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D 7.1 “Long Term Perspectives for DG in Europe”

Summary Report

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Abstract:

This paper gives an overview of the issues at stake with respect to development of distributed power generation for the electricity system of Europe. It discusses the barriers and provides the framework for country and regional case studies. In whole the objective of this paper is, to form a picture of where DG in Europe can and shall go within the next decades.

Executive Summary Report

TASK 7.0: LONG TERM PERSPECTIVES FOR DISTRIBUTED GENERATION IN EUROPE

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1. Distributed Generation – Why?

Some 5 years ago the expression distributed generation (DG) was known only among some specialists of technology development. Today DG is one of the top priority topics in the power industry as a whole. What are the causes of this development?

As can be seen in **figure 1** (which shows the trend in average installed capacity of power plant for the US market) the average size of newly installed power plants throughout the last century steadily increased from 1920 to about 1980 and then sharply decreased, indicating that there is a strong trend towards a more dispersed power generation system, containing more, smaller plants. The average size of new large plants (> 25 MW) has fallen from 290 MW in the early 1980s to less than 100 MW in the early 1990s. The average size of all newly installed power plants in the US has fallen from 150 MW to 29 MW in the period from 1975 to 1994 /1/.

In order to explain this development we want to introduce the expression “economy of scale”. This expression explains that a larger system, on average, is less costly than a smaller system. With respect to power generation in the period between 1920 and 1980 economy of scale meant, that larger power plants had a higher efficiency than smaller power plants. At that time, the energy requirement for own consumption of the plant was about the same for a small plant as for a big plant. Thus a big plant had a relatively lower own consumption. As a consequence, plants were built as large as feasible. During that time most power plants were built on the order or the backing of governmental authorities. Therefore the additional financial risk of bigger plants did not play a significant role.

Since 1980 a number of small power plant technologies have been introduced, which show an efficiency only a few percentage points lower than big power plants. These comprise 2 MW fuel engines and aeroderivative gas turbines. New small scale technologies with high efficiency are under development, including biomass combined heat and power (CHP), micro gas turbines (μGT), fuel cells, wind power plants and to some extend photovoltaic cells (PV). The responsibility for power expansion in many countries has shifted from governmental institutions to private investors. Regulated, predefined electricity tariffs have been replaced by highly volatile electricity market prices. Public resistance to large power plant projects can be seen everywhere. In total the economic risk for constructing a big power plant has become much higher than for a small power plant. More recently, “economy of scale” in the power sector has meant build many small standardized plants, with short lead times, instead of one big plant.

An additional argument for a system of dispersed power generation units can be derived from the current prices of the liberalized European electricity markets. While the market price for electricity from power plants, induced by fierce competition among electricity producers, fell to about 20 to 25 €/MWh, the costs for delivering the electricity to the final household stayed with 50 to 70 €/MWh. It is estimated that, by increased environmental and reliability requirements and by increased personnel costs, the costs of transmission and distribution increased by 35 % in real terms during the period 1955 – 2000 /3/. To break this trend, a focus for the further development of electricity systems will be needed on the reduction of transmission and distribution costs.

Currently it is discussed among experts, to what extend DG can contribute to the reduction of transmission and distribution (T&D) costs. It is, however, without doubt, that on islands, for remote areas, and for heavily populated areas (with restrictions on grid expansion) DG is an opportunity for providing a reliable electricity supply system.

In the present environment of the European liberalized electricity market, corporate business strategies may give a further argument for the popularity of the DG topic. Initially most power producers reacted to market liberalization by reducing costs, concentrating the activities in the core business and by going together with strong partners. According to economic theory this is a good strategy for surviving a difficult period. It is, however, not a long term strategy for making profits. In order to gain profits, new, innovative business areas need to be developed. DG provides such an opportunity, especially when taking into account, that DG can lead to customer loyalty.

DG provides a strong business opportunity not only for power utilities and energy service companies, but also companies, which develop and construct DG technologies can develop a business, for the European and the world wide market.

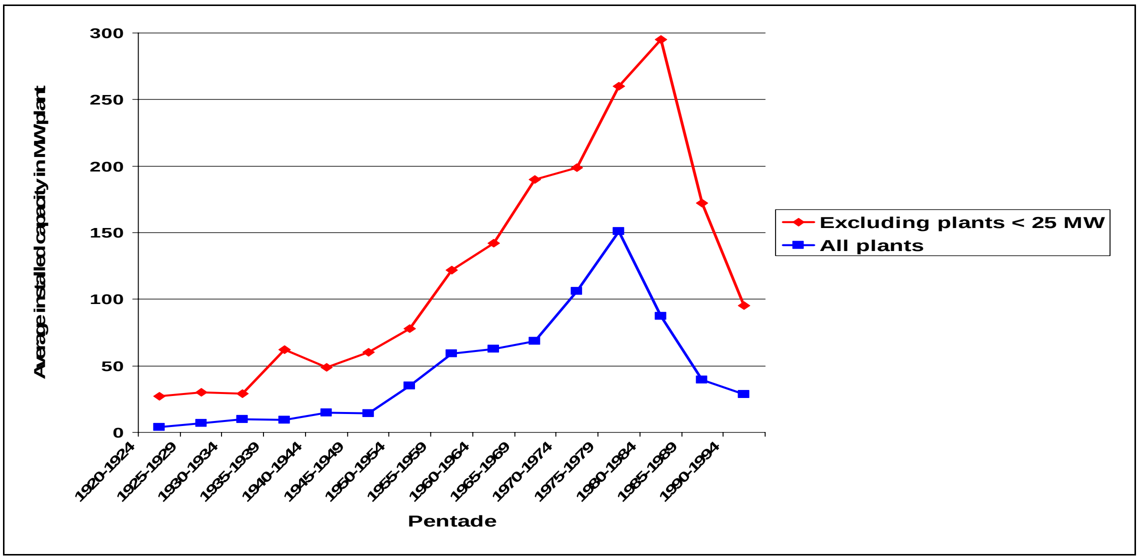
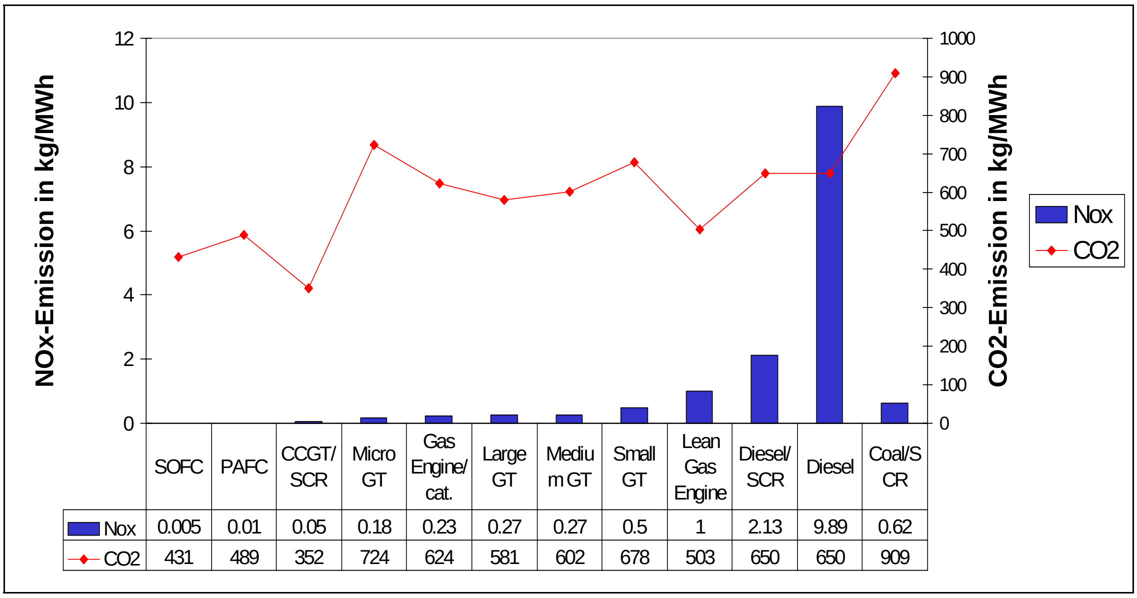


Figure 1: Average size of US power plant additions /1/

Most DG technologies result in low emissions of harmful compounds (see **figure 2**). They can contribute to the reduction of green house gas emissions. As such DG technologies are useful instruments for climate protection. Highly efficient and often renewable, DG technologies contribute to a reduction of import dependence, an increase of the security of supply and to a positive trade balance. As a consequence, in an EU directive on renewables, targets were set for the member countries to increase their share of renewables on total electricity supply /20/. In order to achieve these targets, financial support schemes have been introduced, mostly on the basis of feed in tariffs. They reduce the market risks and are aimed at kick-starting the "new" renewables market penetration. The feed in tariff schemes in many countries provide higher tariffs for smaller units, as additional push for small enterprises and rural areas.

From the consumer's point of view DG provides the possibility of optimizing power use and power generation in an integrated way, of increasing the security of supply and for having an alternative to the volatility of electricity market prices. In some industrial and service sectors energy not served costs are very high (see table 2-1), so that a high reliability standard for electricity supply is requested.



	SOFC	PAFC	CCGT/ SCR	Micro GT	Gas Engine/ cat.	Large GT	Medium GT	Small GT	Lean Gas Engine	Diesel/ SCR	Diesel	Coal/SCR
Nox	0.005	0.01	0.05	0.18	0.23	0.27	0.27	0.5	1	2.13	9.89	0.62
CO2	431	489	352	724	624	581	602	678	503	650	650	909

Figure 2: NOx and CO_2 Emissions of DG-Technologies as compared to a Coal Power Plant
(SOFC = Solid Oxide Fuel Cell, PAFC = Phosphoric Acid Fuel Cell, CCGT = Combined Cycle Gas Turbine, Micro GT = Micro Gas turbine, GT = Gas Turbine, SCR = Selective Catalytic Reduction (of NO_x), cat. = with catalyst)

2. DG Power Generation Technologies

DG technologies can be separated into those based on fossil fuels and into renewable technologies.

Fossil fuel based technologies include /2/:
- different fuel cell types,
- internal combustion engines (gas and Diesel engines),
- Stirling engines, and
- mini- and micro-turbines.

Table 1 gives an overview over these technologies.

Table 1 : Economic comparison of technologies for decentral power generation /3/

	Fuel Cell	**Liquid Fuel Engine**	**Gas Engine**	**Gas Turbine**	**Micro Gas Turbine**
Market introduction	1996-2010	Available	Available	Available	1999-2000
Capacity range (kW)	50-1,000+	20-18,000+	50-5,000+	1,000+	30-200
Electric efficiency (referred to upper heating value)	35-54%	36-43 %	28-42%	21-40%	25-30%
Cost of generation unit ($/kW)	1,500-3,000	125-300	250-600	300-600	350-750
Total investment costs without heat extraction ($/kW)	1,900-3,500	350-500	600-1,000	650-900	600-1,100
Additional costs for heat extraction ($/kW)	Included	NA	75-150	100-200	75-350
Operation & maintenance costs ($/kWh)	0.005-0.010	0.005-0.010	0.007-0.015	0.003-0.008	0.005-0.0010
Life span in operation hours	25,000-80,000	10,000-20,000	80,000	80,000	80,000

NA = not applicable, for fuel cell: development target values

The world market for fossil fuel based DG additions is currently 35 GW/annum, with growth rates expected to increase in the future. According to a power plant manufacturer: “With deregulation in the power market, global efforts to cut pollution and government initiatives to boost electricity production from alternative energy, this market is poised for tremendous growth - especially in Europe” /4/.

The US. Department of Energy sees the opportunities for DG in the following size ranges:
- Small residential and commercial, less than 500 kW (small fuel cells, gas engines and micro turbines);
- Medium commercial and industrial, 0.5 to 5 MW (medium fuel cells, gas engines);
- Large industrial, 5 to 50 MW (large fuel cells and aeroderivative gas turbines).

The world electrical capacity of DG sources will grow to 300 GW by 2011 from today 20 GW, according to a new report from Allied Business Intelligence. Reciprocating engines and small gas turbines should dominate the market until about 2005, from when fuel cells are expected to grow in prominence /5/.

Most renewable generation technologies are also distributed generation technologies. These comprise:

- Wind power plants
- Biomass combined heat and power plants
- Biogas
- Small hydro power plants
- Photovoltaics
- And other more specialised developments like sea current power.

Table 2 gives an IEA estimation of the future world wide growth of renewables for power generation.

Table 2: Expected World Power Production of Renewables /6/

	1995		2010		2020	
	Capacity (GW)	Electricity (TWh)	Capacity (GW)	Electricity (TWh)	Capacity (GW)	Electricity (TWh)
Hydro		623		1035		1241
Geothermal	6.9	39.4	14.9	90.9	19.6	121
Wind	4.4	7.4	25.9	57	47.4	106
Solar/Tide/Other	1.2	2.8	2.8	5.7	6.3	11.9
Waste	24.9	127.9	32.2	164.8	38.3	194.4

But the development of Renewable Energy Sources (RES) has accelerated and already the actual values for 2004 are ahead of the estimates for some sectors. The actual worldwide capacity for the different sectors of RES is shown in **table 3**.

Table 3: Existing World Capacity for RES Power Production at the end of 2004 in GW /23/

Small hydro	61
Geothermal	8.9
Wind	48
Biomass	39
Solar PV	4
Solar thermal	0.4
Ocean power	0.3
TOTAL	**161.6**

Table 4 summarizes the current and future expected investment cost, the operation and maintenance (O&M) costs and the power generation costs of the different DG technologies. Also shown are the costs of a natural gas fired combined cycle (CC) plant as a reference.

Table 4: Economics of DG Power Generation Technology

	Investment Costs in €/kW						**O&M Costs in €/MWh**	**Power generation costs in €/MWh**	
	Year 2000			**2005**	**2010**	**2020**	**Year 2000**	**Year 2000**	**Year 2010**
	Min.	**Max.**	**Average**						
Fuel Cells	1300	19308	3000	2000	1500	800	5 to 10	160 to 220	
PAFC	3000	4500	3000	2000	1500	800			65
MCFC				2600	1500	1200			

Table 4: Economics of DG Power Generation Technology (continued)

	Investment Costs in €/kW						**O&M Costs in €/MWh**	**Power generation costs in €/MWh**	
	Year 2000			**2005**	**2010**	**2020**	**Year 2000**	**Year 2000**	**Year 2010**
	Min.	**Max.**	**Average**						
SOFC			10000	3000	1500	800			
Diesel Engine	335	1100	450				5 to 10		
Gas Engines	410	1842	750				7 to 15		
Stirling Engines			2700					90	
Micro Gas turbine	600	2250	1050				5 to 10	60 to 160	
Mini Gas Turbine	450						3 to 8		
Gas Turbine	300	900	650				3 to 8	43 to 49	
Wind	932	2300	1300	1200	1100	900	14 to 20	42 to 316	40 to 50
Biomass	1198	4000	1600	1500	1400	1200		78 to 171	
Solar PV	1198	8256	4660	4300	4000	3400	1 to 4	300 to 600	
Hydro	799	8300	3000				1.2	50 to 125	
Gas CC (as reference)	533	1531	650					30 to 60	

3. DG System Integration

Distributed generation systems are proposed for islanded operation and as grid connected systems. In both cases the task to meet the intermittent demand of single consumers and the frequently intermittent nature of DG technologies are a major challenge. Grid connected systems must also be compatible with the central power delivery systems in operation today. This chapter discusses the difficulties arising with a wide spread usage of DG and strategies to overcome the barriers.

Figure 3, on the left side shows the electricity demand of a single household. There are very short, and relatively high peaks, and a base load of around 10 % of the peak load. Stoves, TV-sets and light bulbs are switched on and off, frequently. Only heating and cooling devices show some more continuous operation pattern. To follow such a demand by any power generation technology is difficult and would require electricity generation capacities, which are in full use only for a couple of minutes a day, while running at 10 % of capacity most of the time.

One possibility to make the task easier is to meet the demand of some tens of households. The right side of **figure 3** shows, that the demand of 20 households together, already is much smoother.

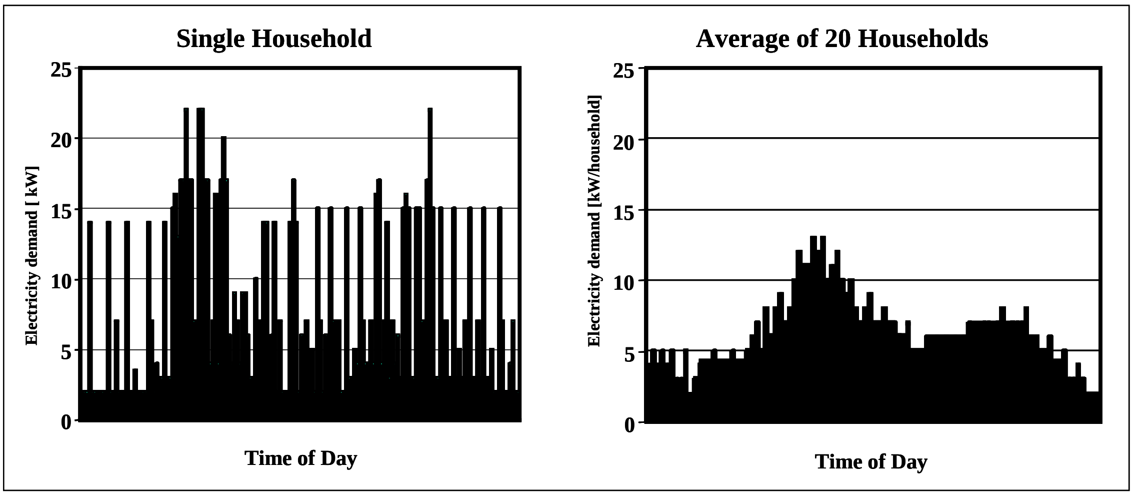


Figure 3: Electricity demand in single household and in a group of 20 households

If, however, the electricity is supplied by an intermittent resource like a wind power plant, PV, run-of-river hydro power or a heat driven combined heat and power plant (e.g. biomass, fuel cell, gas turbine) the situation once again becomes complex. In order to avoid huge over capacities, and in order to be able to utilize the electricity which is generated in excess of demand, an electricity storage system is usually needed (see **figure 4**). But these storage systems are costly and reduce the electricity yield. Such storage systems are discussed later on.

Another option to balance supply and demand of DG is grid connection. The grid, in principle could take up the excess energy and cover the peaks. But this solution also has its limits:

- As we will discuss below, the current systems are not designed for a major feed of electricity into the low and medium voltage levels.
- It is unclear, how much additional intermittent electricity central systems can accept, given the system will already have to deal with the intermittent nature of heat driven CHP or run-of-river hydro power plant, or plants which are highly inflexible such as nuclear power or other stiff base load power plants.

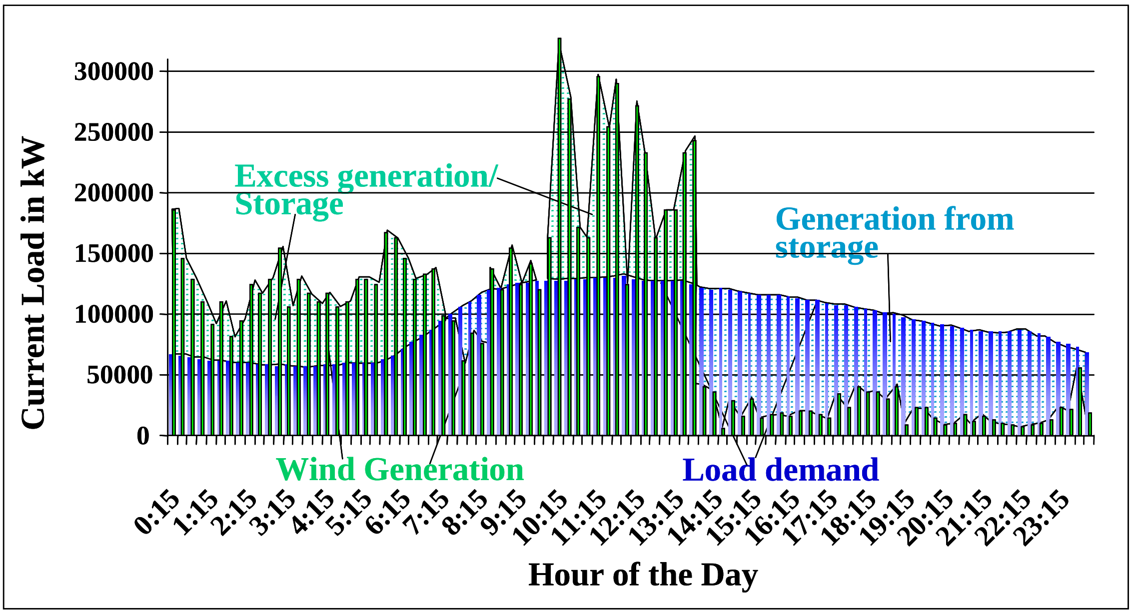


Figure 4: Balancing supply of an intermittent source with demand

A further solution is the construction of mini grids, which have a weak connection to the central electricity supply system, and run almost self-sufficient by a mix of different complementary DG technologies, by some storage capacity and by a high efficient autoregulation system.

3.1 Energy Storage Systems

Electricity is a form of energy which has to be produced in the very instant of its use. In order to be able to follow the fluctuating course of demand, a system of power plants which operate at part load, thus providing spinning reserve, of power plants which can be turned on in half an hour (gas and hydro turbines), of hydro power plants with day and seasonal storage is established. Many renewable resources — wind and solar power, for example — are intermittent resources, i.e., their actual current power generation follows a stochastic pattern and cannot be directly controlled. Storing energy from the renewable source allows supply to more closely match demand. For example, a storage system attached to a wind turbine could store energy captured around the clock — whenever the wind blows — and then dispatch that energy into the higher priced midday market. And energy storage allows solar electricity to be used at night. For dispersed generation, when the mutual support of a large power generation system is not available in the same extent as with central generation, in situ energy and power storage technologies become increasing in importance.

Energy storage devices can be grouped according to the form of energy used for storage:

- Electrochemical energy storage- batteries, fuel cell/hydrogen cycle, regenerative fuel cells.
- Mechanical energy storage- flywheels, compressed air, hydroelectric pumped storage.
- Electrical – super-capacitors (ultra-capacitors) and supra conductors - electricity is stored in form of field energy

The applicability of various energy storage technologies to different storage requirements is listed in **table 5**.

Table 5: Fields of application for different storage technologies

Storage capacity	Technology	Status
Very short term (less than 1 minute)	NiCd Battery Lead- Acid Battery Flywheel	Commercial Commercial Near commercial
Short term (5-60 minutes)	NiCd Battery Lead- Acid Battery Flywheel	Commercial Commercial Near commercial
Medium term (2-12 hours)	NiCdBattery Lead- Acid Battery Flywheel	Commercial Commercial Experimental
Long term (1-3 days)	Lead- Acid Battery Pumped Hydro Hydrogen	Commercial Commercial Experimental

Figure 5 shows the utilization factor (that is the percent of energy which can be extracted from the storage facility per unit of energy put into the storage facility) over the storage time of the most important power sector storage facilities.

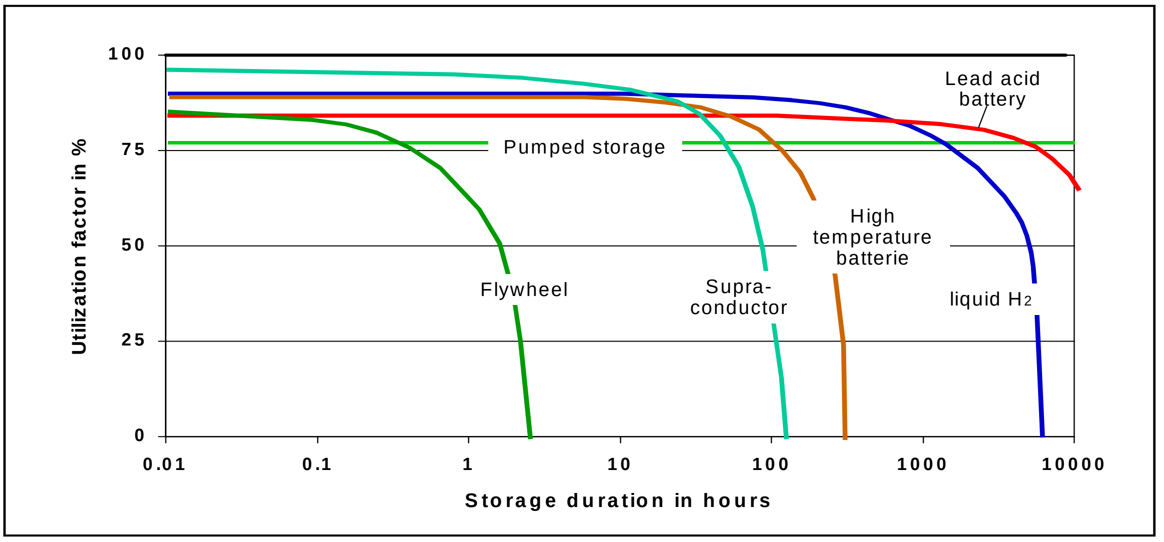


Figure 5: Storage utilization factor over storage duration

3.2 DG Grid Connection and Mini-Grids

As shown above DG faces three major technical obstacles:

- Current grids are not designed in a way that enables significant amounts of electricity to feed into the distribution grid (high losses and voltage peaks may occur)
- The European economy is used to a reliability of the grid of above 99 %. A single DG unit shows an availability of 92 to 93 % (98.36 % at maximum /2/) and thus alone cannot meet with the current supply standards.
- It is difficult and expensive to meet the intermittent demand of a single consumer, e.g. a single household, by a single electricity source, which, to make the problem more complex, might also be intermittent in nature.

The installation of so-called mini grids might bring a solution to these problems (see **figure 6**).

An essential improvement of the power quality can be achieved when the number of DG-units connected to the same part of the grid is increased. The fluctuations in the power output of the single plants simply cancel out. In /7/ a statistical rule is given, which says that by increasing the number n of generation units any effect develops according to (1/√n). E.g. when 100 generation units are connected to the same part of the grid the effect is only 1/10 of the effect of a single unit. As a consequence there seems to be a tendency towards the installation of mini or micro grids, which are optimized and harmonized as subgrids of the existing central grids. These micro grids combine different distributed generation technologies, e.g. intermittent PV, biomass-CHP and fuel cells, with a storage device (a battery or a hydrogen tank) so that the supply can be balanced with the demand and only for exceptional cases, back-up power from the main grid is needed (see **figure 7**).

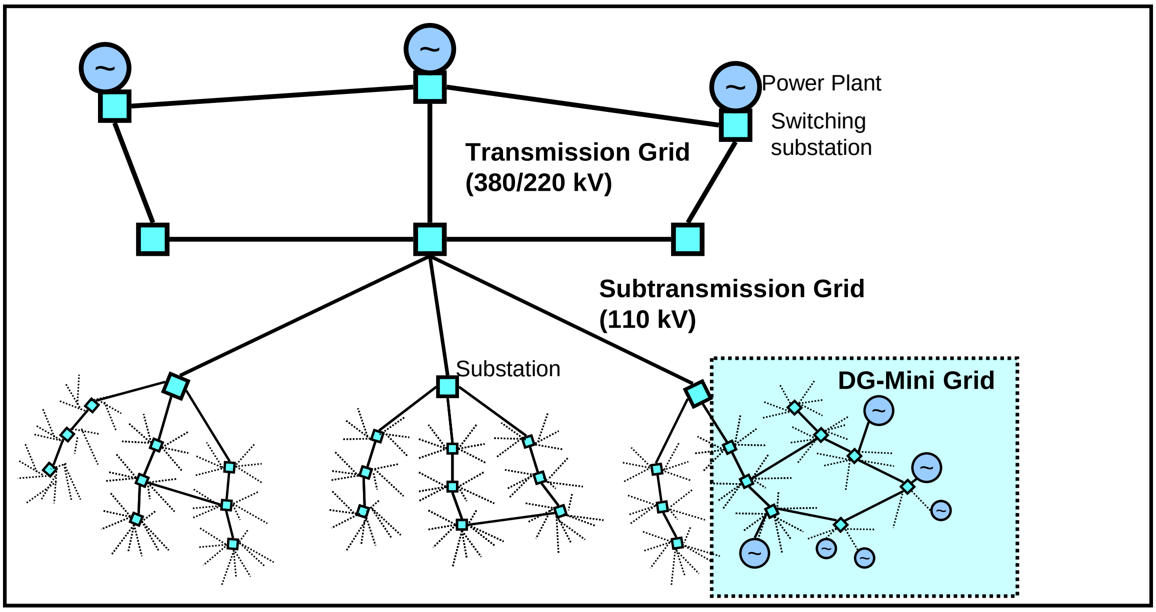


Figure 6: A minigrid as part of a conventional electricity supply system for DG

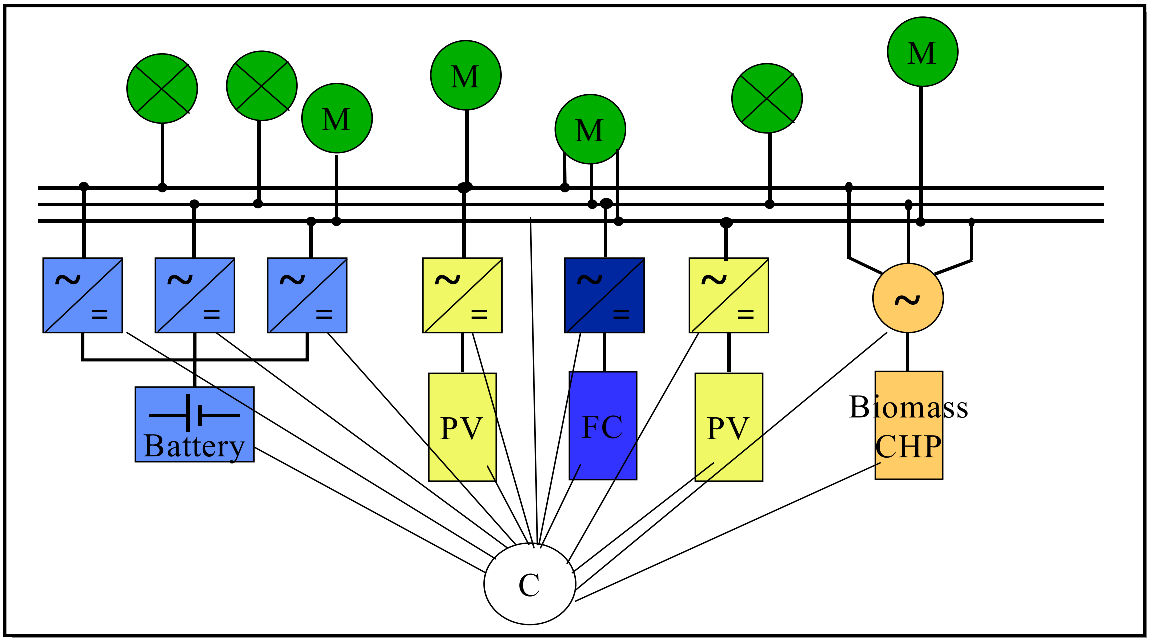


Figure 7: Scheme of a decentralized micro grid (inspired by /8/)

Crucial for the development of such micro grids is the quality of the power inverters and power conditioners which convert the different kinds of power (with different voltage level, DC or possibly AC with different frequencies) to the required kind of power in a technically and economically efficient way. Many projects currently are underway to develop such an inverter, with more than 90 % efficiency even at 10 % part load /9/ and a minimum of harmonics /10/. Also the costs of the inverter system, which currently cover about 50 % of the PV system costs, for example, are aimed at being considerably reduced. To halve the costs within the next decade seems to be realistic.

The second core component of a mini grid is the control and optimization system. All parts of this system are available today, but must be put together and tested for this special application.

Problems related to the technologies involved have also to be considered, for instance :

- Model calculations have shown that a critical situation in a low voltage grid, which is connected to a medium voltage grid, may occur, when the electricity generation from PV cells exceed the local demand. In a report by ELSAM it was recommended to review the procedures for adjusting the MV/LV transformer tap changer position in order to extend the share of PV-electricity for covering the local demand /11/.
- Wind power has to be looked at somewhat differently, as in addition to single wind turbines as part of micro grids, wind power plants will likely be erected as part of small to big wind farms. Dependent upon the size of the farm, power will be fed into the grid on the medium or even the high voltage level. Here an AC/DC/AC inverter is developed which decouples the frequency of the wind turbine from the frequency of the grid and thus allows an optimum adaptation of the power generation to the wind speed /12/,/13/.

Open questions up to now are:

- How can the conventional central grid be optimized in parallel to the optimization of the micro grids?
- Who pays for the back-up services of the central grid, and how much? How are these back-up services measured?
- Can third party traders also use the micro grid, or is the micro grid operator once again a monopoly to be regulated? (It is expected that an investor will only be interested in establishing local grids and decentralized generation, when he/she gets a long term supply agreement with the final users.)
- Can alternatives be developed to the present supply of short circuit power by rotating synchronous generators connected to engines or turbines?
- How well can the demand and supply of the micro grid from/to the central grid be predicted in order to minimize reserve and frequency control costs for the system operator?
- Can the islanding protection costs, a main barrier for DG-development, be reduced?

For future large scale introduction of distributed generation systems the schemes for services like stability control, dispatch and maintenance of the single units, reactive power and back-up reserves are yet to be developed. Initial concepts are under discussion, e.g. the introduction of a high voltage direct current grid, which need to be tested and verified.

Interconnection requirements for large DG installations (~10 MW) are well understood because they are very similar to the interconnections required for central power stations. Interconnection requirements for smaller installations are more difficult because the utility must balance the desire for a safe interconnection with the desire to have a "quick and easy" interconnection design to get the DG running. Interconnection complexity generally increases with project size and is technology dependent. Several utilities have a policy of bypassing standard stages of their interconnection process, such as inspection of protection systems and witnessing of protection system testing.

Figure 8 shows a typical parallel interconnection configuration between DG, the loads it serves, and the electric power system.

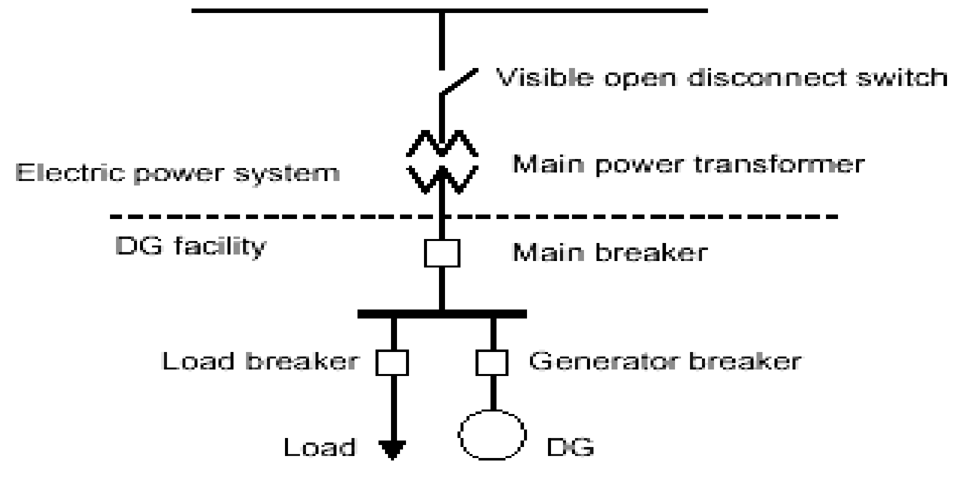


Figure 8: Typical parallel interconnection configuration /14/.

The protective functions typically used for DG require measurements of voltage, frequency and current. Voltage and frequency measurements can be used for fault detection, and identification of abnormal system conditions such as a de-energized utility distribution line. Current measurement is used to detect overloads and fault conditions within the generator and within the utility system.

Utilities develop interconnection technical requirements to maintain grid performance and minimize any negative operational impacts of DG. In addition, a properly designed interconnection is critical to ensuring safety to people and equipment. In particular during maintenance or an outage, a proper interconnection solution will prevent a DG unit from energizing a section of the distribution system where a lineman is working.

There is some difficulty in standardizing protective equipment, since the type of equipment needed to ensure safe interconnection depends on many factors, including:

- Generator type
- Size of generator
- System voltage
- Location in the distribution system
- Radial versus meshed distribution system

Some DG developers consider existing technical requirements to be unreasonable, and believe that they discourage customers from pursuing DG. The technical requirements for interconnections vary. Not all utilities have established well-defined technical requirements for inter-connection. Those that do have such requirements in place usually state the minimum requirements necessary, which are subject to then change with each interconnection.

In total, however, there seems to be no unbridgeable technical barrier against the large scale introduction of distributed generation.

4. The European Electricity System

The EU-15 gross domestic electricity consumption grew almost linearly over the last 2 decades in the European Union (see **figure 9**). The growth rate was about 1.7 %/annum. Demand forecasts made by EU experts and by IEA experts see a future electricity demand growth of 1 to 1.5 %/year. The contribution of the different EU member states to the electricity demand growth varies greatly (see **figure 10**). While the gross domestic electricity consumption in Portugal is expected to increase by 500 % from 1973 to the year 2010, the consumption increase in the same period in the United Kingdom is only 50 %.

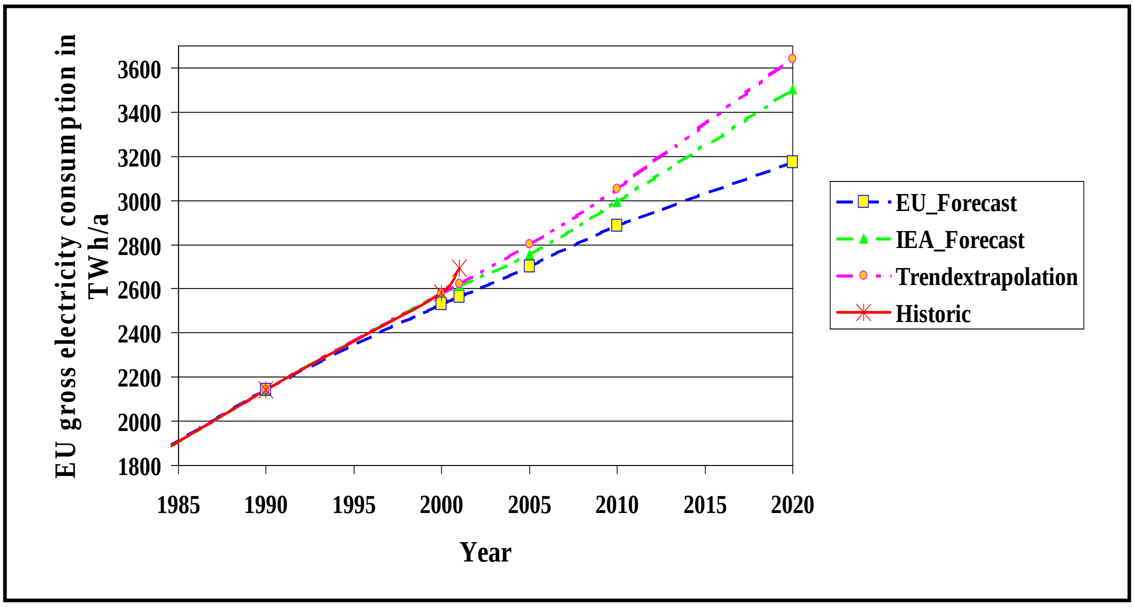


Figure 9: Historic and expected EU gross electricity consumption; forecasts from EU /15/ and IEA /16/ sources

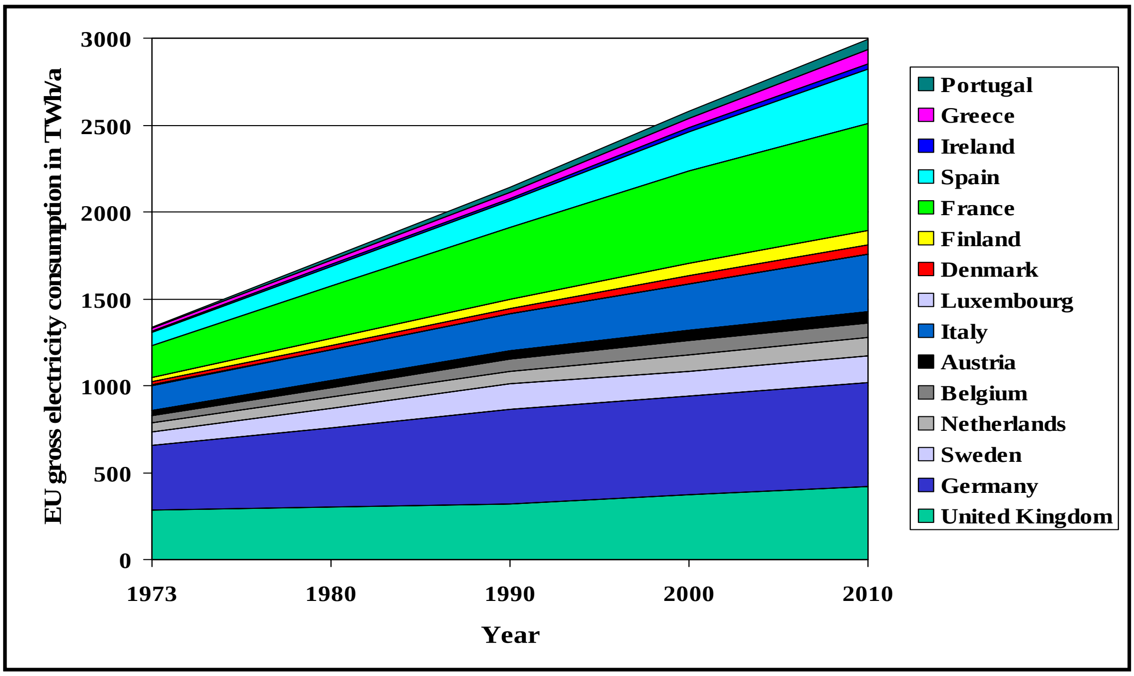


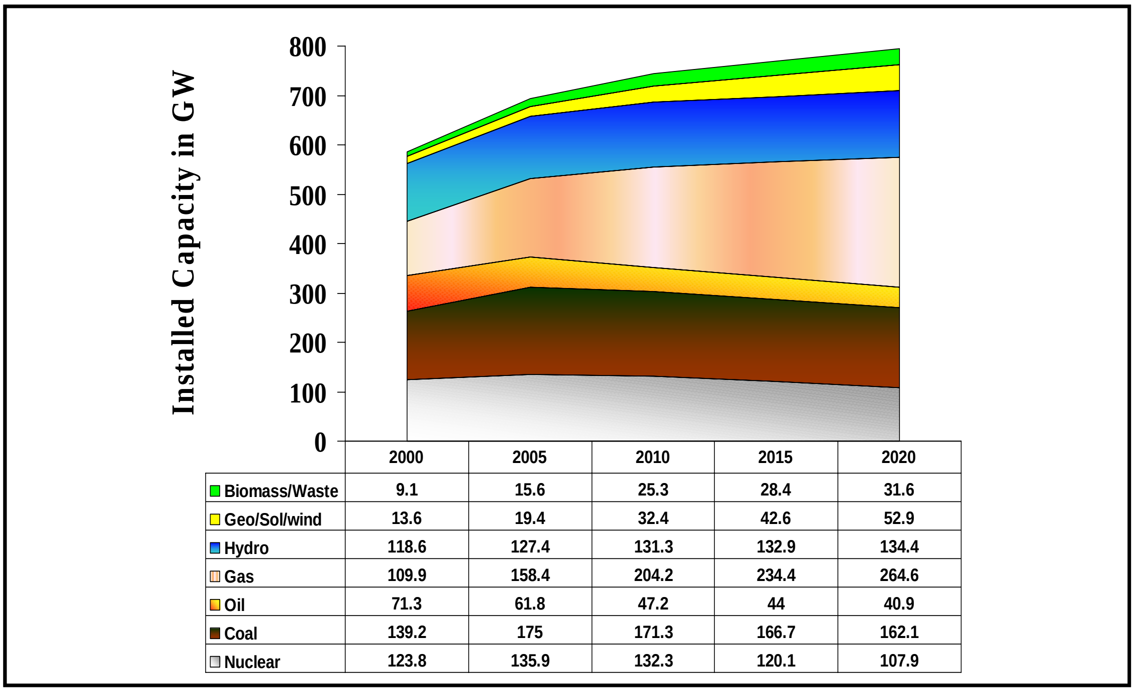
Figure 10: Growth of gross domestic electricity consumption in EU member states (ordered from state with highest growth rate (top) to state with lowest growth rate (bottom).

Table 6 gives an IEA forecast on the development of the installed power plant capacities for many European countries. In spite of the strong interconnection of the European country markets and in spite of the establishment of the internal EU-electricity market, the different member countries seem to go very different ways. While the United Kingdom plans to nearly double its generation capacity in the next five years, the France generation system stays at its present capacity. While some countries, like Ireland, seem to have high growth rates at the beginning and stagnation after 2010, other countries, like Austria, stay at the present level for the next ten years and invest in new capacities afterwards. Behind this picture, however, seems to lie one single pattern. All countries have to adapt their power industry to the liberalized markets. Some start with reducing their over-capacity of inflexible big plants, while others introduce new flexible natural gas fired power plants, for covering the peak load first. Thus the true development going on is adaptation to new requirements of regulation instead of the traditional power expansion. The picture looks very different for a country with high growth in electricity demand and the need for more capacity, for example Turkey. For Turkey, it is predicted that installed capacity of the power generation system needs to increase by more than 7 % every year. Ignoring the large planned capacity expansion in the UK in the next 5 years, the predicted average capacity increase of the EU power system is 0.7 %/annum over the next 20 years. This is below all expectations of electricity demand increase. And therefore the current reserve margins are expected to shrink continuously over the next 20 years.

Figure 11 shows the IEA forecast on the installed power generation capacity by fuel type for the EU-15-community. While nuclear, coal and hydro power are expected to stagnate at about the present level, fuel oil fired power plants will continuously reduce in capacity. The big winners are the renewables and, above all, the natural gas fired power plants. Thus the reference to measure every proposed DG project against should be a natural gas fired technology, that is combined cycle as reference for base load and intermittent projects, and large gas turbines for peaking and back-up plants.

Table 6: Electricity Generation Capacity 2000-2020 in GW

	Total installed capacity in GW				Growth in %/a		
	2000	2005	2010	2020	2000-2005	2005-2010	2010-2020
Austria	17.9	18.4	19.3	22.2	0.6	1.0	1.4
Belgium	15.7	13.7	14.2	16.6	-2.7	0.8	1.6
Denmark	12.7	11.5	11.4	12.4	-1.9	-0.2	0.9
Finland	16.2	17.0	19.4	19.1	1.0	2.6	-0.1
France	115.6	115.2	121.3	131.6	-0.1	1.0	0.8
Germany	118.4	126.7	126.4	125.4	1.4	-0.1	-0.1
Greece	11.0	13.9	16.6	20.4	4.9	3.6	2.1
Ireland	4.7	6.8	8.1	9.4	7.5	3.6	1.5
Italy	75.5	87.0	100.0	118.0	2.9	2.8	1.7
Luxembourg	1.2	1.6	1.6	1.7	5.0	0.8	0.3
Netherlands	21.1	23.5	26.0	29.0	2.2	2.0	1.1
Portugal	10.9	12.6	16.1	21.2	2.9	5.0	2.8
Spain	52.9	62.8	76.8	77.4	3.5	4.1	0.1
Sweden	32.8	31.6	31.5	31.8	-0.7	-0.1	0.1
United Kingdom	79.1	151.2	155.2	158.2	**13.8**	0.5	0.2
EU-15	**585.5**	**693.4**	**743.9**	**794.4**	**3.4**	**1.4**	**0.7**
Czech Republic	15.3	15.8	14.6	14.1	0.6	-1.5	-0.4
Hungary	8.3	7.8	8.1	9.2	-1.3	0.9	1.2
Iceland	1.4	1.5	1.5	1.5	1.7	0.0	0.3
Norway	28.6	28.7	29.1	29.7	0.1	0.3	0.2
Switzerland	17.3	17.7	17.8	17.4	0.5	0.0	-0.2
Turkey	27.3	40.1	58.7	116.2	**8.0**	**7.9**	**7.1**



	2000	2005	2010	2015	2020
🟩 Biomass/Waste	9.1	15.6	25.3	28.4	31.6
🟨 Geo/Sol/wind	13.6	19.4	32.4	42.6	52.9
🟦 Hydro	118.6	127.4	131.3	132.9	134.4
☐ Gas	109.9	158.4	204.2	234.4	264.6
🟧 Oil	71.3	61.8	47.2	44	40.9
🟫 Coal	139.2	175	171.3	166.7	162.1
⬜ Nuclear	123.8	135.9	132.3	120.1	107.9

Figure 11: Forecast of installed power plant capacities by fuel type for EU-15

The implementation of the internal electricity market together with a much slower than expected demand growth in Eastern Europe has resulted in considerable power generation over capacity. The reserve requirement of continental Europe as one market is much lower than the sum of the reserve requirements of the single countries. As a consequence, there was about 20 % over capacity in the European System in the year 2000. **Figure 12** shows two scenarios of how this overcapacity might diminish in the next 4 to 6 years, giving way to needs in new generation capacity thereafter. These scenarios start with the total capacity of the combined UCTE and NORDEL systems at the peak load hour of the year 2000 and the peak load of the year. To the peak load a reserve margin of 5 % is added (red dashed line). For the years 2000 to 2010 it is assumed that existing power plants are withdrawn after 40 years of life time and no further power plants are built after the year 2000, resulting in the full blue line. This full blue line in the year 2006 intersects with the reserve margin line, indicating that in the year 2006 new generation capacities need to become available, if no capacity is added between the years 2000 and 2006. There are, however, the EU renewables' directive targets, requiring the EU member states to install new renewable power generation capacity. When assuming, that this new capacity is added in equal parts over the years from 2001 to 2010 and adding this to the "surviving" capacity of existing plants, the result is the blue dashed line, intersecting with the reserve margin line in the year 2008. This indicates that additional new generation capacity will be necessary in the year 2008. It also indicates that by that time at the latest the European electricity market price will increase to a level which secures the financial means for constructing new generation capacity.

But it should be taken into account also, that due to the intermittent and unpredictable characteristics of most renewables, the installed capacity in renewable power generation can not be relied on to meet the peak load.

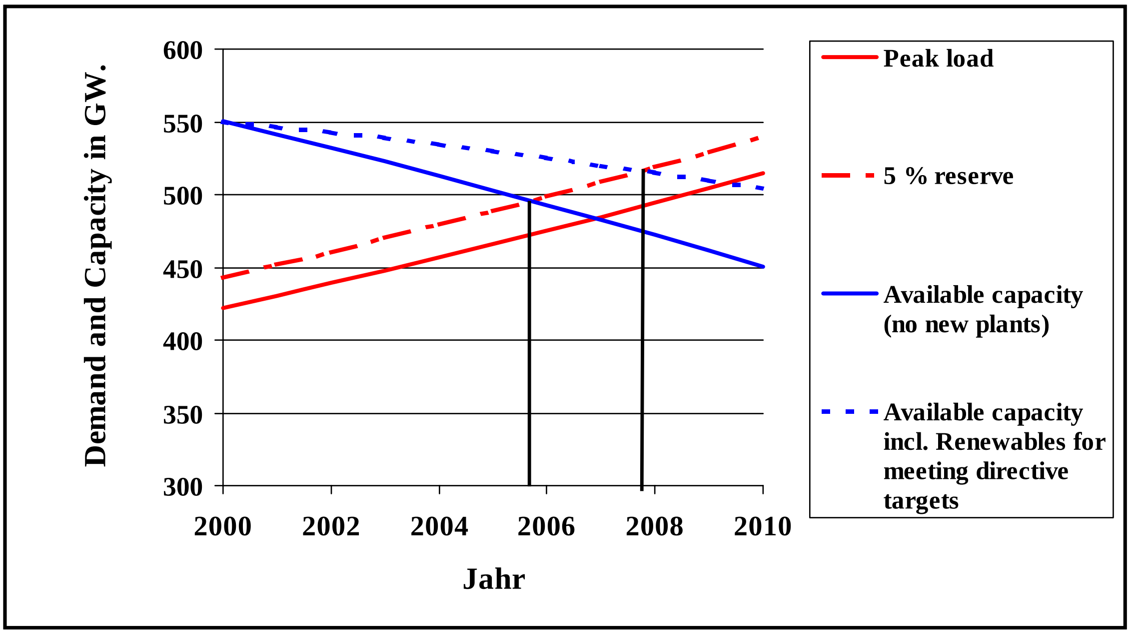


Figure 12: Scenarios of the future development of power generation capacity and demand in the continental European (UCTE-NORDEL) electricity system
Scenario assumptions: a) starting point are the available firm capacities (the capacity available at the peak load hour) and the peak load of the combined UCTE-NORDEL system; b) the existing system was built up between 1960 and 2000 continuously. Power plants are withdrawn 40 years after commissioning; c) peak load demand grows at 2 %/a; d) in the total system a reserve of 5 % over the firm available capacity is assumed as being sufficient.

The current over capacity is not equally distributed over Europe, but concentrated between France and Poland. As has been shown above Italy and the countries in South-Eastern Europe need to import electricity from the north. This electricity transfer from countries with over capacity to countries with additional demand, however, is limited by the capacity of the European transmission grid. A bottle neck is the Alps and especially the connection between France and Italy. As consequence some 5 % of the power transported from France to Italy takes the long way around the Alps via Austria, Hungary and Slovenia. In order to further improve the efficiency of the European electricity supply system new inter-country transmission lines are planned in the framework of the TEN (Trans-European-Network) initiative of the EU.

Figure 13 shows the development of the industrial energy prices in OECD-Europe over the last 21 years. It can be seen that for coal, oil products and natural gas, the price level in the 1980s was much higher than in the 1990s. Since 1995 two waves of ups and downs of these fuel prices can be identified. Clearly the changes in the crude oil price are followed by changes in natural gas and coal price. The correlation factor e.g., between the oil product price and the natural gas price in the years from 1995 to 2001 is 85 %, indicating that the natural gas price is virtually bound to the crude oil price.

The industrial electricity price increased slowly over the 1980s, decreased slowly during the 1990s and then dropped over the period 1998 to 2000. This 7.5 % drop can be attributed to the liberalization of the electricity markets in part of OECD-Europe. In 2001 the industrial electricity price, however, started to rise once again. It increased by 3 %, following the price increase of the fossil fuels and the introduction of renewables promotion fees in some European countries. This electricity price increase can also be interpreted as a sign that the hottest phase of EU electricity market liberalization is already over.

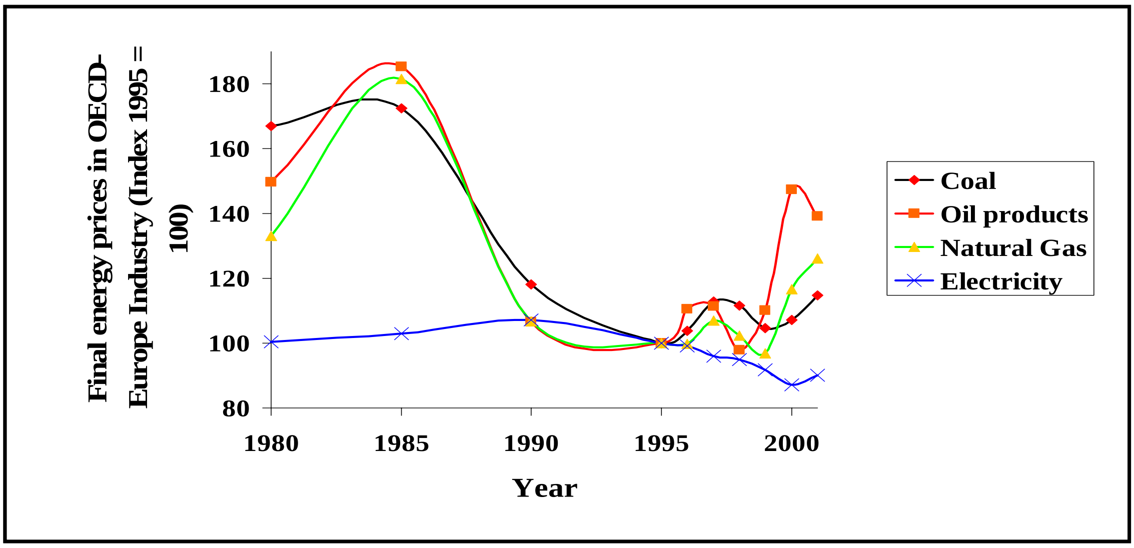


Figure 13: Final Energy Prices in OECD-Europe Industry, indexed to the year 1995

The liberalization of the energy markets has resulted in a “dash” for gas. Natural gas based technologies are generally environmentally friendly, flexible, can be constructed with short lead times and show relatively low investment costs. The higher fuel costs as compared to e.g. coal play a minor role. Currently the stock in and around Europe is dispersed (see **figure 14**, left side), allowing for some competition, in spite of the dominance of the Russian stock. With current trends, however, all stocks in transport range, other than stocks in Russia and Turkmenistan, will be gone (see **figure 14**, right side). This could result in import dependence in the electricity sector which is as problematic as the import dependence which currently can be observed in the transport sector.

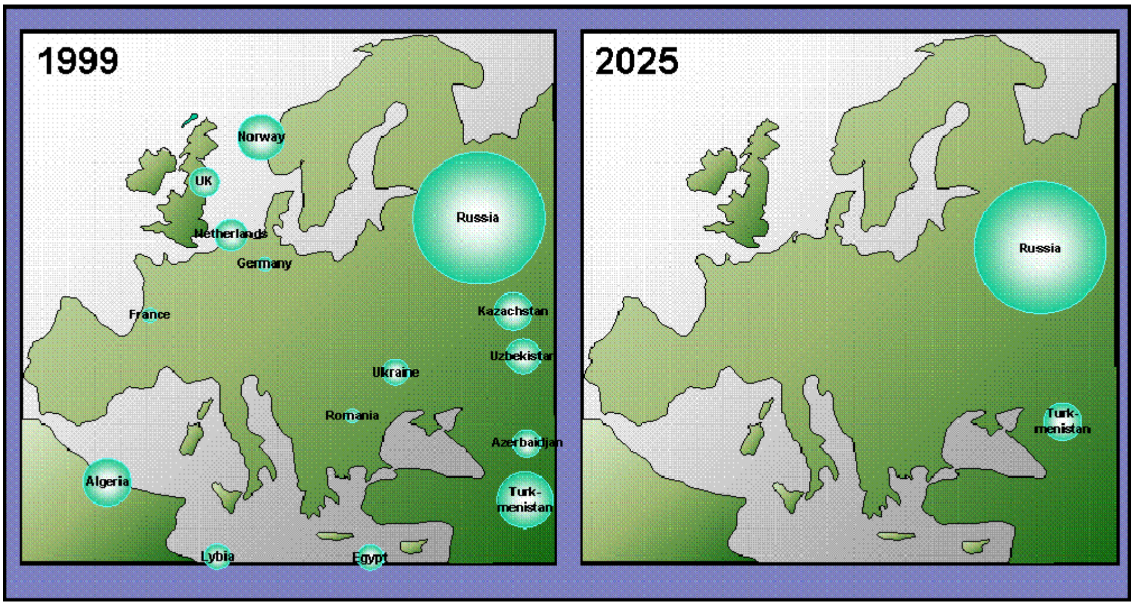


Figure 14: Natural gas stock in and around Europe /17/

Realizing the vulnerability of the European economy with respect to long term energy resources, the European Commission has started a series of initiatives and issued green papers /18/ and directives with the objective to increase the efficiency of the European energy system and to activate the potentials of domestic resources.

In the second half of the 1990s the focus of energy policy lay with efficiency improvement of the electricity and gas markets by liberalization. Now the more technical aspects of developing efficient renewables and combined heat and power (CHP) technologies, once again have gained momentum.

In July 2002 a directive on the promotion of CHP /19/ was issued with the aim to increase the share of electricity from CHP from the current level of 11 %. In August 2001 a directive on the promotion of renewables for electricity production was released /20/, setting targets for its member countries to be achieved by the year 2010.

Following the success of the feed in tariffs for wind energy in Germany, the support of renewables technologies and CHP by feed in tariffs is now looked at much more positively than 5 years ago, when the market distorting effect of feed in tariffs was the primary topic.

The more market oriented renewable certificate trading mechanism has attracted attention and interest especially with electricity traders. However, there are also set backs, like the withdrawal of the certificate scheme for small hydro power plants in Austria. The scheme simply was too complex to be accepted by the market.

The achievements of CO_2 reduction within the European Union are shown in **figure 15**.

The biggest CO_2 abatement effect can be seen in Germany in the first 4 years of the 1990s. This effect can be attributed to the break down of the industry in Eastern Germany and the shut down of many coal power plants in this region. Aside from Germany only the United Kingdom and Luxembourg managed to lower CO_2 output significantly. Especially the Northern countries and France succeeded in stabilizing their emissions. Greece, Ireland, Spain and Portugal increased their emission by more than 10 %. The total CO_2 emissions of the EU from 1990 to 2000 decreased by 0.5 %. This is far from a linear path to the agreed Kyoto target of minus 8 % for the years 2008-2012.

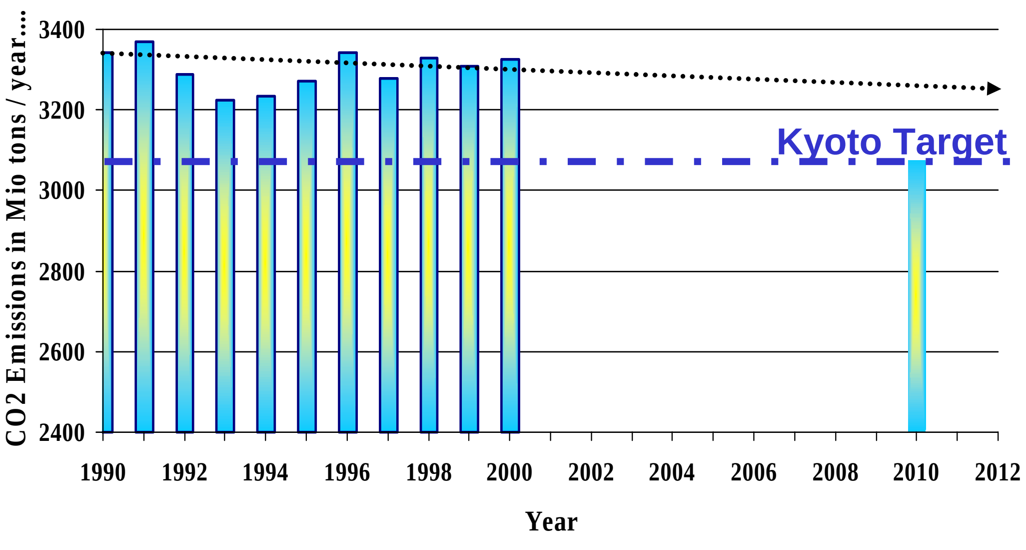


Figure 15: Development of CO_2-emissions in EU-15 throughout the 1990s as compared to the Kyoto target

5. Barriers to DG Market Penetration

In order to stack the barriers in their order of importance with respect to the further development of DG in Europe, the Dispower team members were asked to name the 3 most important barriers from their point of view. **Table 7** shows the scores resulting from the answers of 18 questionnaires. 3 points were given for a first place, 2 for a second and 1 for a third place. Multiple answers were possible.

Table 7: Evaluation of DG barriers

Types of Barriers	Scores
Economic barriers	**58**
High investment costs	25
Low electricity market prices/Overcapacities in Europe	10
Lack of public support	7
High fuel costs	5
High transaction costs	3
Lack of financing opportunities	3
Uncertain pay-back/missing long term policy	3
Inecological taxation	2
Technical barriers:	**28**
Low, uncertain output	10
Utility interfaces are not standardised	4
Grid not optimized for DG integration	4
Lack of technology maturity	4
Lack of experience with DG operation	3
Safety matters still as a problem	3
Social barriers	**24**
Lack of information	7
Competing interests involved (distributors little benefit)	7
Floriani principle (NIMBY)	4
Environmental impact of DG	4
Conservative attitude	2
Administrative barriers/licensing	**11**
connection procedures are not standardised	7
Licensing too complex	4
Planning barriers	**5**
Lack of decision tools	5

6. The Case Studies

A comprehensive description of the case studies and results can be found in the WP 7 reports D 7.2 and D 7.3. The public report of the **Dispower** project also contains details on the case studies.

In total the case studies range from field testing of new control and training equipment, over simulation of real time operational effects, to the simulation of long term energy system development. The general objective is to bring equipment and software developed throughout the **Dispower** project into operation in order to

- prove their viability
- investigate possibilities for improving the quality of electricity from DG
- solve short and long term planning problems
- develop scenarios for the future development of DG in the European electricity system.

Most of the case studies deal with the implementation of some real DG plants or DG related systems, or are restricted in region and/or time. Hence, the conditions are mainly clear and do not allow for the development of several scenarios. Nevertheless, a framework for the case studies, stating common methodologies and parameters, has been deployed as far as applicable and reasonable for each specific case study.

The tools and concepts developed in the **Dispower** project have been applied on national, regional or local grids in different European countries. The main objective was to demonstrate the implementation of distributed generation (DG) and Renewable Energy Sources (RES) technology both on interconnected grids and island power systems, and in this way to contribute to the dissemination and exploitation of the results of the **Dispower** project.

Eleven case studies have been carried out:

- 5 case studies on interconnected grids in Germany, France, Spain and Austria
- 5 case studies on weak grids and island power systems in the United Kingdom, Greece and the French Caribbean
- 1 case study on training programs and courses, developed for a operator training simulator

All together shall help in forming the basis for a higher market penetration of DG in Europe. **Table 8** gives the titles of the case studies:

Table 8: Titles of the Case Studies

Task	Title
7.1	Wind generation on the German interconnected grid
7.2	Advanced grid control unit for DG integration in Germany
7.4	Wind generation on the French interconnected grid
7.5	Distributed Generation in Spain
7.6	Distributed Generation from Renewables in Austria
7.7	Increased wind energy penetration on weak networks in England
7.8	Controlling island grids in the UK
7.9	Concepts for high penetration of RES on Greek islands
7.10	Renewable energies in the French island Iles des Saintes
7.11	Interconnection of solar power mini grids on Kythnos island
7.12	Analysis of network and operation training

7. Future Development of DG for Electricity Generation in Europe

We estimated the possible effect of two EU energy policy strategies on the market penetration of DG within the European electricity system:

- In the Liberal strategy, more or less everything is done by the market and its participants. As a result the development of DG technologies is delayed, as is the cost reduction development of these technologies. Thus in the first years of the planning horizon up to the year 2010, not much market penetration of DG can be expected. However also as result of this strategy DG technologies will become competitive, especially after the year 2020. Also the lack of domestic (Western European) natural gas resources, by that time will bring the need for alternative electricity sources, so that by the year 2030 high DG growth rates can be expected.
- In the Macro Economic Strategy the costs for meeting the Kyoto target are fully put on greenhouse gas emitters, traditional energy sources are taxed to ease the labour costs, research and development is actively supported and the risk for investing long term technologies in volatile electricity markets is taken over by the government. As a result the current momentum for DG market penetration is preserved, so that maximum market penetration rates can be achieved by the year 2010. From the year 2020 on saturation problems will occur, which will slow down the further growth, however on a much higher level than in the liberal strategy.

A series of papers and reports were investigated in order to determine the possible effect these two strategies “Liberal” and “Macro Economy” on the market penetration of the single EU member state countries and of the EU as a whole. The major guideline was found in IEA statistics /21/ and in estimates of Eurelectric experts /22/. In **figure 16** the effect of the Liberal and the Macro Economic Strategy on DG market penetration is shown. It can be seen, that in the Liberal Strategy the slow down of market penetration which has started in 1998 by introducing the market liberalization will continue throughout the year 2020. Later on the DG market penetration will be once again accelerated. In the Macro Economic Strategy the high growth rates of the years 1990 to 1997 will be continued, leading to the highest growth rates between 2010 and 2016. Then first saturation effects can be identified.

Figure 16b shows the same DG market penetration but as share of the overall electricity generation. Here the saturation of the market can be identified to lie at about 35 %.

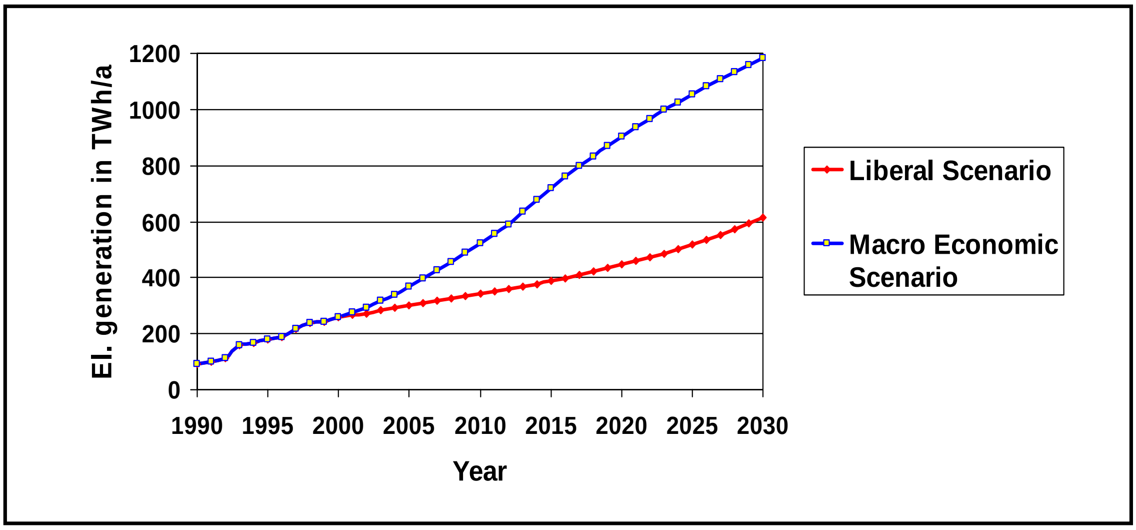


Figure 16a: Electricity generation from DG (Wind, Small Hydro Power, Biomass+Biogas, PV, Geothermal Energy, Small CHP) as result of Liberal and Macro Economic Strategy in EU-15

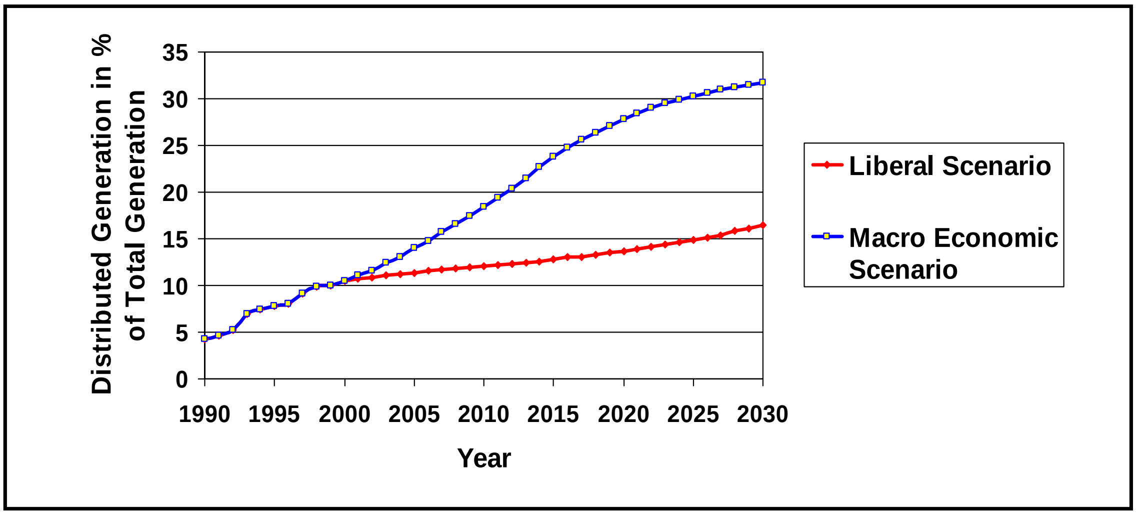


Figure 16b: Share of DG on total electricity generation as result of Liberal and Macro Economic Strategy in EU-15

In EU-15 total the share of DG increases from 10,5 % in the year 2000 to 17 % in the year 2030 in the Liberal Strategy and to 32 % in the year 2030 in the Macro Economic Strategy.

Figures 17 and 18 show the market penetration of the different DG technologies in the Liberal and in the Macro Economic Strategy, respectively. In the Liberal Strategy the bulk of growth lies with small CHP, followed by wind and biomass. PV plays nearly no role. The role of geothermal electricity is even smaller. In the Macro Economic Strategy, especially wind and biomass but also PV (after 2015) get a real boost.

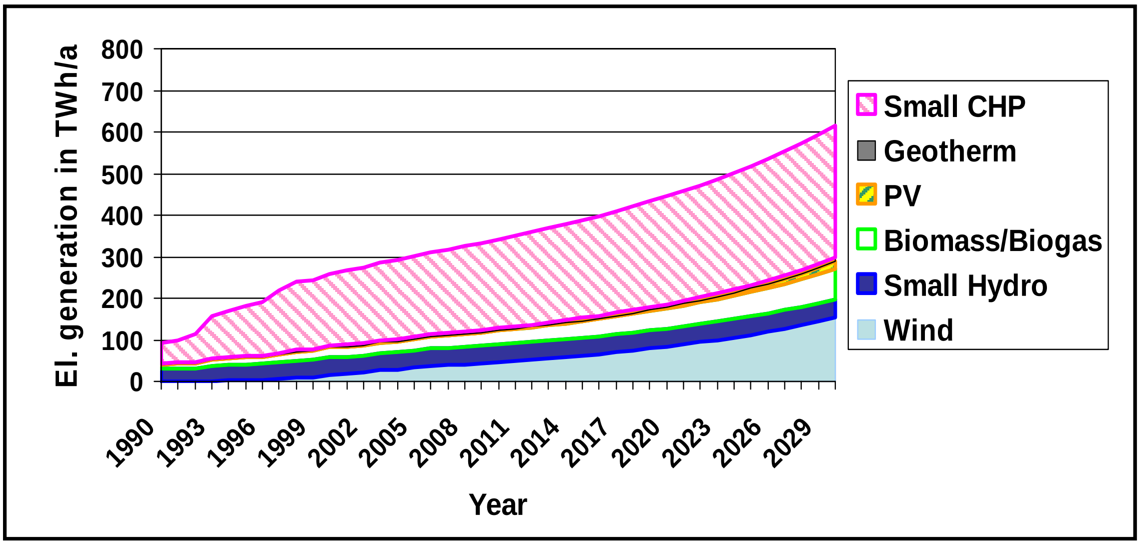


Figure 17: Electricity generation from DG as result of Liberal Strategy in EU-15

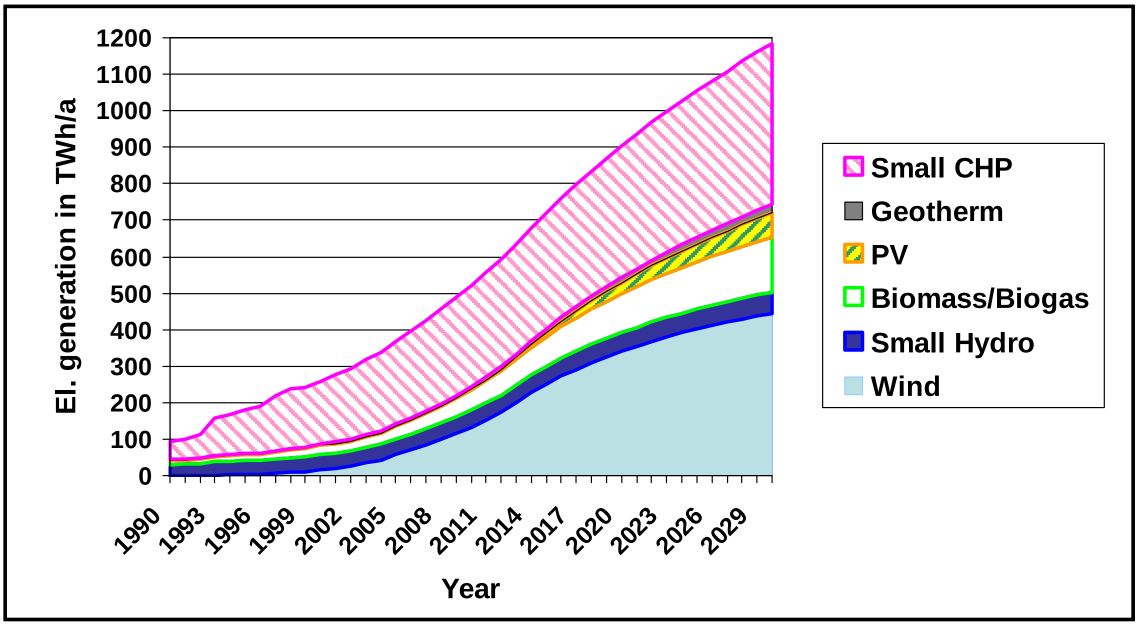


Figure 18: Electricity generation from DG as result of Macro Economic Strategy in EU-15

8. Focus for Research and Development on DG

During the elaboration of this study in general and the implementation of the 11 case studies in particular some lessons have been learned and several issues and tasks for further research and development have been identified.

Reflecting the main topics for an increased integration of DG into the European energy systems, the single tasks are assigned to 4 thematic blocks, namely:

- Interactions between DG and the central system
- Load management
- Solutions to increase DG & RES on islands & weak grids
- Important features, capabilities and ancillary services

The integration of DG into the existing central oriented distribution networks is one of the big challenges for research and development on the DG topic, and therefore addressed in several national and international research programmes. The lessons learned are:

- Perception of penetration: The term penetration level of DG is not clearly defined and several players in the market may, depending on their specific focus, understand the term differently.
- Influences of DG on control and operation of the networks: Several case studies allowed for detailed insights in the control mechanisms and operation processes of networks with increasing share of DG.
- Voltage regulation and ride through capabilities for wind turbines: The case studies which focused on DG from wind power developed technical expertise on reasonable connection conditions for DG, especially concerning voltage regulation and fault ride through capabilities.
- Use of probabilistic methods: In order to obtain information about the impact of DG on the system, investigations of extreme scenarios give the broadest possible range. But the additional use of probabilistic methods in order to deal with penetration and impact of DG in the system might provide more realistic results.
- Difficulty to obtain grid data: The case studies that dealt with the planning and implementation of DG plants connected to a superior grid reported difficulties in obtaining complete and high quality data for the basic grid conditions.

Demand side management is complementary to the increased share of DG in the networks. Modern ICT can handle intermittent generation as well as fluctuating demand. The lessons learned are:

- Feasibility of voltage and frequency control: The case studies dealing with DG in weak grid situations report experiences and references with controlling the systems voltage and frequency by using load management.
- Effective strategy to improve RES penetration: Combining DG from intermittent RES with load management to adjust the demand of less crucial applications seems to be a reasonable strategy to increase RES/DG penetration in the networks.

Specific solutions had to be developed for matching the conditions for DG & RES on islands and weak grids. The lessons learned are:

- Energy storage and power electronic interfaces: The respective case studies revealed that especially on islands and weak grids energy storage is a main factor for network stability. Power electronic interfaces can provide network services, that are even more important in weak network situations.
- DG could be profitable in islands: From an economic point of view the potential of DG lies in supplying electricity to remote areas.

Finally several case studies proved, that in most cases DG will not decrease the power quality levels but improve them. DG plants and power electronic interfaces can provide ancillary service to the network like voltage regulation and frequency control and have fault ride through capabilities. However, proper standards and regulations on these topics are lacking in most EU countries. Appropriate monitoring and control systems with communication means as well as appropriate forecasting tools for RES will enable a higher penetration of DG in the networks.

The **Dispower** research project finally achieved its objectives and such can provide some answers to recent problems concerning DG integration. Nevertheless several new questions have shown up during the implementation of the project and further demand on R&D is given, like the following research fields:

- Upgrading and extrapolation of the respective case study results to all EU countries with increasing wind power penetration. Integration of all specific national boundary conditions.
- Communication standards must be implemented in wind turbines and in DG in general.
- Continue the work on wind power integration on the system.
- Study of probabilistic methods in order to deal with penetration and impact of DG in the system.
- Extend the study to all the countries assessing the global penetration and future estimations of RES in order to advance the influence for the system in terms of quality and reliability of supply and control and operation.
- Verification of the DG planning concept for European regions for rural electrification based on RES in developing countries.
- The necessity of adapting grid and planning development tools to try to gather all the capabilities in only one comprehensive tool.
- Develop training courses for small island grids.
- Further work on load management like potentials and applications of load control and load control strategies (e.g. binary loads).
- Further work on solutions to increase DG & RES on islands & weak grids like development of appropriate energy storage devices, provision of ancillary service by DG plants, appropriate monitoring and control systems with communication means and FRT capabilities for DG units.

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