level (110 kV). In relation to wind energy, 95% of the DG customers are connected to MV (Ackermann, 2013).

Regarding electricity generation, wind energy, biomass and solar PV are the technologies that contribute the most to the distributed generation mix. Solar PV is the one with the highest growth rate in the period 2004-2012. On the other hand, electricity generation from hydro sources has remained nearly the same over time. By the end of 2012, electricity generation from DG accounted for 143.5 GWh with a share of gross electricity consumption of 22.5%. In the 1990s the share of gross electricity consumption was mainly driven by hydro with an average share of only 4%. After this, an important increase in other renewable energy sources is observed. This is in line with the implementation of the EEG, which entered into force in 2000. Figure 5 depicts the trend of electricity generation from DG over time.

[Insert Figure 5 about here]

Concerning ownership, more than 50% of DG is owned by customers (private owners, industrial companies and farmers) and only 5% is owned by the Big 4 utilities (Trendresearch, 2012). The integration of more electricity from renewable energy sources to the grid is affecting negatively the Big 4 utilities due to the reduction of wholesale prices. Utilities such as RWE, which is the largest power producer in Germany, are negatively affected due to the reduction of wholesale price especially that based on the expansion of solar PV. In general, the expansion of renewable energy generation is fostering competition. The RWE strategic roadmap suggests a radical change that allows the firm to create value by leading the transition to the future energy world (from its traditional business model based on large-scale thermal power production to a project enabler, operator and system integrator of renewables)[14].

3.1.2.2 Grid Access, Charging Methodologies for Connections and Use of System Charges

The EEG requires that grid operators priority connect generating facilities that produce electricity from renewable energy sources and from mine gas. Thus, distributed renewable generators have to be connected before conventional power plants. The first Feed-in Tariff scheme did not define the sharing of connection costs between the generator and the grid operator (DSO). The 2000 amendment suggested the connection of the generating facility to the technically and economically most appropriate grid connection point. This approach would help to prevent grid operators from using their dominant position to exclude potential competitors from power generation (Jacobs, 2012). In terms of grid access, they are required to prioritise the purchase, transport and distribution of the entire available quantity of that electricity[15]. A shallow connection charging methodology was adopted, in which the renewable generator has to pay the costs for connecting the renewable generating unit to the grid connection point based on the closest or technically and economically most suitable connection point; including any installation of metering devices for recording the

[14] See: http://www.energypost.eu/exclusive-rwe-sheds-old-business-model-embraces-energy-transition/

[15] The priority grid access applies to the dispatch and to the curtailment of renewable energy sources. This means that fully economic dispatch is not applied (i.e. biomass plants would have preference over nuclear plants, regardless of marginal costs). However in practice, due to the fact that wind and solar are among the renewable energy sources with lower marginal costs, these are usually the first in being dispatched (by merit order). In addition, according to BNetzA curtailment is not yet an issue, which represented 0.44% (555 kWh) of total feed-in in 2013 with a total compensation payment of €43.7m (Bundesnetzagentur, 2014). The injection of electricity from RES such as wind and solar has contributed importantly to the reduction of spot market prices by €6 /MWh in 2010 and by €10 /MWh in 2012 (Cludius et al., 2014).

quantity of electricity transmitted and received. Any required additional work (e.g. network reinforcement) should be borne by the grid system operator (DSO) but only when the related costs are economically reasonable. Germany was among one of the first countries in Europe to implement a shallow connection charging approach. The introduction of this approach was made after the liberalisation of the electricity market. The shallow connection methodology applies to most types of renewable generation installations (excluding offshore wind). In relation to use of system charges, renewable generators are not required to pay these charges to the DSO but only the direct costs associated with the connection to the grid.

In order to facilitate the reduction of the generation output by remote generators in the event of grid overload and to call up the current electricity feed-in at any given point in time, grid operators need to take technical control over the installations (including CHP) connected directly or indirectly to their grid system. Following the EEG 2014, installations with a capacity over 100 kW (including CHP) are required to install the control and communication equipment. Solar PV with a capacity between 30 kW and 100 kW may decide between installing the control and communication equipment that allows the reduction of generation output remotely or face being limited to 70% of their maximum effective exported capacity.

A compensation of 95% of the lost income is provided to the generator including additional expenses (net of any savings) as a result of a grid bottleneck. However, if the lost income in a year exceeds 1% of the income for that year, a compensation of 100% of the lost income is applicable. The methodology for estimating compensation payments for electricity generated from wind, biogas, biomass and CHP installations can be found at the BNetzA Guidelines on renewables energy feed-in management.

3.2 Denmark

3.2.1 Background on Electricity Market

The Danish electricity market was opened to competition in 2003. Similar to Germany, it has a decentralised structure with a large number of private and publicly owned utilities. There is a single transmission system operator (Energinet) and a single independent energy regulator (Danish Energy Regulatory Agency). Energinet, a state-owned company created in 2005[16], covers both electricity and gas markets. In general, the number of distribution electricity firms is decreasing primarily due to acquisition/merger of very small firms (DERA, 2011). In terms of generation, the market is dominated by central generation plants, the majority of them owned by DONG Energy (publicly-owned) and Vattenfall (Swedish-owned). The rest of firms in the market are owned by other private companies, local authorities, larger industries and cooperatives (Poblocka *et al.,* 2011a). Denmark is integrated into the Nord Pool, one of the world's most successful international electricity markets. Table 3 summarises the Danish electricity market.

[Insert Table 3 about here]

By the end of 2012 the total generation installed capacity was around 14.17 GW from which large-scale units (electricity and combined heat power - CHP) account for 51% of total installed capacity; from this CHP alone accounts for 45% of total installed capacity. Up until the early 1990s electricity production capacity was dominated by large-scale power units (DEA, 2012). The share of renewable energy sources in gross final energy consumption has risen from 14.5% (2004) to 26% (2012), see Figure 6.

[Insert Figure 6 about here]

In contrast with Germany, the average share in Denmark over the period 2004-2011 (19.5%) is above the average of the 28 EU MS (10.9%). Similar to Germany, Denmark is among the EU MS that expects to exceed its target of share of renewable energy in gross final energy consumption, set at 35% by 2020 (EREC, 2011).

[16] Energinet was created by the merger of Eltra, Elkraft System, Elkraft Transmission and Gastra; and as of August 2012, acquired the 10 former regional transmission firms.

In relation to its key energy policies, the Danish Energy Agreement of March 2012 is one of the most ambitious national energy plans. The new agreement supplements the energy policies already proposed in the Energy Strategy 2050 published in February 2011. The Energy Agreement was launched by the Danish Minister of Climate, Energy and Building and established, among others, specific targets along with different investment programmes by 2020 with a focus on energy efficiency, renewable energy and the energy system. This will facilitate the transition to a low carbon economy by the phase out of fossil fuels and the expansion of energy supply to be covered only by renewable energy by 2050, with an intermediate target of 33% reduction in the use of fossil fuels (KEBMIN, 2011). Table 4 summarises the main targets and goals.

[Insert Table 4 about here]

3.2.2 Distributed Generation

3.2.2.1 Distributed Generation Figures

In 2009 the share of DG in total electric power was around 43%, of which 50% came from wind (Cherian, 2013). In general, most renewable energy sources, including onshore wind, are connected to the distribution grid and only the biggest offshore plants are connected to the transmission grid (132 or 150 kV) (Poblocka *et al.,* 2011a). According to Energinet, as of 2013 the total DG installed capacity was around 6.6 GW (including small scale CHP). Wind power generation is the one with the highest share of DG (53%) followed by CHP installations (36%). Solar PV only represents around 8.1% of total DG connected capacity, however an impressive increase in solar PV connected capacity has been observed in the last four years. The installed capacity increased from 6 MW in 2009 to 563 MW in 2013. On the other hand, biomass installations have remained without any relevant changes over the last four years. Following Energinet, the number of distributed generators by the end of 2013 was 97,952 of which solar PV generators have the highest share (93%) followed by wind generators (5.5%). Figure 7 depicts the trend in DG installed capacity over the period 2005-2013.

[Insert Figure 7 about here]

Wind power generation plays an important role in the expansion of DG. According to IRENA-GWEC (2012), the long-term commitment from the government to address climate change and to achieve energy independence, have been the main drivers for developing wind energy. There are many conditions that have contributed to this expansion. Denmark was a first mover in the implementation of an industrial and export-driven strategy for commercial scale wind. In addition, it has the most developed permitting and sitting procedures which have improved over time. Priority access to the grid is given to wind energy along with long-term targets for wind development. As of 2012, there were around 5,020 wind turbines which accounted for 30% of the domestic electricity supply. The size of the majority of wind turbines is between 0.5 and 0.9 MW and represents 42% of the total wind capacity (DEA, 2012).

Figure 8 illustrates the trend in wind energy (onshore and offshore) installed capacity during the last decade. We can observe that the installed capacity for the period 2003-2008 has remained nearly the same. Among the main reasons that may explain this fact are the removal of the Feed-in Tariff scheme and the restructuring of Denmark's power supply sector. In general, energy policy developments were considered very unambitious between 2001 and 2008 (IRENA-GWEC, 2012). The situation improved after the introduction of the energy policy statement of 2008.

[Insert Figure 8 about here]

3.2.2.2 Grid Access, Charging Methodologies for Connections and Use of System Charges

According to Electricity Supply Act, electricity from renewable sources is not granted priority connection, thus the non-discriminatory principle applies. Grid operators should not discriminate between types of users or favour their own companies or owners. In addition, the Act establishes that generation installations that produce electricity from renewables or use waste products as fuel and decentralised co-generation plants have priority access to the grid[17]. This means that in the case of network constraints these have priority over conventional energy sources. Prioritised electricity generation may be reduced only if the reduction of other electricity generation is not enough to maintain the balance in the system. The priority access is also applicable to tendered offshore wind farms, which can be curtailed only under special conditions subject to compensation for operational loss. Concerning the connection charging methodology, the shallow approach has been adopted; this means that generators only incur the direct cost of connection to the nearest connection point to the distribution grid. Reinforcement costs are incurred by the grid operator and they are required to receive a permission to proceed with the reinforcement works. The energy regulator has to approve the planned investment because electricity customers ultimately bear the cost through the Public Service Obligation. In the case of wind energy plants over 1.5 MW, the connection costs are borne by the wind generator and the grid operator, see section 4 for further details. According to Energinet, only environmentally sustainable generators are not required to pay distribution use of system charges; however they are required to pay a fee to the distribution company for handing metering and administration. In addition, all generators must pay a tariff to the TSO (transmission network use of system charge). The use of system charges are not differentiated by location.

3.3 Sweden

3.3.1 Background on Electricity Market

The Swedish electricity market was liberalised in 1996. The distribution market is operated by regional and local distribution utilities. Svenska Kraftnät is the TSO, a state-owned public utility established in 1992. As of 2010, the 3 largest electricity firms dominated the retail market, with a combined market share over 50%, each serving more than 0.8m customers. Four large companies

[17] The priority grid access applies to the curtailment of renewable energy sources only. For the dispatch, the economic principle applies (merit order). According to Energinet, since the introduction of a cap in the negative prices in 2009 (-€500/MWh), curtailment is close to zero. In addition, the strong interconnection with Germany and Norway and the availability of hydro resources in Norway have also contributed to a lack of curtailment (Insight_E, 2014).

own the electricity generation assets: Vattenfall AB, E.ON Sverige AB, Fortum Power and Heat AB, Statkraft Sverige AB. Vattenfall AB, a state-owned company, has the highest share in generation capacity (40%). In addition, the three largest firms (Vattenfall AB, E.ON Sverige AB, Fortum Power) accounted for 80% of the domestic electricity generation in 2011 (IEA, 2013a). Similar to Denmark, the move towards a greener environment started in the early 1970s, when oil accounted for more than 75% of Swedish energy supply. By 2012 this share had fallen considerably and now amounts to 21.5%. Sweden and Switzerland are among the IEA member countries with the lowest share of fossil fuels in their electricity mix (IEA, 2013a). Table 5 summarises the Swedish electricity market.

[Insert Table 5 about here]

In terms of installed capacity, hydro and nuclear power are the ones with the highest share in total installed capacity. By the end of 2012 the share was 62.5% and 25.1% respectively. Excluding hydro power, wind power had the highest share among renewables (10%). The share of renewable energy sources in gross final energy consumption has risen from 38.7% (2004) to 51% (2012), which would imply that the 2020 target has been already met (set at 50%), see Figure 9. This fact is explained by the large proportion of hydropower and biofuels in the energy system. Sweden is among the EU MS with the highest share of renewable energy sources in gross final energy consumption.

[Insert Figure 9 about here]

Regarding the energy policies, the integrated climate and energy policy approved by Swedish Parliament in 2009, sets the strategic targets in line with the EU Directives. A share of renewable energy in the gross final consumption of at least 50% is envisaged by 2020. Among other targets are those related to climate, transport, energy efficiency, vehicles, and reduction of fossil fuels in heating. Table 6 summarises most of them.

[Insert Table 6 about here]

In addition, under the Climate Roadmap 2050, launched in December 2012, different emission scenarios in several sectors are proposed in order to achieve the 2050 vision of zero net GHG emissions. The proposal suggests different types of actions such as the reduction of domestic emissions, contributions from an increased net uptake of carbon in forests and fields, and the purchasing of emissions allowances in international markets.

3.3.2 Distributed Generation

3.3.2.1 Distributed Generation Figures

As indicated by the Sweden Energy Agency, the definition of DG in Sweden is related to micro generation which usually is associated with those plants behind a fuse of 100 A[18]. This kind of installation usually corresponds to a plant with a maximum capacity of 40 kW. In terms of solar PV, the Swedish Energy Agency has stated that in general not all solar PV plants are approved for green certificates because this requires that the power output be metered every hour and usually the associated costs exceed the income they would receive for the certificates. For this reason, many solar PV plants remain outside of the green certificate system. The information provided by the Swedish Energy Agency is based on the annual survey conducted by the International Energy Agency under the Co-operative Programme on Photovoltaic Power Systems (IEA, 2013c). Even though the data refer to the total solar PV connected capacity in Sweden, we believe that these figures reflect the trend in distributed solar PV connected capacity (solar PV installations are usually connected at the distribution grid). Figure 10 depicts the trend in solar PV connections over the period 1992-2012.

[Insert Figure 10 about here]

By the end of 2012 the solar PV installed capacity was around 24.3 MW. An important upward trend is observed in recent years. The increase may be explained by the implementation of the support scheme for solar PV in July 2009. The category of grid-connected distributed generation is the one with the most impressive growth in the last years. As of 2012, this category is the most representative of the total solar PV installed capacity with a share of 65%.

[18] In order to make proper comparisons we have asked the energy regulators to provide DG connected capacity data in the format required, this means installed capacity data of generation plants connected within the distribution network. However, the DG data provided by the regulator was not in the format required, except for solar PV.

3.3.2.2 Grid Access, Charging Methodologies for Connections and Use of System Charges

Based on the Electricity Act, grid operators are obliged to connect generation plants on reasonable terms regardless of technology, unless there are special reasons. Thus, the principle of non-discrimination applies. However grid operators are not required to incur the costs of grid expansion. Following Poblocka *et al.* (2011b), the main connection issue is the so-called threshold effect. If reinforcement is required in a specific area, the first generator to ask for a connection would bear the whole investment cost. This fact contributes to delays in the expansion of renewable energy sources. The TSO and the DSO are the ones that make the decision on cost sharing. Based on the same principle of non-discrimination, electricity produced by renewable energy sources is not given preference. The Electricity Act proposes a similar treatment for grid access across all generation installations, regardless of technology. This means that electricity produced by renewable energy sources will not have priority over electricity produced by conventional energy sources. In the case of constraints, the TSO has the right to reduce the generation of electrical power. Generation plants will be compensated based on the market value of the electricity. Grid operators are required to pay the use of system charges. However, a reduced tariff is applied to those generation plants with installed capacity less than 1.5 MW.

4. Discussion of case studies and main findings

Figures from the case studies have shown important progress in the integration of DG – mainly wind and solar - within the distribution grid. This is associated with the large and early support that countries like Germany, Denmark and Sweden have provided to the expansion of renewable energy resources within the respective national policies. Some of them were driven by their dependency on oil import and fossil fuels. The consolidation of wind technology industry in Demark, has also contributed to this integration. Van der Vleuten and Raven (2006) evaluate three stages of national electricity regimes in Denmark and suggest that the relative success of DG is due to the introduction of different energy policies that promoted the revival of DG with a focus on the wind turbine industry and decentralised CHP. This allowed the emergence of the hybrid regime (centralised supply system and grid-connected DG) in the 1990s which contributed to the expansion of DG. In Germany, the movement towards a renewable energy portfolio involved the phase out of nuclear generation plants by 2022. However in Sweden, nuclear power is part of the future energy portfolio and hydro power remains the main renewable energy source. Subsidy schemes represent the main source of support. These schemes show a dynamic design over time, from simplistic models (fixed rate) to sophisticated support mechanisms that involved premiums, flexible digression rates, stepped tariffs and tendering (i.e. Germany from 2017 onwards)[19].

Thus, support mechanisms have been adapted in response to the expansion of renewable energy sources, technology maturity and to the specific targets set in the light of European and national energy policies. In agreement with Ferreira *et al.* (2010), we also observe that the expansion of DG might be linked to the energy market structure. The three countries that are part of this study have decentralised distribution electricity systems with a large number of DSOs. This market structure facilitates the connection of more generation units by reducing the distance to the point of connections, by lowering the costs of more specialised equipment required to connect the generation units to higher voltage levels (by connecting to the local DSOs instead of the national or regional DSOs) and by accelerating the connection process (DG customers have more options to select among potential DSOs).

The expansion of DG has been also linked to the type of ownership. Carley (2009) in his evaluation of the US electric market, suggests that private utilities are more likely to adopt DG systems than the public-owned ones (e.g. cooperatives, municipals). The author also finds that consumer-owned DG

---

[19] Some of the bonuses applied in Germany have been recently abolished under EEG 2014. In contrast with fixed rates, flexible rates depend on the expansion of the renewable generation capacity. Stepped tariffs were applied in Germany for solar PV and recently have been extended to wind and biomass under the EEG 2014. For instance in Germany wind farms receive a maximum tariff for the first five years of operation. However, if after this period the wind generator produces at least 130% of the energy produced by the reference wind turbine, the tariff will be reduced for the remaining 15 years (basic tariff). The period of five years can be extended if the generated electricity stays below the reference yield. In Denmark, wind turbines connected to the grid from 21 February 2008 to 31 December 2013, receive a premium for the first 22,000 full load hours, after this the electricity is sold at the market price.

and utility-owned DG are affected differently. State regulation (e.g. Renewable Portfolio Standards) and interconnection standards are those that encourage consumer-owned DG, while market forces related to greater market competition are those that encourage utility-owned DG.

Connection and the associated charging methods also have an important role in the integration of DG. Different rules are observed across the case studies. Germany is the country that has adopted the most favourable connection conditions. A DG customer is not subject to the payment of reinforcement (if applicable), does not pay use of system charges, and has a priority connection to the grid and in grid access. As already mentioned this means that renewable DG plants are connected ahead of conventional plants and have priority when the electricity is purchased and needs to be exported into the grid. The least favourable conditions applied to renewable DG plants in Sweden where grid operators (DSOs) have the obligation to connect the generation plant but they are not necessarily required to incur the reinforcement costs (when applicable). In addition, based on the threshold effect, the first potential DG customer who asks for connection is the one that would incur the whole network upgrade investment cost. At the end of the day, in practice the TSO and the grid operator (DSO) are those who make the decision on cost sharing due to the lack of clarity in the connection rules described in the Electricity Act. Table 7 summarises the different connection methodologies.

[Insert Table 7 about here]

For instance, in other jurisdictions such as Great Britain, a shallowish method is applied, which implies that generators would only pay a proportion of the reinforcement costs under specific conditions (OFGEM, 2009). However, in practice, the DG customer would need to cover the reinforcement costs if the costs associated with the extension of the distribution network have not been budgeted by the DNO. We observe that in comparison with the shallowish connection, the option of shallow connection tends to facilitate the connection process at the expense of increasing the socialisation costs. DG customers are those that benefit from this approach (i.e. have no reinforcement costs) and DNOs are not affected because any cost related to reinforcement costs will be passed on via higher charges to demand customers.

Therefore, Germany and Denmark are the ones where demand customers are the most negatively affected because reinforcement costs are socialised and reflected in the electricity tariff. For instance in Germany, based on the Ordinance on Incentive Regulation of Energy Supply Grids (AregV), distribution operators are allowed in some specific cases to request approval for network expansion or restructuring investment ("investment measures") in order to facilitate the integration of installations under the EEG and the Co-Generation Act (KWKG). Such approval allows DSOs to include additional costs in the estimation of grid fees. The latest amendment of the Ordinance on August 14 2013 mandates the treatment of specific mechanisms for DSOs, namely the expansion factor and lump-sum allowances for investment. Regarding the expansion factor, the Ordinance has established that a sustained change in the grid operator's supply task should be reflected in the determination of the revenue cap by a factor (expansion factor). However, the application of the expansion factor is limited to networks below 110 kV. DSOs may also claim a lump-sum investment allowance which has to be included in the determination of revenue cap prior to the beginning of the regulatory period. In all cases, these additional costs are borne by demand customers through electricity tariffs.

In Denmark, the investment risk (associated with the network upgrades for connecting generating units) may be transferred to DSOs but under specific conditions. According to Energinet, the Udligningsordningen is a mechanism which helps to compensate DSOs for the costs they incur due to the integration of distributed environmental and friendly power production with a focus on wind power generation. This is in accordance with the Promotion of Renewable Energy Act, which mandates the share of connection costs between the DSO and the wind developer/generator above 1.5 MW. The wind turbine generator incurs the cost of connecting the turbine at a defined connection point inside the area designated by the municipality. If required, DSOs are obligated to pay the related reinforcement costs of the network. Under this scheme, Energinet determines and covers the DSO's grid expansion costs caused by new electricity production units based on an expense model that takes into account a base amount, the quantity of cable required and the digging work. Thus, if the estimations made by the DSOs are lower than those computed by Energinet, the DSO retains this excess. An opposite situation is also possible, when a DSO receives less money than the incurred costs. In the last case, the DSO is responsible for the loss[20]. This model allows to DSOs to plan a cost-efficient solution that meets future demand (the TSO does not interfere in the solution). It addition, it has low transaction costs (i.e. with annual turnover about US$ 35m (£20.9m), transaction costs are 1%). This is based on a simple refund process and releases resources to focus on special cases (especially when modelling is insufficient). Similarly to the other initiatives, costs associated with the network expansion are borne by all demand consumers through the Public Service Obligation.

We observe that in both cases, reinforcement costs are still borne by the demand customers through the electricity tariff and the use of more innovative or smart solutions (technical and commercial) is not observed (at least as business as usual or deployment). Smart solutions, which allow the active management of power generation output in constrained areas of the distribution grid, might contribute to the more efficient use of the distribution electricity infrastructure (i.e. offers of non-firm connections) and lower reinforcement costs (i.e. network deferral) which translates into lower socialisation costs. According to CEER (2014), only 42% of 27 EU countries have a strategic road map in place for the implementation of smart grids[21]. Denmark has already implemented the plan at national level, Sweden is already working on this with a due date of December 2014 and Germany has not introduced yet any plan. Great Britain has introduced a high level route map. In the majority of countries DSOs play the major role in the smart grid development. Only in some of them (e.g.

[20] Following Energinet, total refund provided by Energinet for the 18 projects was around DKK 60.3m (£6.7m) and the total expenses reported by the DSOs were around DKK 57.8m (£6.4m).

[21] In agreement with a European Energy Regulators paper, *' A smart grid is an electricity network that can cost-efficiently integrate the behaviour and actions of all users connected to it in order to ensure economically efficient, sustainable power systems with low losses and high levels of quality and security of supply and safety'*, CEER (2014, p. 10).

Great Britain, Norway and Italy) is the dissemination of demonstration project results compulsory. Among the demonstration projects in Great Britain are those funded under the Low Carbon Network (LCN) Fund, managed by OFGEM. Flexible Plug and Play (FPP) and the Accelerating Renewable Connections (ARC) projects have suggested novel commercial arrangements (non-firm connections) and smart technical solutions. For further details about smarter commercial arrangements see Anaya and Pollitt (2014).

Finally, network planning is also a key element in the integration of DG units. It is not only about promoting the expansion of DG but also about taking into account the impact that this expansion might have on the distribution network. According to EPRI (2014) one of the main problems that Germany is facing in relation to this expansion is the lack of effective technical integration, with a focus on solar PV. Until recently, generators were not required to be equipped to provide grid support functions (e.g. reactive power management, frequency control), ignoring power load limitations and grid design. This fact produced an increase in network upgrades for all demand customers. The use of smart inverters can help to avoid this kind of issues including mass disconnection risk of DG customers (EPRI, 2014). In addition, specific remote equipment for managing the generator output (such as those required by solar PV generation units in Germany), can help to deal with technical problems in the event of grid overload and contribute to the efficient integration of DG.

5. Conclusions and Policy Implications

5.1 Conclusions

This study has evaluated the integration of DG within the distribution grid in three leading countries. Incentive schemes applied to electricity generation from renewable energy sources have had a corresponding effect of DG growth. We have explored the current methods for connecting DG to the distribution grid, the charging scheme including the use of system charges and the way in which the connections and reinforcement costs are distributed between parties.

We have found that there is a lot of socialisation of connection costs, especially in Germany and Denmark where the shallow approach is the connection methodology and the grid operator or DSO is obligated to reinforce the network and transfer the related costs to demand customers. This is reflected in the high electricity tariff that electricity customers from those countries are required to pay. In terms of subsidies, again Denmark and Germany are the ones with the most sophisticated methodologies. However, this sophistication remains in the subsidies and it is not evident in the business model for the connection of more DG in a cost efficient way. An interesting initiative is the recent implementation of the EEG 2014 in Germany which attempts to minimise the socialisation of costs by the imposition of direct selling into the market from 1 August 2014 onwards. Nevertheless, initiatives to reduce the socialisation of DG connection to the grid are not generally observed. In Denmark, the expense model proposed by Energinet is quite interesting but is still based on the option of reinforcing the network, and does not relate to the practice of smart connection arrangements that may help to defer investment and to avoid charging demand customers for what may be unnecessary network expansion.

5.2 Policy Implications

The socialisation of connection costs implies higher electricity prices for end customers. Governments should encourage the prompt implementation of national policies that promote the development of smart grids. These might contribute to the integration of DG units in a quicker and more cost-efficient way. Currently, smarter grid integration initiatives are only demonstration trials. Auctions which include connection costs in the ranking of the bids for new DG units would represent a novel way that may bring value-added to the current distribution business model. There are well-document decentralised auctions (usually performed by electric utilities from the US) that could help as reference points. Most of these take into account the provision of additional services required by generators which can help with the integration of the new DG units into the distribution grid.

5.3 Limitations and Further Research

This study has only focused on three leading countries in the integration of DG. Further research, would consider not only expanding the list of case studies on DG integration (e.g. to include examination of Spain, Italy, France) but also assess the progress on specific initiatives on smart grids that promote the efficient integration of DG units into the distribution grid. The evaluation of these policies (with a focus on their impacts on end customers) would bring additional value to this research.

Acknowledgments

The authors wish to acknowledge the financial support of UK Power Networks via the Low Carbon Networks Fund's Flexible Plug and Play project and an anonymous reviewer. The authors also want to acknowledge the support of OFGEM, the Federal Network Agency for Electricity, Gas, Telecommunications, Posts and Railway from Germany (BNetzA), the Danish Energy Agency (Energinet), the Danish Energy Association and the Swedish Energy Agency for the provision of valuable information and clarifications. The authors are also grateful to Laura Hannant and Sotiris Georgiopoulos from UK Power Net- works for their valuable comments on this study. The views expressed herein are those of the authors and do not necessarily reflect the views of the EPRG more generally or any other organisation that is also involved in the Flexible Plug and Play project.

References

Ackermann, T., 2013. What Matters for Successful Integration of Distributed Generation, presented at IEA Workshop, Paris, October 1st 2013. http://www.iea.org/media/workshops/2013/futurechallenges/9ackermann.pdf

AGEE-Stat, 2013. Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, Arbeitsgruppe Erneuerbare Energien-Statistik. http://www.energiestiftung.ch/files/downloads/energiethemen-erneuerbareenergien/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland.pdf

Anaya, K.L., Pollitt, M.G., 2014. Experience with smarter commercial arrangements for distributed wind generation. Energy Policy 71, 52-62.

BMU, 2011. The Federal Government's energy concept of 2010 and the transformation of the energy system of 2011, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). http://www.germany.info/contentblob/3043402/Daten/3903429/BMUBMWi_Energy_Concept_DD.pdf

BMU, 2012. Distributed Generation in Germany: From policy planning to implementation to performance, presented at the Great Wall Renewable Energy Forum 2012, Sino-German International Symposium on Renewable Energy and Distributed Generation, Beijing, December 10th 2012.

BMU, 2013. Renewable Energy Sources in Figures: National and International Development. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). http://www.fes-japan.org/wp-content/uploads/2013/04/broschuere_ee_zahlen_en_bf.pdf

BNetzA, 2014. Monitoring Report 2013. Bundesnetzagentur fur Elektrizitat, Gas, Telekommunikation, Post und Eisenbahen, Bundeskartellamt.

http://www.bundesnetzagentur.de/SharedDocs/Downloads/EN/BNetzA/PressSection/ReportsPublications/2013/MonitoringReport2013.pdf?__blob=publicationFile&v=11

Bundesnetzagentur, 2014. Bericht. Monitoringbericht 2014. Bundesnetzagentur fur Elektrizitat, Gas, Telekommunikation, Post und Eisenbahen, Bundeskartellamt. http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2014/Monitoringbericht_2014_BF.pdf?__blob=publicationFile&v=4

Carley, S., 2009. Distributed generation: An empirical analysis of primary motivators. Energy Policy 37, 1648-1659.

CEER, 2014. CEER status review of European Regulatory Approaches Enabling Smart Grids Solutions ("Smart Regulation"). Council of European Energy Regulators. http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_PAPERS/Electricity/Tab3/C13-EQS-57-04_Regulatory%20Approaches%20to%20Smart%20Grids_21-Jan-2014-2.pdf

Cludius, J., Hermann, H., Matthes, F.C., Graichen, V., 2014. The merit order effect of wind and photovoltaic electricity generation in Germany 2008-2016: Estimation and distributional implications. Energy Economics 44, 302-313.

Cossent, R., Gomez, T. and Frias, P., 2009. Towards a future with large penetration of distributed generation: Is the current legislation of electricity distribution ready? Regulatory recommendations under a European perspective. Energy Policy 37, 1145-1155.

Currie, R.A.F., Ault, G.W., McDonald, J.R., 2006. Methodology for determination of economic connection capacity for renewable generator connections to distribution networks optimised by active power flow management. IEE Proc. Gen., Transm., Distrib. 153, 456-462.

Cherian, S., 2013. Denmark: Smart grids, renewables and distributed generation, presented at NARUC Summer Committee Meetings, Denver, Colorado, July 21-24. http://www.narucmeetings.org/Presentations/Dr.%20Sunil%20Cherian%20-%20Denmark-%20smart%20grids,%20renewables,%20distributed%20generation%20%20-%20NARUC%202013%20SUMMER%20MEETING.pdf

DEA, 2012. Energy Statistics 2012. Data, tables, statistics and maps. Danish Energy Agency. http://www.ens.dk/sites/ens.dk/files/info/tal-kort/statistik-noegletal/aarlig-energistatistik/energy_statistics_2012.pdf

DERA, 2011. 2011 National Report to the European Commission Denmark. Danish Energy Regulatory Authority. http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/NATIONAL_REPORTS/National%20Reporting%202011/NR_En/C11_NR_Denmark-EN_v3.pdf

EEG, 2014. Gesetz für Gesetz den Ausbau erneuerbarer Energien (Erneuerbare-Energien-Gesetz. http://www.gesetze-im-internet.de/bundesrecht/eeg_2014/gesamt.pdf

EPRI, 2014. The Integrated Grid. Realizing the full value of central and distributed energy resources. Electric Power Research Institute. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002733

EREC, 2011. Mapping renewable energy pathways towards 2020: EU Roadmap. European Renewable Energy Council. http://www.erec.org/fileadmin/erec_docs/Documents/Publications/EREC-roadmap-V4_final.pdf

Ferreira, H., Fulli, G, Kling, W.L., L'abbate, A., Faas, H., Pecas Lopes, J., 2010. Distributed generation in Europe: the European regulatory framework and the evolution of the distribution grids towards smart grids, presented at the Fifth IEEE Young Researchers Symposium in Electrical Power Engineering Proceedings, p. 1-6. Institute of Electrical and Electronics Engineers (IEEE).

Gil, H.A. and Joos, G., 2006. On the quantification of the network capacity deferral value of distributed generation. IEEE Trans. Power Syst. 21, 1592-1599.

Harrison, G, Piccolo, A., Siano, P., Wallace, R., 2007. Exploring the trade-offs between incentives for distributed generation developers and DNOs. IEEE Trans. Power Syst. 22, 821-828.

Hung, D.Q. and Mithulananthan, N., 2012. A simple approach for distributed generation integration considering benefits for DNOs, presented at 2012 IEEE International Conference of Power System Technology (POWERCON).

IEA, 2011. Energy Policies of IEA Countries: Denmark 2011 Review. International Energy Agency. http://www.iea.org/publications/freepublications/publication/Denmark2011_unsecured.pdf

IEA, 2013a. Energy Policies of IEA Countries: Sweden 2013 Review. International Energy Agency. http://www.iea.org/textbase/nppdf/free/2013/sweden2013_excerpt.pdf

IEA, 2013b. Energy Policies of IEA Countries: Germany 2013 Review. International Energy Agency. http://www.cne.es/cgi-bin/BRSCGI.exe?CMD=VEROBJ&MLKOB=734697974949

IEA, 2013c. National survey report of PV power applications in Sweden 2012. Task 1: Exchange and dissemination of information on PV power system, Co-operative Programme on Photovoltaic Power Systems. International Energy Agency.
http://www.energimyndigheten.se/Global/Forskning/Kraft/Solcellsstatistik/National%20Survey%20Report%20of%20PV%20Power%20Applications%20in%20Sweden%202012.pdf

IEEE, 2012. Power system of the future: The case for energy storage, distributed generation and microgrids. Sponsored by IEEE Smart Grid with analysis by ZPRYME.
http://smartgrid.ieee.org/images/features/smart_grid_survey.pdf

Insight_E, 2014. Curtailment: an option for cost-efficient integration of variable renewable generation? http://www.insightenergy.org/ckeditor_assets/attachments/36/het2.pdf

IRENA-GWEC, 2012. 30 Years of Policies for Wind Energy: Lessons from 12 Wind Energy Markets. International Renewable Energy Agency and the Global Wind Energy Council.
http://www.irena.org/DocumentDownloads/Publications/IRENA_GWEC_WindReport_Full.pdf

Jacobs, D., 2012. Renewable Energy Policy Convergence in the EU: The Evolution of Feed-in Tariffs in Germany, Spain and France, Ashgate Publishing Limited, England.

KEBMIN, 2011. Energy Strategy 2050 – from coal, oil and gas to green energy. Danish Ministry of Climate, Energy and Building.
http://www.ens.dk/sites/ens.dk/files/dokumenter/publikationer/downloads/energy_strategy_2050.pdf

KEBMIN, 2012. Accelerating Green Energy Towards 2020: The Danish Energy Agreement of March 2012. Danish Minister of Climate, Energy and Building.
http://www.ens.dk/sites/ens.dk/files/dokumenter/publikationer/downloads/accelerating_green_energy_towards_2020.pdf

Klessmann, C., Nabe, C., Karsten, B., 2008. Pros and cons of exposing renewables to electricity market risks- A comparison of the market integration approaches in Germany, Spain and the UK. Energy Policy 36, 3646-3661.

Lai, L.L. and Chan, T.F., 2007. Distributed Generation: Induction and Permanent Magnet Generators, John Wiley & Sons, Ltd., Chichester, England.

Lopes, J.P., Hatziargyriou, N., Mutale, J., Djapic, P., Jenkins, N., 2007. Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities. Electr. Power Syst. Res. 77, 1189-1203.

Lund, H., 2005. Large-scale integration of wind power into different energy systems. Energy 30, 2402-2412.

Mendez, V.H., Rivier, J., Gomez, T., 2006. Assessment of energy distribution losses for increasing penetration of distributed generation. IEEE Trans. on Power Syst. 21, 533-540.

OFGEM, 2009. Electricity distribution price control review. Final proposal – Incentives and Obligations. Office of Gas and Electricity Market, London.
https://www.ofgem.gov.uk/ofgem-publications/46748/fp2incentives-and-obligations-final.pdf

Passey, R., Spooner, T., MacGill, I., Watt, M., Syngellakis, K., 2011. The potential impacts of grid-connected distributed generation and how to address them: A review of technical and non-technical factors. Energy Policy 39, 6280-6290.

Poblocka, A., Bruckmann, R., Piria, R., Frank, R., Bauknecht, D., 2011a. Integration of electricity from renewables to the electricity grid and to the electricity market, RES-Integration. National report: Denmark, Client: DG Energy. Eclareon and Öko-Institut e.V.
http://www.eclareon.eu/sites/default/files/denmark_-_res_integration_national_study_nreap.pdf

Poblocka, A., Brückmann, R., Herling, J., Becker, L., Bauknecht, D., 2011b. Integration of electricity from renewables to the electricity grid and to the electricity market – RES Integration. National Report: Sweden, Client: DG Energy. Eclareon and Öko-Institut e.V.
http://www.eclareon.eu/sites/default/files/sweden_-_res_integration_national_study_nreap_final.pdf

SEMI, 2013. The Swedish electricity and natural gas markets 2012. Swedish Energy Markets Inspectorate.
http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/NATIONAL_REPORTS/National%20Reporting%202013/NR_En/C13_NR_Sweden-EN.pdf

SVK, 2012. Annual Report 2012. Svenska Kraftnät.

Trendresearch, 2012. Anteile einzelner Marktakteure an Erneuerbare Energien-Anlagen in Deutschland (2. Aufl age). Trend:Research, Institut für Trend- und Marktforschung.

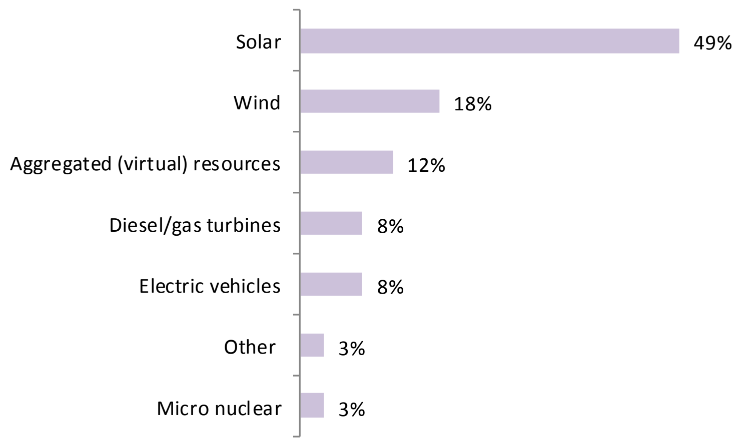
van der Vleuten, E. and Raven R., 2006. Lock-in and change: Distributed generation in Denmark in a long-term perspective. Energy Policy 34, 3739-3748.

Wang, D.T.C, Ochoa, L.F., Harrison, G.P., 2009. Distributed generation and security of supply: Assessing the investment deferral, presented at 2009 IEEE Bucharest Power Tech Conference, June 28th-July 2nd, Bucharest, Romania.

Wojszczyk, B. and Brandao, M., 2011. High penetration of distributed generation and its impact of electric grid performance – utility perspective, presented at Innovative Smart Grid Technologies Asia (ISGT), 2011 IEEE PES.

Figures

Figure 1: Distributed generation technologies with the highest expected demand over the next 5 years (% of executives surveyed)



Own elaboration. Source: IEEE (2012)

Figure 2: Solar and Wind renewable energy primary production in the EU-27 MS (period 2000/2011)

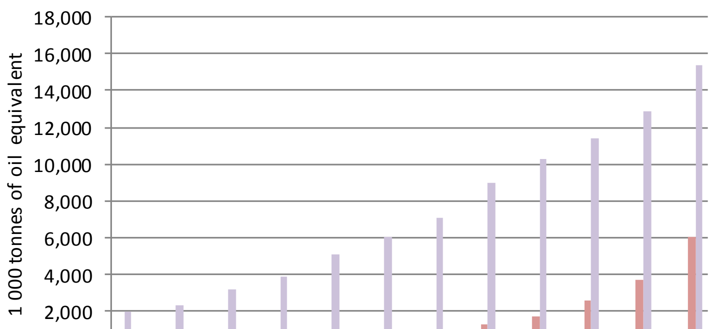
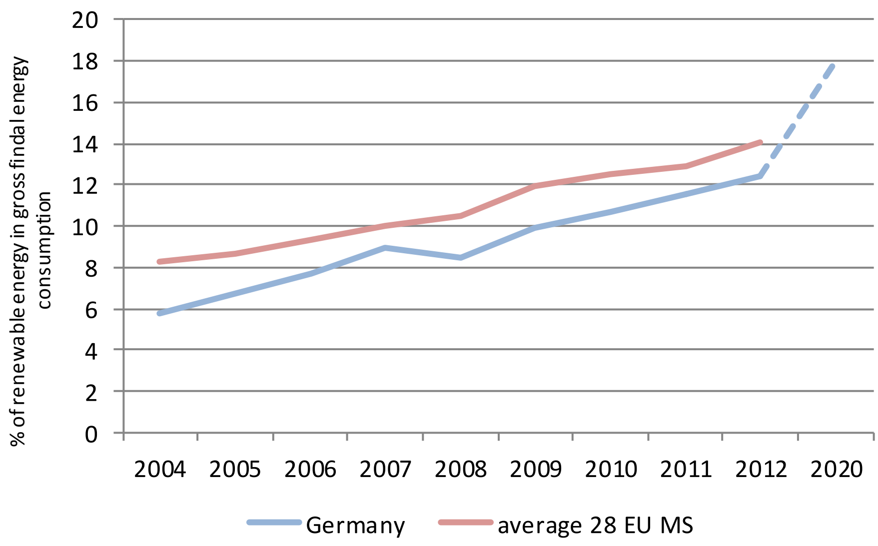
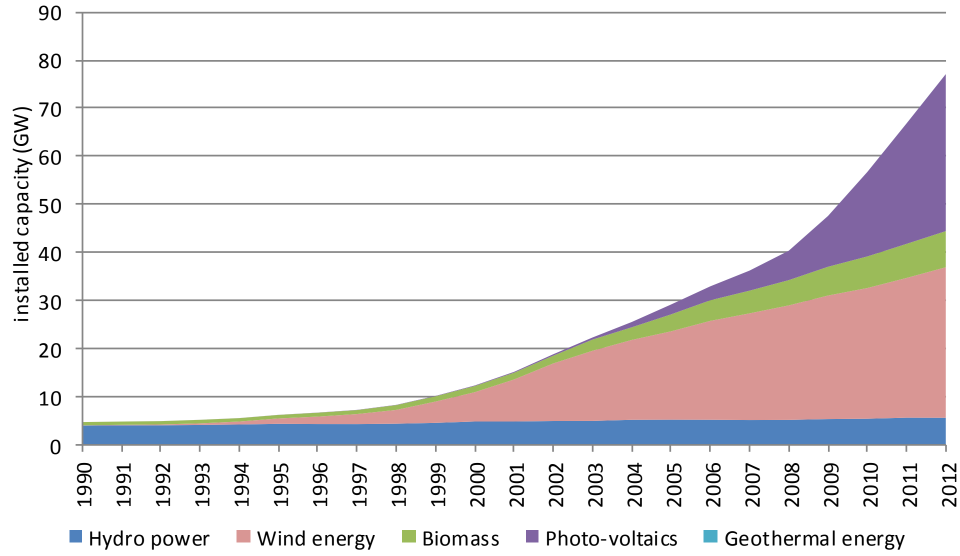


Figure 3: Share of renewable energy in gross final energy consumption



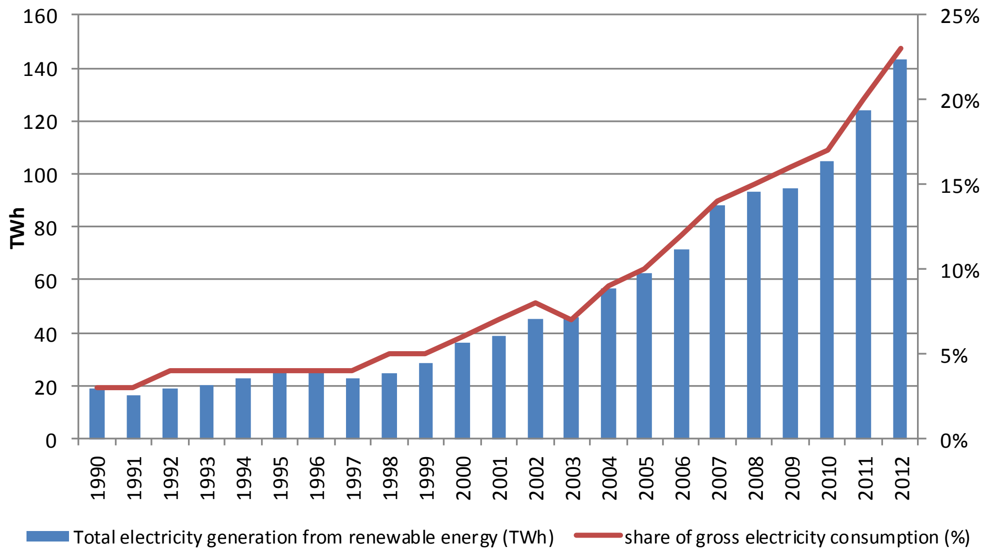
Ow n elaboration. Source: Eurostat

Figure 4: DG Installed capacity in Germany



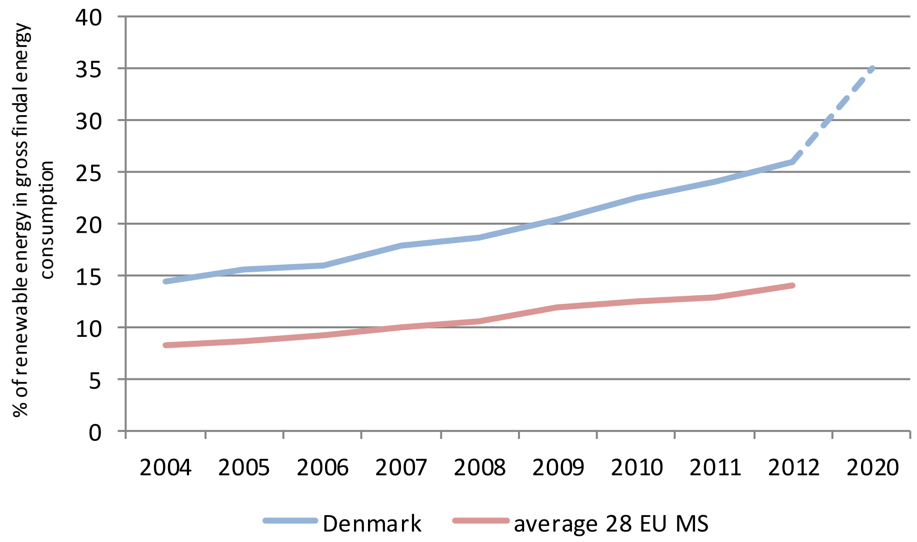
Own elaboration. Source: AGEE-Stat (2013) and BMU (2013)

Figure 5: Electricity generation from DG in Germany



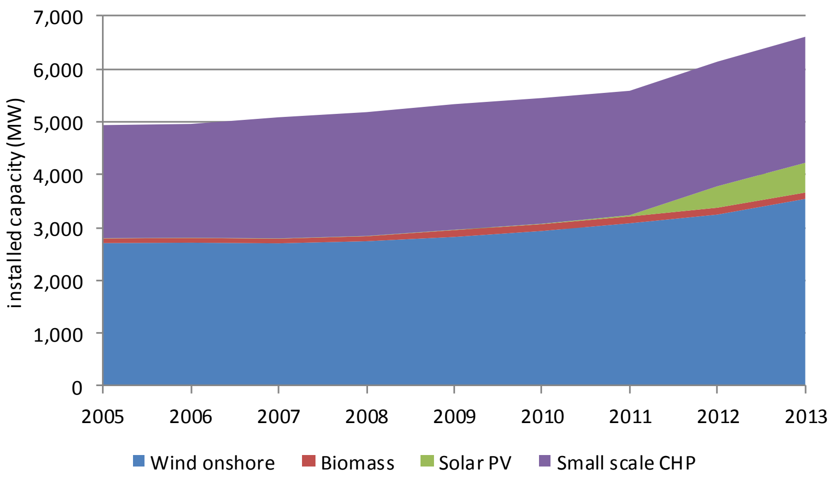
Own elaboration. Source: AGEE-Stat (2013) and BMU (2013)

Figure 6: Share of renewable energy in gross final energy consumption



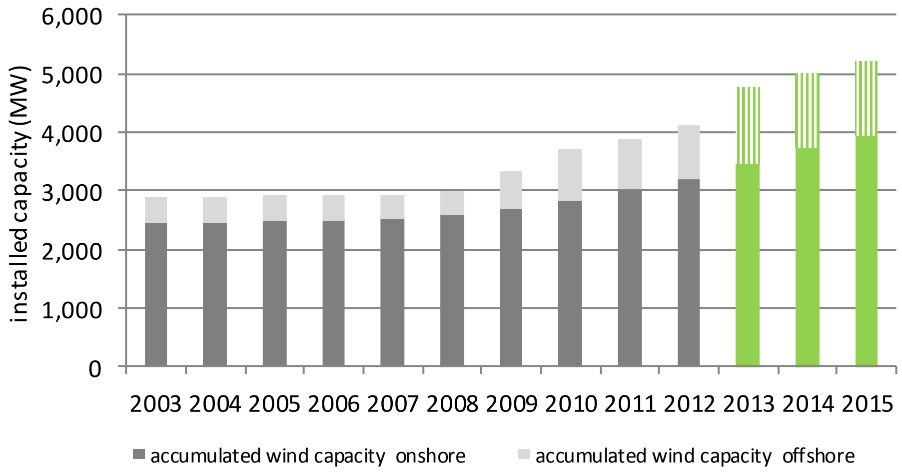
Own elaboration. Source: Eurostat

Figure 7: DG installed capacity in Denmark



Own elaboration. Source: DG data provided by Energinet

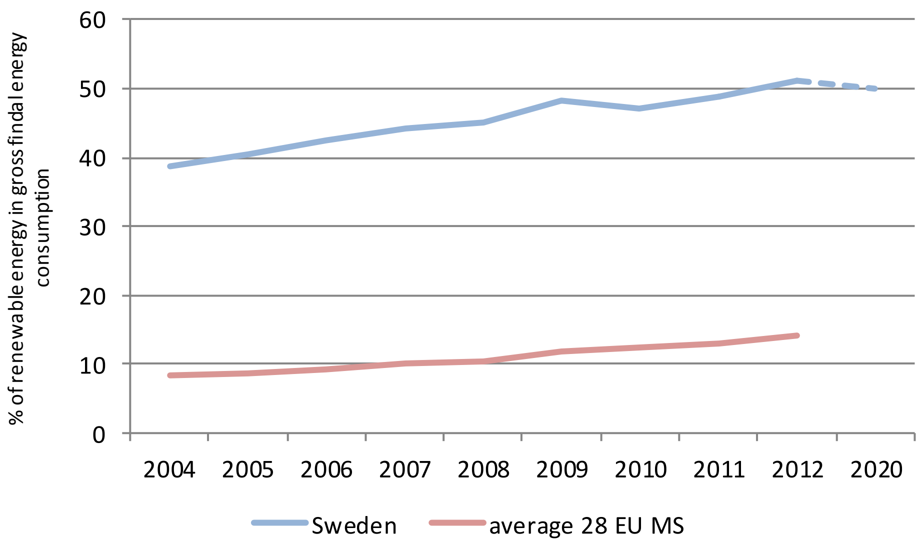
Figure 8: Accumulated wind capacity (MW) in Denmark



Own elaboration. Source: Danish Wind Industry Association (DWEA).

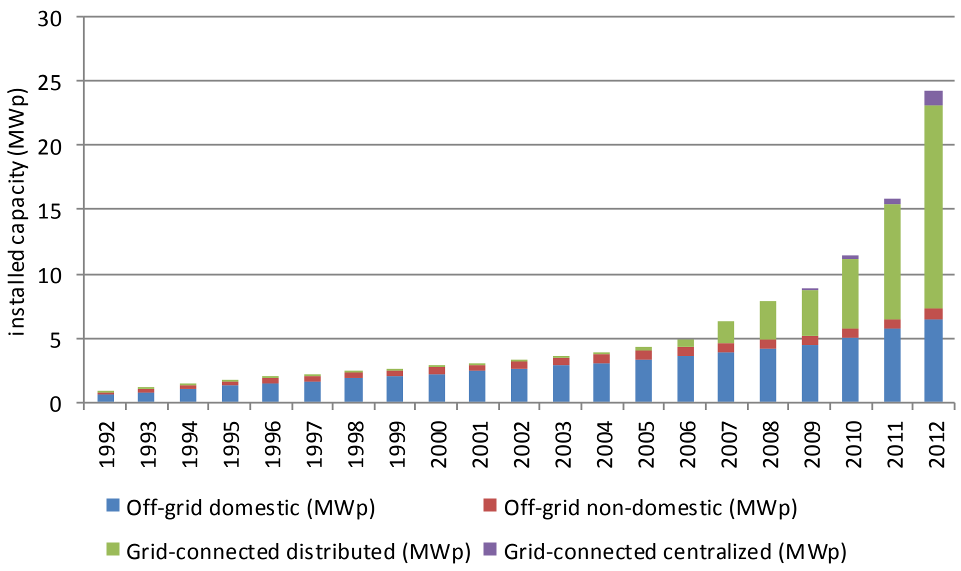
The green bars refer to projected figures (2013-15), solid fill (onshore), pattern fill (offshore).

Figure 9: Share of renewable energy in gross final energy consumption



Own elaboration. Source: Eurostat

Figure 10: Solar PV installed capacity in Sweden



Own elaboration. Data provided by Swedish Energy Agency based on IEA (2013c)

Tables

Table 1: German Electricity Market

Electricity Market										
Electricity Market liberalisation	Distribution Grid (km)	Distribution voltage level	Transmission Grid (km)	Transmission voltage level	# DSOs	#TSO	Customers (m)	Electricity Production (TWh)	Installed capacity (GW)	Installed capacity Renewable (GW)
1998	1,753,290	<= 110 kV	34,841	150 kV, 220 kV, 380 kV	888	4	48.8	576.6	178.3	75.6

Source: BNetzA (2014). 2012 figures (excluding #DSOs and #TSOs which refer to 2013).

Table 2: The German Targets and Goals

Concept	Targets and Goals	2020	2030	2040	2050
Climate	Reduction of greenhouse gases (base year 1990)	-40%	-55%	-70%	-80%
Renewable Energy	Share in total final energy consumption	18%	30%	45%	60%
	Share in electricity consumption	35%	50%	65%	80%
Energy efficiency	Reduction of primary energy consumption (base year 2008)	-20%			-50%
	Reduction of electricity consumption (base year 2008)	-10%			-25%
	Reduction of final energy consumption in the transport sector (base year 2005)	-10%			-40%
	Building renovation rate: from 1% a year to 2% of total building stock				

Own eleboration. Source: BMU (2011).

Table 3: Danish Electricity Market

Electricity Market										
Electricity Market liberalisation	Distribution Grid (km)	Distribution voltage level	Transmission Grid (km)	Transmission voltage level	# DSOs	#TSO	Customers (m)	Electricity Production (TWh)	Installed capacity (GW)	Installed capacity Renewable (GW)
2003	168,000	<= 60 kV	6,300	132 kV, 150 kV, 400 kV	77	1	3.2	35	13.6	6.4

Source: IEA (2011), DERA (2011). 2010 Figures.

Table 4: The Danish Targets and Goals

Concept	Targets and Goals	2020	2050
Climate	Reduction of greenhouse gases (base year 1990)	-34%	-80%
Renewable Energy	Share in total final energy consumption	>35%	100% renewable energy in the energy and transport sector
	Share in electricity consumption (wind power). Total of 3,300 MW new power capacity (includes repowering) by 2020	50%	
Energy efficiency	Reduction in gross energy consumption (base year 2010)	-7.6%	
	Energy companies: energy savings by consulting energy experts, subsidies to households/business.		

Own elaboration. Source: KEBMIN(2012)

Table 5: Swedish Electricity Market

Electricity Market										
Electricity Market liberalisation	Distribution Grid (km)	Distribution voltage level	Transmission Grid (km)	Transmission voltage level	# DSOs	#TSO	Customers (m)	Electricity Production (TWh)	Installed capacity (GW)	Installed capacity Renewable (GW)
1996	530,000	Regional: 40-130 kV	15,000	220 kV, 400 kV	168	1	5.2	162.0	37.3	23.4
		Local: <40 kV								

Source: SEMI (2013), SVK (2012). 2012 Figures.

Table 6: The Swedish Targets and Goals

Concept	Targets and Goals	2020	2030	2050
Climate	Reduction of greenhouse gases or 20m tonnes of carbon dioxide equivalent (base year 1990)	-40%		-100%
Renewable Energy	Share in gross final energy consumption	>50%		
	Share in transport sector	10%		
Energy efficiency	Reduction in gross energy consumptio (base year 2008)	-20.0%		
Vehicle			Vehicle stock independent of fossil fuels	

Own elaboration. Source: IEA (2013a)

Table 7: Summary of Connection and Grid Access for DG

Country	Connection method			Use of system charges		Connection to the grid		Grid access	
	deep	shallowish	shallow	Yes	No	Priority	Non-discriminatory	Priority	Non-discriminatory
Germany			X		X	X		X	
Denmark			X		X		X	X	
Sweden	X			X			X		X

Own elaboration. In the case of Denmark, use of system charges (in distribution) is not applicable only for environmetally green technologies.