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# Distributed generation and distribution market diversity in Europe

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ABSTRACT

The unbundling of the electricity power system will play a key role on the deployment of distributed generation (DG) in European distribution systems evolving towards Smart Grids. The present paper firstly reviews the relevant European Union (EU) regulatory framework: specific attention is paid to the concept of unbundling of power distribution sector in Europe. Afterwards, the focus is on the current state of penetration of DG technologies in the EU Member States and the corresponding interrelations with distribution features. A comparison between the unbundling of the distribution and supply markets using econometric indicators such as the Herfindahl–Hirschmann ($I_{HH}$) and the Shannon–Wiener ($I_{SW}$) indices is then presented. Finally, a comparative analysis between these indices and the current level of penetration of distributed generation in most EU is shown; policy recommendations conclude the paper.



## 1. Introduction

The European electric power sector is undergoing important modifications in response to the three key objectives set by the European Union (EU) within its current energy policy: environmental sustainability, security of supply, and competitiveness (European Commission, 2006a, b, 2007a, b, 2009; European Parliament and Council, 2004, 2006, 2009a, b). Essential herein are the EU's specific targets to be attained by 2020:

- a reduction in greenhouse gas emissions of 20% below the 1990 levels;
- a 20% share of energy consumption covered by Renewable Energy Sources (RES);
- a 20% reduction in primary energy use compared with projected levels, which assume a yearly increase of 1.5% until 2020 (European Commission, 2006c).

Some resulting trends are already more and more apparent, for example, within electric power distribution systems, where several EU countries report a steady increase in the installation of small and medium generation systems with capacities of some tens of MW and generally placed close to the final user. It is obvious to classify these systems under the heading of distributed generation (DG), although there is no globally accepted definition for this concept. In order to create an unambiguous context inside this article, DG is here defined in accordance with the relevant European legislation (European Parliament and Council, 2009b) as based on "generation plants connected to the distribution system" (see also Section 2). It should be noted however that a wide variety of alternative definitions, often more detailed, are used. These are generally based on criteria, such as voltage level, generation capacity, applied technologies, and the like. In general, DG comprises units based on RES, like wind turbines, photovoltaic panels, and hydraulic micro-turbines as well as generators not necessarily based on RES, such as gas micro-turbines, diesel engines, and fuel cells that can be used for Combined Heat and Power (CHP) generation.

Due to its decentralised nature and low environmental impact, DG has the potential to foster the achievement of the EU energy policy objectives. DG is believed to offer concrete benefits to the electric system including increased security of supply, reduced fossil fuel consumption, higher system efficiency, lower transmission and distribution losses, improved quality of supply, new market opportunities, and enhanced system competitiveness. DG may also, indirectly, be the chosen solution in response to apparent social and environmental opposition to the construction of large-size power plants and higher-capacity transmission infrastructures.

It should be stressed however that numerous technical issues have to be addressed in order to allow for a successful increased penetration and integration of DG (including RES) into distribution grids.

However, beyond technical issues, also market and regulatory challenges are to be addressed towards an increased penetration

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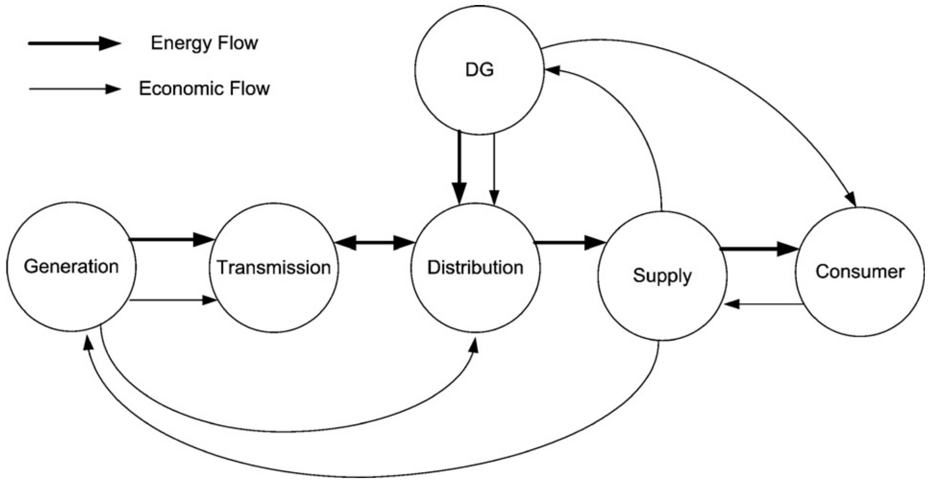


**Fig. 1.** Energy and economic flows.

and integration of DG into distribution networks in Europe. Firstly, there is a clear need for appropriate policies and associated regulatory instruments that support the integration of DG into distribution networks. A particularly relevant aspect for DG integration is the unbundling requirement for DSOs (Distribution System Operators), which is laid down in European legislation (European Parliament and Council, 2009a). Successful implementation of unbundling at the distribution network level is generally seen as an important requirement for fair and non-discriminatory network and market access for new DG entrants (L'Abbate et al., 2007).

A model integrating both the economic and energy flows in the power sector can be observed in Fig. 1. In order to highlight the interactions of DG operators in both the network and the market, micro-generation is not considered.

In terms of energy flow one can observe the axial role of the distribution networks, interconnecting DG, transmission, and supply. The emergence of reversed flows between transmission and distribution, due to the integration of DG, is showed there. The possibility of reversed flows demands a special attention, since neither of the networks, nor the connection points between them, were usually designed for such situation.

In terms of economic flows, the supply sector acquires, on the electricity market, the energy either from the traditional generation operators or from DG operators. These operators will pay to the network operators, the usage of their networks. This payment can be done applying Use of System charges and/or Connection charges.

As highlighted in this article, a diversified electricity distribution market may offer the most favourable circumstances for large penetration of DG. Alternatively, a heavily concentrated distribution market is assumed to generally limit the deployment of DG. Naturally, various additional factors influence the level of DG penetration and thus complicate the context analysis.

The present article aims at addressing some market and regulatory issues related to DG integration in the European electricity system. Particular attention is given to the relation between the unbundling level of the distribution market sector and the penetration of DG.

## 2. Vertical unbundling and DG in the EU regulatory framework

DG is considered in several European Directives that address technical, economic, environmental, and regulatory aspects of the EU electricity market. An overview of these Directives and of their contents is given in Fig. 2.

Concerning both DG and unbundling, the principal act of the EU is the Directive 2009/72/EC (European Parliament and Council, 2009b), which is part of the Third Electricity and Gas Liberalisation Package, focusing on the common rules for the internal electricity market. This Directive introduces the principle of proportionality in the authorisation procedures for DG connection, it allows EU Member States (MS) to promote DG based on RES, waste or CHP, and it requires DSOs to consider DG when planning the development of distribution networks as an alternative for upgrading or replacing electricity network capacity.

Furthermore, it regulates the whole process of unbundling transmission and distribution from generation to supply in the EU. Several possibilities do exist in order to achieve the desired unbundling of the entity in case, which include functional, legal, operation, and full ownership unbundling. The functional unbundling is the simplest form of it, in accordance with the minimal requirements of Article 9(1) for transmission, and consists on setting independent organisation and decision making. The legal and functional unbundling demands a more complete separation of the former vertical integrated companies. It is the minimum requirement for distribution, as defined by Article 26. The usage of independent system operators and the separation between network ownership and its operation is defined starting from Article 13. Finally, the complete separation between companies is the ultimate form of unbundling. In Fig. 3, it is possible to observe the different categories of unbundling.

For the unbundling of distribution systems, EU MS can define thresholds of exceptions for companies with a limited number of clients (100,000 customers or less) or small isolated systems, as stated in Article 26(4), and for companies operating closed distribution systems, as stated in Article 28.

Although quite common, the separation between transmission and distribution is not mandatory. However, the rules set in Article 29 concerning the combined operator have to be respected. Concerning network ownership unbundling, it may belong to the same entity or not. A comparison between some of the different possibilities of unbundling – from Vertical Integrated Undertaking (VIU) scheme to fully vertically unbundled company – is displayed on Fig. 4.

The success of the unbundling process of the distribution sector is considered to be an important condition for high DG penetration levels. In actual fact, the aim of unbundling is the creation of a non-discriminatory and transparent environment for all energy market stakeholders and to eliminate the potential

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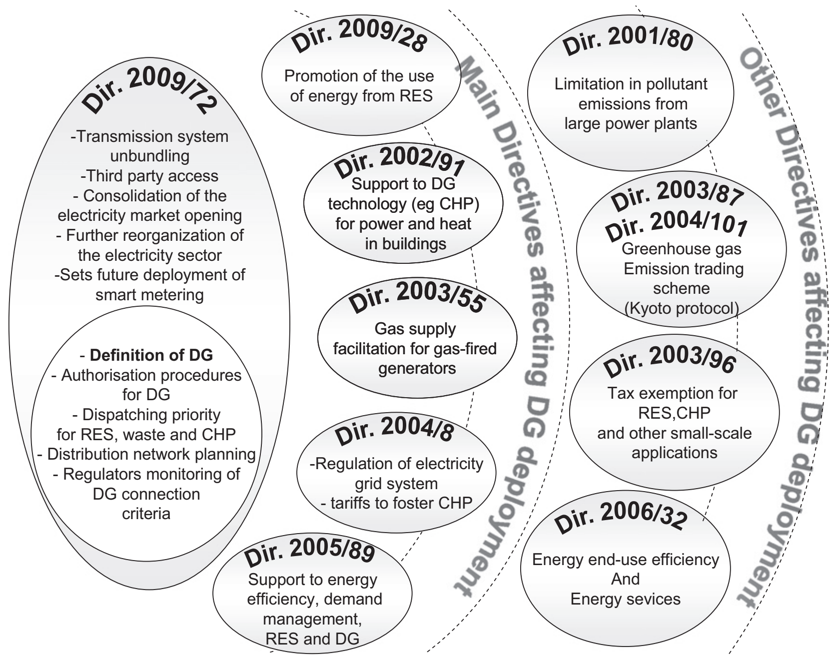


**Fig. 2.** European directives with direct impact on the development of DG.

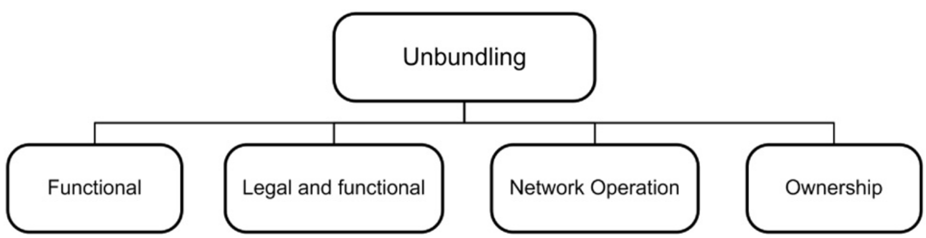


**Fig. 3.** Unbundling modes set by Directive 2009/72/EC, increasing from left to right the degree of separation.

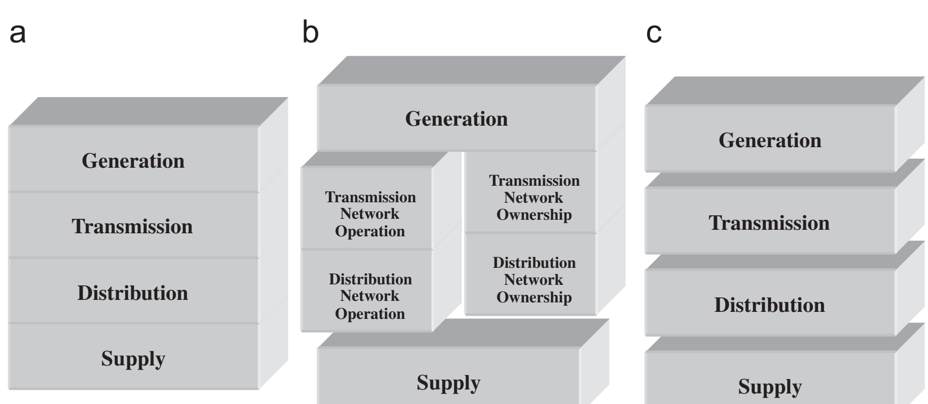


**Fig. 4.** Comparison between different forms of unbundling: (a) Vertical integrated undertaking; (b) Network operation unbundling; and (c) Ownership unbundling.

abuse of the position of an integrated utility that is, at the same time, a producer or a trader, on one hand, and a Transmission System Operator (TSO) or a DSO, on the other hand. The implementation of the unbundling process should result in securing a non-discriminatory and independent position of a DSO, an optimisation of the quality of the individual processes and related costs, and an improvement of transparency of the mentioned individual processes, but also of costs, revenues, and cash-flow. This can be reflected on the side of DG penetration as the open distribution network access potentiates the market admittance to new DG entrants (ERGEG, 2009).

As stated, Directive 2009/72/EC sets forms of minimal unbundling. However, some EU MS (e.g. The Netherlands) have opted for the ownership unbundling: this means that the system is run by different operators and owners from production down to utilisation. In this way, no all-encompassing (vertically integrated) holding and no shared operational activities are allowed. Within this philosophy, ownership unbundling is perceived as a precondition for the full privatisation of commercial activities (i.e. production, trade, metering, and sales) (Kunneke and Fens, 2007), while the distribution networks are operated as regulated monopolistic activities. For example, ownership unbundling prevents cross-subsidies between the network and the commercial activities. Many EU MS, however, have chosen the legal and functional form of unbundling and have even been slow in the implementation of this scheme. Some reports suggest that the regulatory processes have been unduly influenced and that the timing of implementation of unbundling regimes can be explained by "questionable" influence activities by VIUs (van Koten and Ortmann, 2007).

Some authors state that DSO ownership unbundling – which is still uncommon in the European panorama – may "at least distort and impede efficient investment in DG" (Brunekreft, 2005). This would be due to the competing interests of short term profit versus long term profit. In this framework, in fact, it has been argued that the unbundled DSO would limit the DG access to the network, trying to maximise the profit in the short term by avoiding or shifting the DG connection and its associated costs, while the integrated DSO would be oriented to the longer term profit provided by the system charges due by DG developers.

To address this dilemma, however, the economic network regulation plays here a key role, as it has the potential of balancing the initial increased costs of connecting DG, taking in consideration both the reduced revenue due to the decreased usage of the network and the benefits such as lower grid losses (Ropenus, 2009).

The European Commission (EC) continuously monitors the evolution of the unbundling process in the 27 EU MS (EU-27). This is a key aspect for fostering the integration of RES and DG into the European power system, also in view of the EU 2020 targets.

**Table 1**
Number of DSOs per MS in the EU-27 (2007–2008) (ERGEG, 2008).

| EU Member State | DSOs in 2007 | DSOs in 2008 | DSOs having more than 100,000 customers in 2008 |
|---|---|---|---|
| Austria | 130 | 130 | 13 |
| Belgium | 26 | 26 | 5 |
| Bulgaria | 4 | 4 | 4 |
| Cyprus | 1 | 1 | 1 |
| Czech Republic | 280 | 282 | 3 |
| Denmark | 101 | 89 | 5 |
| Estonia | 40 | 40 | 1 |
| Finland | 102 | 101 | 6 |
| France | 169 | 169 | 5 |
| Germany | 855 | 862 | 75 |
| Greece | 1 | 1 | 1 |
| Hungary | 6 | 6 | 6 |
| Ireland | 1 | 1 | 1 |
| Italy | 163 | 131 | 12 |
| Latvia | 10 | 10 | 1 |
| Lithuania | 7 | 7 | 2 |
| Luxembourg | 9 | 8 | 1 |
| Malta | 1 | 1 | 1 |
| Netherlands | 8 | 8 | 3 |
| Poland | 18 | 20 | 14 |
| Portugal | 13 | 11 | 1 |
| Romania | 30 | 35 | 8 |
| Slovakia | 48 | 49 | 3 |
| Slovenia | 5 | 1 | 1 |
| Spain | 326 | 350 | 5 |
| Sweden | 175 | 177 | 6 |
| United Kingdom | 18 | 18 | 14 |

## 3. Unbundling and DG in the EU

When referring to the unbundling process, its possible forms should be differentiated, particularly between vertical and horizontal unbundling. While vertical unbundling, as seen in Section 2, refers to the separation between generation, transmission, distribution and supply, horizontal unbundling refers to the market structure diversification. A high level of vertical unbundling encourages market diversification, since it allows the provision of similar conditions to the participants in that market.

Unlike for large centralised generation plants, collecting accurate and consistent data on DG units installed in the European networks is a quite intricate task. The reasons are multiple and vary throughout the EU countries: there exist different definitions of DG (for instance, according to the size and type/voltage level of connection to the network); there is lack of a centralised database and of a communication structure between DSOs and TSOs; there is the geographically dispersed nature of the distribution system; there is also the limited access of DG to electric markets.

The values of the capacity of the installed DG in the 27 MS of the EU – estimated in relation to the total capacity of installed generation – are reported in Fig. 2 for 2008 within two bands. Fig. 2 shows also the maximum distribution voltage level and the amount of DSOs in EU-27 for 2008 (ERGEG, 2009; EURELECTRIC, 2005; European Project DG-GRID; European Project SOLID-DER).

The data related to the number of DSOs in the EU-27 are listed in detail in Table 1, where the evolution per country from 2007 to 2008 in terms of number of DSOs can be observed. The number of DSOs with more than 100,000 customers, which are, as stated in Section 2, the companies under the scope of the unbundling process, is also indicated.

In what concern the values displayed in Table 1 it should be stated that 13 Finnish regional network operators of 110 kV grids are considered as DSOs. Similarly, for Sweden, 5 regional network operators are part of the group of DSOs. This does not apply to Denmark, where 9 regional operators of 132/150 kV grids, which are transmission voltages, are not considered as DSOs.

From Fig. 5 and Table 1, it may be observed that in some countries a dominant DSO controls the entire distribution grid, whereas in other cases, there are numerous DSOs which run their networks on a regional or municipal basis. Those differences are due to historic, geographical, socio-political, and economic reasons. However, in countries having a large number of DSOs, there is in general also a limited amount of DSOs operating large part of the network (see Table 1).

Moreover, due to the transformations of the European electricity markets, the number of DSOs is continuously changing (Jenkins et al., 2000), as it can be also seen in Table 1. Besides, in the latest years, the number of DSOs, especially in some countries like Denmark and Germany, has progressively decreased due to merging grid companies. The main goal of mergers is the achievement of efficiency improvements by network utilities. By merging, two or more electricity network companies can exploit the economies of scale arising in the operation of the electricity grid. These economies of scale include more efficient organisation of work, typically leading to a higher specialisation of work functions. The efficiency improvements derived lead to lower expenses for administration, operation, and maintenance, while the quality of these functions is maintained or even improved. In the longer term, benefits from mergers may also become apparent in terms of better planning of the grid as well as better procurement and financing of grid components.

In the short term, however, a merger does not necessarily lead to lower operating expenses. During the years around a merger, migration costs (e.g. costs linked to merging different information systems) could overshadow any efficiency improvements resulting from the merger (DERA, 2008). Considering the effects of the amount of DSOs on DG penetration, a reduction of the number of these companies due to mergers, especially in countries with hundreds of DSOs, can be an opportunity to simplify the picture and rationalise the distribution sector, allowing then a potential

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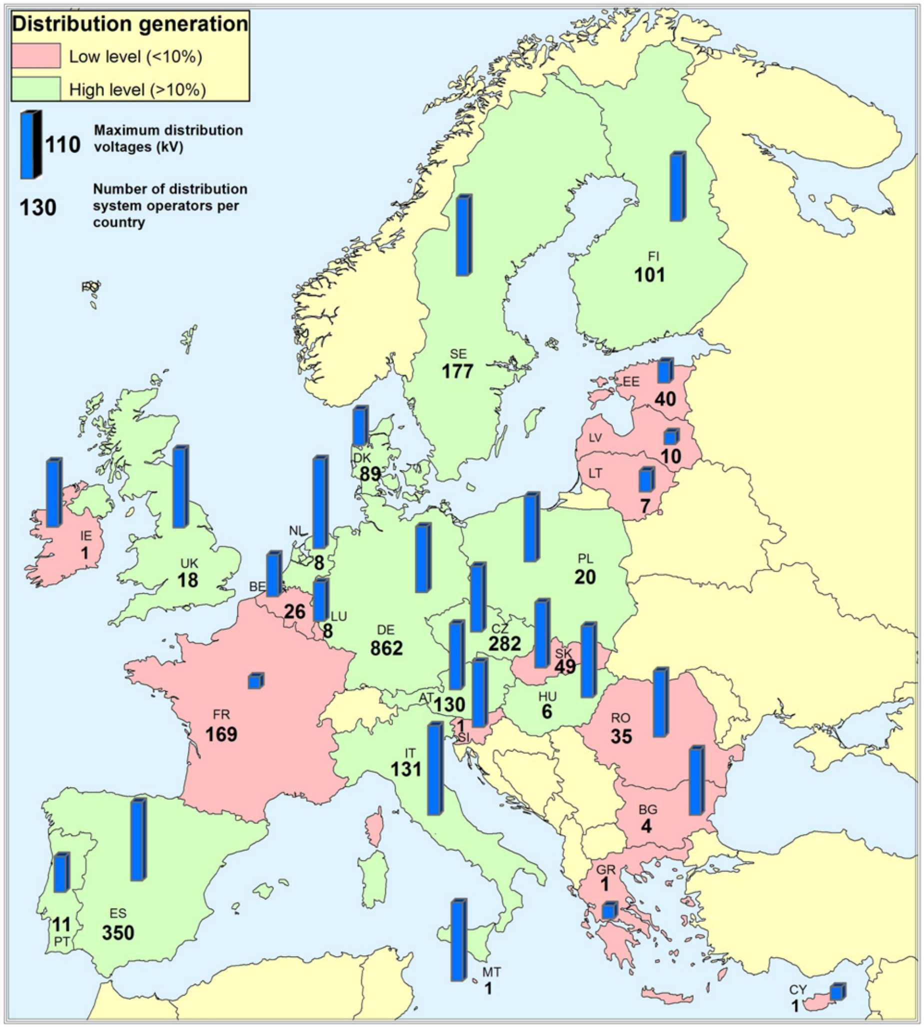


**Fig. 5.** Number of DSOs, maximum voltage level on distribution networks and DG capacity penetration range in the EU-27 (2008).

DG penetration increase. On the other hand, a very limited number of DSOs may lead to the former vertically integrated environment situation, where DG options may be hindered or constrained.

Although the unbundling process is, in most of the EU-27 MS, still at a quite formal level, progress has been made after the issuing of the Directive 2003/54/EC and then by its successor, Directive 2009/72/EC. After the separation of previous sister companies, the usage of different logos and websites is now more common. Nonetheless, in some cases interest exists in developing a corporate culture that goes beyond the legal obligation, and the national regulators have been fostering the functional unbundling (ERGEG, 2009).

In most of EU countries, however, there are no requirements for ownership unbundling of DSOs. In more cases, the legally unbundled DSOs still belong to the same group of companies as electricity retailers and/or generators. Often, the parent company of a legally unbundled DSO is a generating or retailing company. On the other hand, it may also occur that some electricity retailers are owned by a group of DSOs. In most cases, the legally unbundled DSOs belonging to a group of companies share their operational, managerial, and financial responsibilities. Moreover, part of the strategic and operational tasks of DSOs are done in collaboration with other parts of the company or outsourced to them. Frequently, the DSO and the retailer have at least a common customer service.

By examining the data displayed in Fig. 2, it is possible to identify different groups of EU countries concerning their DG capacity penetration level, the maximum level of voltage in the respective distribution networks, and the number of DSOs. Nevertheless, the scope of this article is not to compare the DG penetration levels in the EU-27 also in view of the different regulatory regimes applied throughout EU-27.

A general classification of EU-27 MS in two main groups is hereby proposed:

(a) Member States with a low penetration of DG ( $<10\%$)
(Malta, Slovenia, Slovakia, Ireland, Romania, Bulgaria, Belgium, Luxembourg, Lithuania, Estonia, Greece, Cyprus, Latvia, and France)
It is possible to infer in this group a potential direct correlation between the DG penetration rate and the number of DSOs. As a matter of fact, with the exception of France and Slovakia (where however a few DSOs control large part of the distribution system), all these states display a relatively low number of DSOs in their territory. Other aspects impacting on DG capacity penetration deal with the maximum distribution voltage level across the EU-27.
Looking in particular at the case of France, which has a DG capacity that does not reach 6.8% of total 117,628 MW of installed capacity and 6% of production (2008 data), an element that influences the relatively low DG capacity penetration is the

relatively low maximum distribution voltage level of the French system, 20 kV. Higher voltage levels – 45, 63, and 90 kV – are already part of the transmission system, operated by the French TSO RTE: the generation therein connected can, according to the EU definition applied to the French system, not be considered as distributed, in spite of what may occur in other EU countries. Then, a generation capacity level of 12 MW is the estimated threshold for distinguishing centralised from distributed generation: generation units having a capacity higher than 12 MW are to be connected to the transmission system. An emblematic regional case in France is represented by Corsica, where, out of a total of 432 MW (2008 data) of generation capacity, a significant share (136 MW) of hydroelectric units connected to the 90 kV grid cannot be considered as DG. The DG capacity in Corsica is then only given by 17 MW of hydroelectric and 18 MW of wind capacity, i.e. 35 MW (8.1% of regional capacity). However, with the ongoing development of photovoltaic units in the region, the local share of DG is projected to increase fast (EDF SEI; RTE, 2009).
A slightly higher DG capacity trend is visible in Belgium, where a DG capacity of 1585 MW corresponds to 9.5% of the total 16,670 MW, while in Slovenia, where hydroelectric units are generally connected to the transmission grid, a 210 MW of DG capacity (from RES and CHP) results in a share of 6.7% (out of 3112 MW) and a 4% share in terms of DG production (ERGEG, 2008).

(b) Member States with a mid-high penetration of DG ( > 10%) (Italy, Sweden, Hungary, United Kingdom, Finland, Germany, Austria, Netherlands, Spain, Poland, Czech Republic, Portugal, and Denmark)

This group presents a wider homogeneity in terms of voltage levels, with a maximum distribution level being usually 110 kV. Some of these nations (like Italy, Sweden, Finland, Germany, Austria, Spain, Czech Republic, and Denmark), present a high level of DSOs. Moreover, almost all the above mentioned countries have dominant distribution operators. A particular case is provided by the United Kingdom, where the liberalisation and unbundling process has long been effectively completed. Also in The Netherlands, reforms to foster DG penetration have been put in place in the latest years. In terms of share of DG, the results are even more promising if compared with the ones of the previous group, which may be due to more mature solutions concerning the technical and regulatory challenges for DG promotion.

Looking in particular at the case of Germany, there has been an upward trend in the latest years, with the incentivized promotion of RES and CHP. This has led to the current DG capacity penetration level of 45.3 GW (2008 data) which corresponds to 30.8% of the total installed capacity in Germany (147.1 GW). The maximum distribution voltage in Germany is 110 kV, with a general threshold capacity of 100 MW. This allows a broad potential for a further increase of DG. Considering only incentivised RES units, the related DG share corresponds to an energy quota of 65,256 GWh, and a power capacity of 33,209 MW.

Another particular case is the one of Austria, where a mid-high DG penetration has been already a reality for some years. This corresponds to a share of about 27% of DG (2008 data). Also for Austria, as for Germany, the threshold for the maximum distribution voltage is 110 kV and the rating is 100 MW.

It has to be noted that in countries where the DG technologies have reached a good level of integration in the distribution system, the high capacity penetration is not necessarily the legacy of a high number of DSOs. In actual fact, The Netherlands and Portugal present a reduced number of DSOs on their territory. Amongst the countries with very high DG capacity penetration there are the Czech Republic, whose DG capacity has reached 42% level of the total installed generation (2008), and Denmark, which has the highest DG penetration in Europe, over 50% of the total capacity (ERGEG, 2008).

## 4. Diversity in the European electricity distribution market

In this section, supply and distribution sector diversity are evaluated as relevant measures for the status of the ongoing horizontal unbundling process at distribution level. The relation between the market concentration at distribution and supply level will be displayed in the following and the potential of using one as approximation of the other evaluated. Concerning data on distribution, 2008 information has been made available by 10 of the EU national regulators. On supply, the most recent data, made available from Eurostat (2010) and some national regulators, refer to 2008 and concern the number of electricity retailers and their respective market shares in the EU-27. However, due to confidentiality rules, some countries have not provided this type of data (partially or completely), such as

- *Denmark*: no data available for 2008;
- *Finland*: only the number of the main electricity suppliers is available, but not their respective shares of the market;
- *The Netherlands, Germany and Bulgaria*: only the number of main electricity suppliers and their cumulative market shares are available.

A supplier or DSO is considered to be a main one if its market share is at least 5% of the total national electricity consumption. Calculating the mean electricity consumption per (main) supplier for each country would only provide highly averaged information. Therefore, in order to have a more accurate description of diversity, we decided to calculate genuine diversity indices.

In general, the diversity of a system can be further broken down into three more basic features: "variety" or the number of options in a system, "balance" or the relative contribution of each option, and "disparity" or the degree to which options differ from each other in their intrinsic characteristics (Grubb et al., 2006; L'Abbate et al., 2007; Stirling, 1994, 2010). For an electricity distribution market, it is obvious that variety and balance correspond to the number of DSOs or electricity suppliers and their relative market shares, respectively. In this case, the disparity feature has not been addressed. Therefore, two diversity indices have been selected to take into account variety and balance: the Shannon–Wiener Index ($I_{SW}$) and the Herfindahl–Hirschmann Index ($I_{HH}$). The two indices are used in order to measure to which extent the results depend upon the choice of diversity index and to increase the confidence level of current analysis.

$I_{HH}$ is traditionally used to measure market concentration, which is the opposite of diversity, decreasing thus with diversity. $I_{HH}$ is applied by both the US Federal Trade Commission and the UK Office of Fair Trading for practical policy-making (Skea, 2010), and is defined as

$$I_{HH} = \sum_{n=1}^{N} p_n^2, \qquad (1)$$

where $N$ is the total number of electricity suppliers and $p_n$ the relative market share of each supplier. The minimum value of this index is $1/N$ and is reached when all the shares are equal to $1/N$; the maximum value is 1 and is obtained when one of the shares is equal to 1 and the rest is 0 (monopoly case). It has been agreed upon that a resulting $I_{HH}$ of less than 0.1 indicates a competitive market place, while a resulting $I_{HH}$ greater than 0.18 indicates a concentrated market place (Herfindahl, 1959; Hirschman, 1964). Although it originates from communication theory, $I_{SW}$ has been successfully used for market diversity studies (Shannon and Weaver, 1962; Skea, 2010). Using the same notations, $I_{SW}$ is here defined as

$$I_{SW} = \frac{-1}{\log N} \sum_{n=1}^{N} p_n \log p_n. \tag{2}$$

The "log $N$" factor, which is normalising the index, is sometimes omitted (Skea, 2010). The maximum value of $I_{SW}$ is 1 and is reached when all the shares are equals to $1/N$; the minimum value is 0 and is obtained when one of the shares is equal to 1 and the rest is 0.

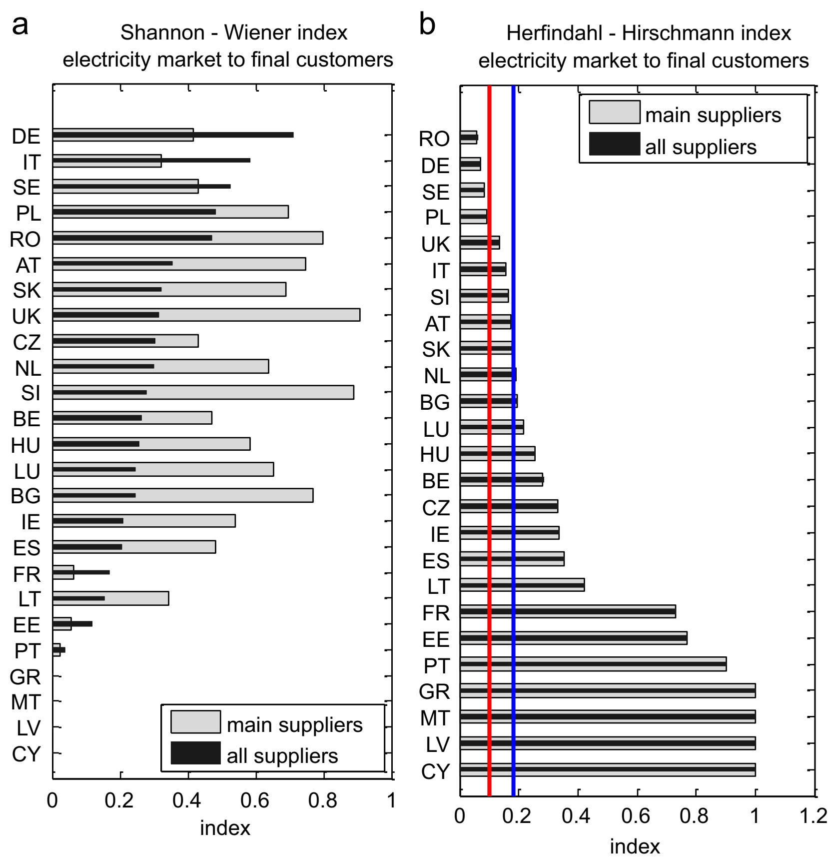


**Fig. 6.** Diversity indices for the electricity supply market (no data available for Denmark and Finland). (a) Shannon–Wiener index for all the suppliers normalised by the maximum number of suppliers in all the countries (940, Germany) and the same index for the main suppliers normalised by the maximum number of main suppliers in all the countries (8, Romania). (b) Herfindahl–Hirschmann index together with the cut-off values 0.1 and 0.18.

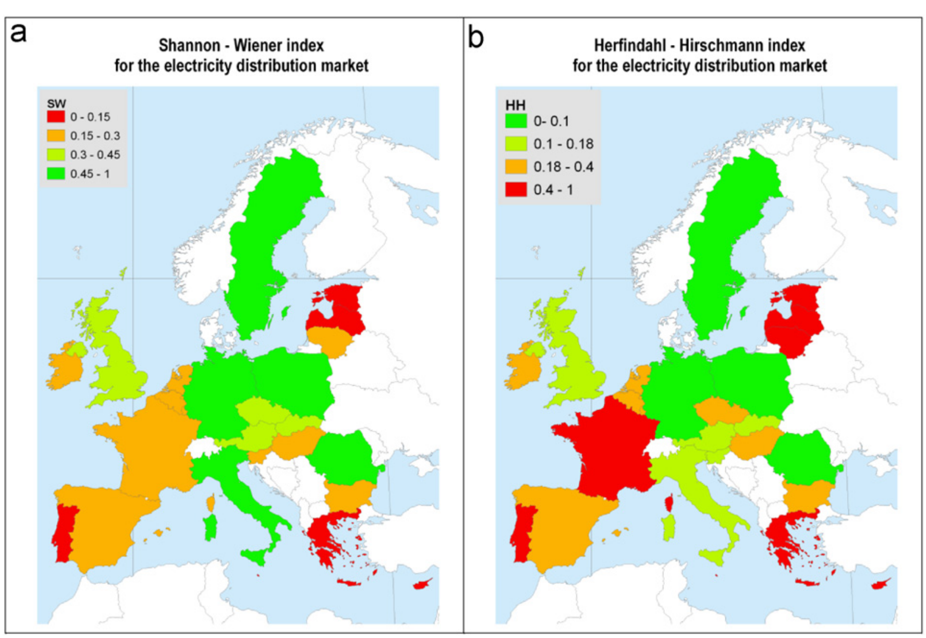


**Fig. 7.** Maps showing $I_{SW}$ and $I_{HH}$ diversity index classes for the analysed countries (all electricity suppliers are taken into account).

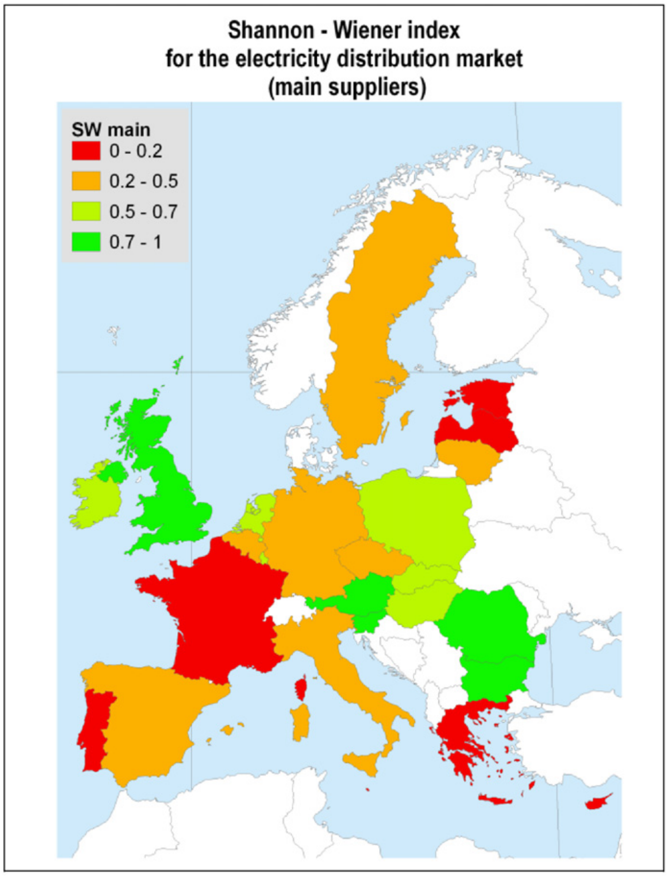


**Fig. 8.** Map showing the $I_{SW}$ index classes for EU countries (only main electricity suppliers are considered).

In general, one clear deficiency related to both indices must be highlighted: if a particular country hosts many electricity suppliers with quite equal shares but they are not covering the same geographical area, then the country would have a "good" diversity index, whilst at a given place in the country there could be only one electricity supplier.

Fig. 6 shows the resulting values obtained for the two diversity indices for EU-27 (excluding Denmark and Finland), concerning suppliers. Both $I_{SW}$ and $I_{HH}$ were evaluated taking into account (a) all electricity suppliers and (b) only the main suppliers. For the three countries, for which only the number of main suppliers and their cumulative market shares have been made available (The Netherlands, Germany, and Bulgaria), equal market shares between the main suppliers have been assumed, leading to an overestimation of their corresponding indices. In the $I_{HH}$ plot, the 0.1 and 0.18 cut-off lines are included to indicate the threshold values. The $I_{SW}$ parameter is found to be sensitive to the considered population (all suppliers or only main suppliers), which is not the case for $I_{HH}$. Nevertheless, both indices show the same qualitative trends, confirming that $I_{SW}$ and $I_{HH}$ are consistent parameters.

In order to show the same information in a geographic way (i.e. on EU maps), the $I_{SW}$ and $I_{HH}$ data have been divided into classes. For the $I_{HH}$ index the threshold values 0.1 and 0.18 employed in literature to distinguish between competitive and concentrated markets have been used as class breaks, together with a natural class break (0.4). For the $I_{SW}$ index the natural class breaks 0.15, 0.3, and 0.4 have been used. Fig. 7 provides the maps for the diversity indices based on all electricity suppliers.

In the case when only the main electricity suppliers are considered, the map for the $I_{HH}$ index remains the same as the one obtained for all the suppliers. The $I_{SW}$ map, however, changes significantly, in line with the stated observations about the $I_{SW}$ sensitivity. The adapted map is presented in Fig. 8. In this figure, the intervals for determining the classes have been chosen differently

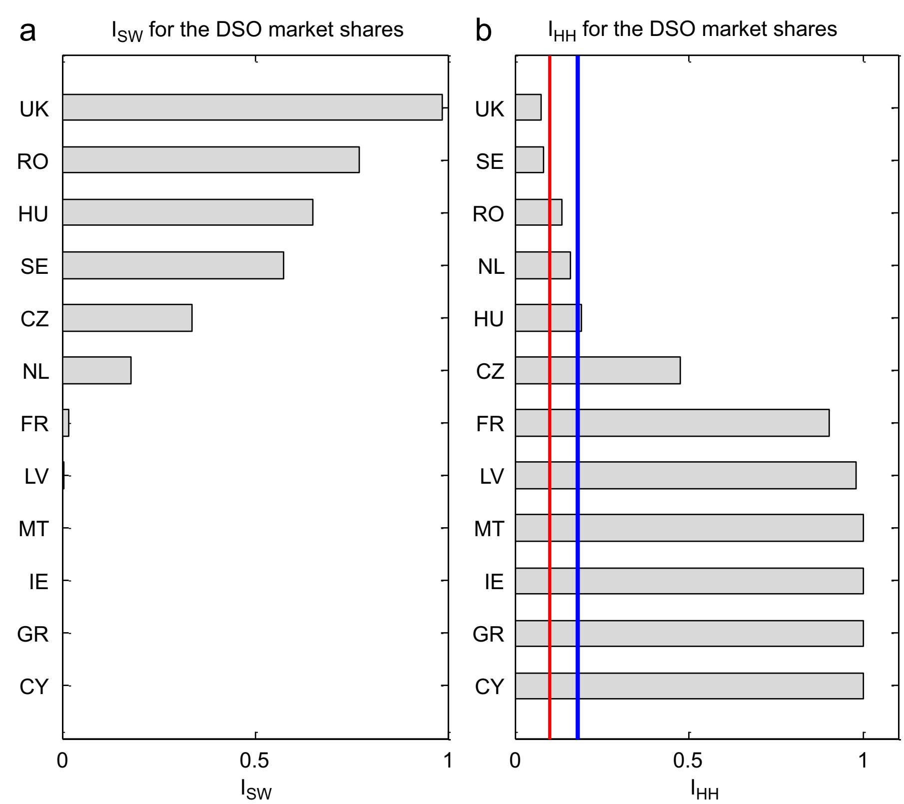


**Fig. 9.** Diversity indices for some EU-27 MS distribution markets.

than on the map considering all suppliers, in order to respect the natural groups formed by the index values.

The groups formed for the 2 $I_{SW}$ studies are quite different. Thus, in the leading group, only Romania remains in the two studies. Observing the comparison between the "all suppliers" with the "main suppliers" results, Italy and Germany change from the leading group to the third one. On the other hand, Bulgaria and Slovenia move in the opposite direction, from the third to the first group.

However, the supply market is not the distribution market. For this reason, an analysis has been made to compare data on the

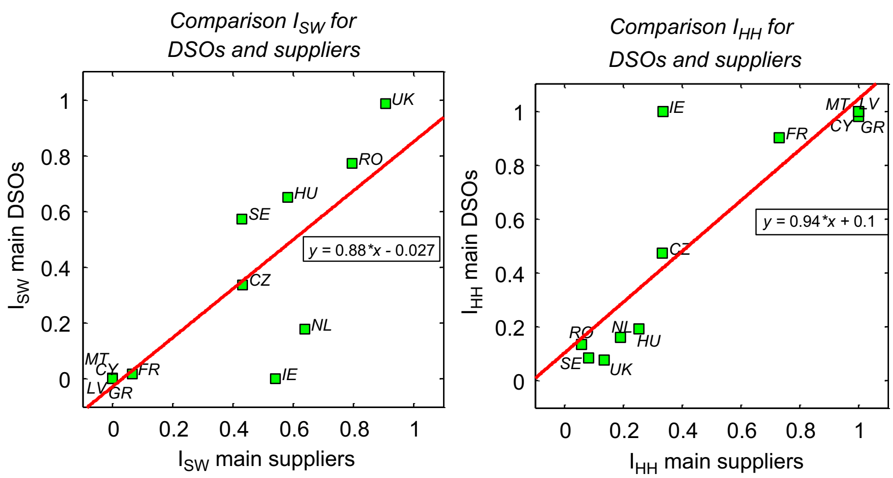


**Fig. 10.** Diversity indices comparison between supply and distribution electricity markets.

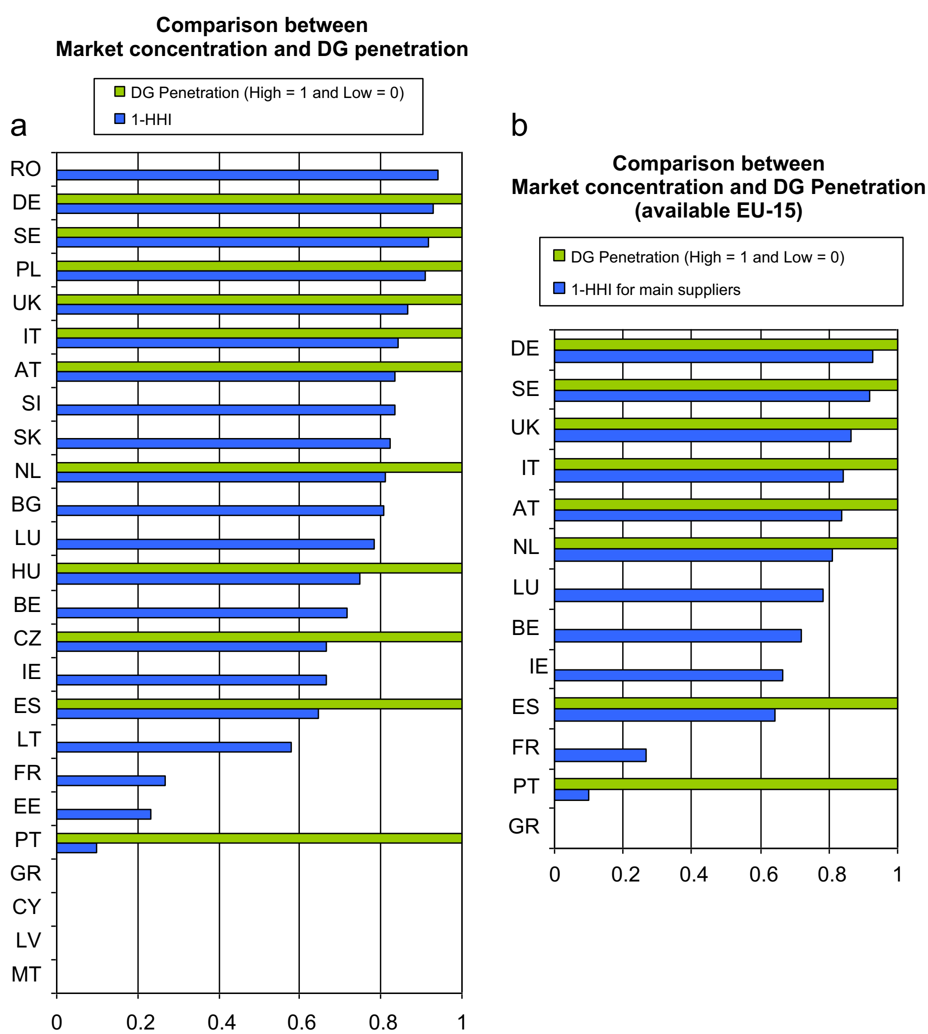


**Fig. 11.** The level of market diversity computed by $1-I_{HH}$, concerning main suppliers and comparison with DG penetration for the EU-27 and EU-15 (except from Denmark and Finland).

market share of DSOs received from some national regulators. It should be noted that Finland could not be included due to the unavailability of data. In Fig. 9 the calculated values of both econometric indices are represented for the available countries. The comparison of the results shows again coherency between both indices.

In Fig. 10 the values of the indices, comparing both $I_{SW}$ and $I_{HH}$ for main players of supply and distribution are displayed. The relation between the supply and distribution is linear for both indices, with quite high values of the (linear) correlation coefficient. Thus, it is found that the correlation coefficient between supply and distribution is equal to 0.82 for $I_{SW}$ and to 0.89 for $I_{HH}$. It should be emphasised however that, in the Irish case, there is a regulated market at distribution level with only one DSO and more suppliers at retail level (ERGEG, 2008). Excluding Ireland from the calculation would lead to an even better linear correlation between distribution and supply (0.91 for $I_{SW}$ and 0.98 for $I_{HH}$).

Taking into account this linear relationship, it is then assumed that the presented indices on the supply are a good approximation for the distribution ones and, therefore, for the present level of concentration of the distribution markets.

## 5. Comparative analysis between the concentration level of the markets and the penetration of DG

Considering the supply markets as proxies for the distribution markets, at least for the time being (2008) in Europe, it is possible to even extend this approach, comparing the level of concentration of EU supply markets (measured by $I_{HH}$), or reversely the level of market diversity (computed by $1-I_{HH}$), with the penetration of DG. From Fig. 11(a), one can state that as the diversity level of the market increases, so does the number of countries with a high deployment of dispersed generation, and vice-versa. It is possible to observe that, on one hand, among the 7 more diversified markets, 6 present a high level of DG capacity penetration. On the other hand, among the 8 less diversified markets, only one presents a high level of DG deployment.

This correspondence is even more visible when considering only the EU-15 Member States. From Fig. 11(b), it is possible to observe that there seems to exist a closer relation between the two levels mentioned, as the countries with the highest level of diversity display a high level of DG deployment, being the contrary also generally true. The exceptions to this situation are the two Iberian countries, which, although display comparably concentrated markets, present some of the highest levels of penetration of DG of the EU-15.

## 6. Conclusions

In this article, after an overview of the EU regulatory status quo relevant for impacting on distribution and DG developments, we focus on the analysis of the unbundling process in the European Union. Collected data on DSOs and DG penetration in the EU Member States have been presented and compared in light of the vertical and horizontal unbundling processes ongoing at distribution level throughout Europe. It has been observed that in some countries a dominant DSO controls the entire distribution grid, whereas, in other cases, there are numerous DSOs which run their networks on a regional or municipal basis. Those differences are due to historical, geographical, socio-political, and economical reasons. However, in countries having a large number of DSOs, there is in general also a limited amount of DSOs operating large part of the network.

Considering the effects of the amount of DSOs on DG penetration, a reduction of the number of these companies due to mergers, especially in countries with hundreds of DSOs, can be an opportunity to simplify the picture and rationalise the distribution sector, allowing then a potential DG penetration increase. On the other hand, a very limited number of DSOs may lead to the former vertically integrated environment situation, where DG options may be hindered or constrained.

To deepen the investigation related to the impact of horizontal unbundling on DG penetration, econometric indices dedicated to measure market concentration have been used. These are the Herfindahl–Hirschmann ($I_{HH}$) and the Shannon–Wiener ($I_{SW}$) indices; their utilisation has allowed an assessment of the horizontal unbundling level in most of the EU MS on the respective electricity supply market. Although the $I_{HH}$ use is more expanded, it has been possible to compare the results with the $I_{SW}$ considering both the whole sector (all suppliers) and only the main suppliers. Having available data concerning the distribution market on some EU MS it has been possible to compare the obtained values for those indices, and observe that, generally, there is a linear correlation between supply indices and market indices. Extending this result, it can be assumed that the levels of distribution market concentration in the EU MS are of the same order of magnitude of the ones of supply. This can be explained by the fact that, apart from a few exceptions among the EU MS, the two sectors (retail supply and distribution) have been less concerned by vertical unbundling over the latest years, differently from generation and transmission.

Moreover, it has been possible to detect that the EU MS showing less concentrated markets generally have a higher deployment of DG, and that, on the other hand, EU MS having more concentrated markets, apart from few particular cases, present a lower level of DG penetration.

In order to favour the DG deployment, one measure that clearly emerges from the presented results is then related to fostering the market diversity of distribution and supply sectors in those EU MS where DG penetration is still limited. Naturally, the different local situations need to be taken into due account; in general, it would be desirable to achieve a level of distribution market diversity, measured by $1-I_{HH}$, comprised between 0.8 and 0.9.

This would entail the further opening of the distribution market, by the introduction of additional regulatory reforms and/or increasing incentives in some EU MS, and/or by promoting self-regulation across the EU.

The present analysis is based on the current EU MS situation, in which the approximation of the market diversity of distribution by the one of supply can be generally assumed. This can be considered to be valid in a short term horizon. However, in a mid-long term horizon, in view of further vertical unbundling, this assumption may not be hold any more: further analysis will have then to be carried out to directly assess and quantify the market diversity of the specific distribution sector throughout Europe.

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“The views expressed are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission”.

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