EFFICIENCY IN ELECTRICITY GENERATION

Report drafted by:
EURELECTRIC "Preservation of Resources" Working Group's "Upstream" Sub-Group in collaboration with VGB

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UNION OF THE ELECTRICITY INDUSTRY
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The Union of the Electricity Industry - EURELECTRIC, formed as a result of a merger in December 1999 of the twin electricity industry associations, UNIPEDE and EURELECTRIC, is the sector association representing the common interests of the European electricity industry and its worldwide affiliates and associates. Its mission is to contribute to the development and competitiveness of the electricity industry and to promote the role of electricity in the advancement of society.

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VGB PowerTech was founded in Leuna (East Germany) in 1920. It is a voluntary association of power as well as heat generating utilities. Its main objective is joint support and improvement of operational safety, availability, efficiency and environmental compatibility of power plants (fossil-fired, nuclear, renewables) both in operation or under construction. Further, VGB is involved in standardization as well as in elaboration of technical guidelines and regulations in the field of thermal power plants. Within the framework of its legal possibilities, VGB supports the work on the mandatory pressure vessel- and steam boiler regulations and nuclear regulations in Germany and also in the European Union.

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I. INTRODUCTION

This report gathers state-of-the-art knowledge on energy efficiency in electricity generation based on thermal processes, on renewable energy sources and on distributed generation technologies. The aim of the report is to support policy analysis made not only by electricity companies' analysts but also by policymakers, consultants and other stakeholders. The efficiencies presented in this report are related to the most recent generation technologies on the market or expected to be available in the near future. The report is the result of collaborative work between the Union of the Electricity Industry-EURELECTRIC and VGB PowerTech's experts.

The report is divided into two distinct parts: one on energy efficiency values in electricity generation (Chapter III, IV and V), which is the core of the report, and the other part on related issues such as impacts on the environment (Chapter VI), power plant scales and generation costs (Chapter VII), indicators (Chapter VIII) and benefits of improving energy efficiency (Chapter IX).

II. ELECTRICITY GENERATION: main purpose

Electric energy generation is the conversion of other kinds of energy, mainly primary energy, into electrical energy.

Examples:	
Hydro power plant	The conversion of the water "mechanical" energy into electrical energy
Nuclear power plant	The conversion of the nuclear energy released by nuclear fuel into electrical energy
Fossil-fuel power plant	The conversion of the chemical energy of fossil fuel into electrical energy
Fuel Cell	The conversion of the chemical energy from an oxygenation controlled reaction directly into electrical energy

Generally, the process of generating electricity goes through several transformations, as there is little primary energy directly convertible into electricity. For instance, in a thermal power station the primary energy is converted to high temperature steam, as an intermediate heat source, then into mechanical energy in the turbines physically connected with the generators where the electric energy is produced. Direct energy conversion might represent greater efficiency since it means that electricity could be generated without intermediate equipment.

III. EFFICIENCY IN ELECTRICITY GENERATION BASED ON THERMAL PROCESSES

3.1 INTRODUCTION

In thermal power plants the steam is generated by burning fuels or from the heat released by nuclear fission or is extracted from underground geothermal reservoirs.

The different energy resources used may be grouped as follows:

- Fossil fuels such as coal, oil, natural gas;
- Fuels artificially prepared, such as hydrogen, alcohol and acetylene;
- Converted fuels, such as methane and biogas;
- Nuclear fuels
- Geothermal steam

Fuels converting into electricity may also be grouped into solid, liquid and gaseous fuels, as follows:

Solid fuels:

- Fuel wood [1]
- Forest products [1]
- Coal: anthracite; bituminous coal; sub-bituminous coal; lignite (brown coal)
- Peat: peat is considered as a substance somehow between forest product and coal
- Carbon wastes

Liquid fuels:

These fuels result from refining crude oil:

- The lighter products first to distillate are liquefied petroleum gases (LPG)
- The following distillate products will give gasoline, petrol and gas-oil
- The residue, which is not distillate, is fuel-oil.

There are also on the market some mixtures of gas-oil and thick fuel-oil which result in:

- Diesel-oil
- Burner-oil
- Thin fuel-oil

Other liquid fuels:

- Alcohol (especially ethanol)

Gaseous fuels

- Natural gas is a mixture of hydrocarbons, chiefly methane (CH4)
- Liquefied petroleum gases (LPG), butane; propane
- Manufactured gas: derived from the industrial petrochemical process
- Other fuel gases: hydrogen, acetylene, et al.

Fossil fuels

Fuel is an organic substance used for its energy content. The energy content of a fossil fuel, before any treatment or conversion, corresponds to primary energy. A fuel is characterised, giving the common feature inherent to its heat energy generation, by the calorific value. Calorific value (GCV-Gross Calorific Value or NCV-Net Calorific Value) is the quantity of heat released by the complete combustion of a unit quantity of a fuel in a well-determined condition. Its calculation may, or not, take into account the vapour condensation of the water, determining the GCV or the NCV.

Generation Efficiency

The electric power plant efficiency η is defined as the ratio between useful electricity output from the generating unit, in a specific time unit, and the energy value of the energy source supplied to the unit, within the same time.[2]

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[1] Considered as renewable

[2] The type of energy converted in a fuel-burning installation is variable. The output of the conversion process may either be electricity (power), heat or a mixture of both, which makes it difficult to define efficiency of the process (it is even more complex in a three-product system of electricity, heat and a high-quality syn-gas product, i.e. produced in gasification plants).

Different energy conversion processes have different thermodynamic limitations. Therefore, the term “efficiency” should only be used for one process with one energy source and one energy product, specifically referring to the output, i.e. “electrical efficiency”.

In physics theory, η of a thermal electricity generation process is limited by the Carnot efficiency.

$$\text{Carnot efficiency} = (\text{T source} - \text{T sink}) / \text{T source}$$

Example of the Carnot efficiency:

A heat engine supplied with steam at 543ºC (T source = 816K)
And the choice of a sink in a river at 23ºC (T sink = 296K)
In theory, the Carnot efficiency η = 64%

In practice, the process efficiency is less than that ideal maximum, about 40%[3].

Example:
Energy value of fuel supplied in a time unit (available energy)
1 toe (tonne of oil equivalent) <> 11,628 kWh in NCV
(implicit "heat equivalent of 1 kWh" = 86 grams of oil equivalent)

Useful electricity output from the power station in a time unit (electricity supplied)
1 toe <> 4,505 kWh
(implicit average heat consumption per 1 kWh = 222 grams of oil equivalent)

Thermoelectric power plant efficiency η = 4,505/11,628 = 38.7% (in NCV)
(Or η = 86/222 = 38.7%)

Energy value of fuel – the denominator – represents its heat content, which is the product of the burned mass times the NCV or GCV. Electricity output – the numerator – represents the net power output of the power station in the same period. The difference between these two terms represents the losses.

Transformation sequence: *Example*

At the fuel
CV - Calorific value (= **100%**)

The solid, liquid and gaseous fuels used in a thermal power plant are mainly hard coal, lignite, fuel-oils, gas-oil and natural gas. Their values of GCV and NCV are on an average the following:

	GCV	NCV*
Heavy fuel-oil	42.6 MJ/kg (= 10,175 kcal/kg)	40.57 MJ/kg (= 9,690 kcal/kg)
Light fuel-oil	43.3 MJ/kg (= 10,342 kcal/kg)	41.2 MJ/kg (= 9,840 kcal/kg)
Burner-oil	44.1 MJ/kg (= 10,533 kcal/kg)	42.16 MJ/kg (= 10,070 kcal/kg)
Gas-oil	45.7 MJ/kg (= 10,915 kcal/kg)	43.75 MJ/kg (= 10,450 kcal/kg)
Natural gas	42.0 MJ/m^3 (=10,032 kcal/ m^3)	37.9 MJ/m^3 (= 9,052 kcal/m^3)
Hard coal	35.4 MJ/kg (=8,448 kcal/kg)	34.1 MJ/kg (=8,145 kcal/kg)
Lignite	24.0 MJ/kg (=5,732 kcal/kg)	23.0 MJ/kg (=5,493 kcal/kg)

1 calorie = 4.1868 Joules

Processes like CHP (see page 10) have two different efficiencies. When added, these data together represent the utilisation of the input energy fuel. This is called "fuel utilisation" or "overall efficiency". In electricity statistics, the share of fuels used for electricity generation is estimated based on conventional/design values of the two different efficiencies mentioned above.

[3] Efficient turbine technologies are currently close to 60% [29]

Note: All figures are calculated for water and ash free fuels. For hard coal and lignite containing water and ashes the values are lower (e.g. lignite: water content 40-60% and ash content of 5%, NCV of 9.2 MJ/kg instead of 23 MJ/kg).
* Generally in Europe, for calculating efficiency the NCV is applied
Ref: VDI 4660 conversion factors for specific emissions from energy conversion systems

The efficiency of a fossil fuelled power station with once-through water-cooling depends directly on the "Steam generator" efficiency and the "Turbine plant" efficiency.

The losses occur in the steam generator (e.g. head losses, mass losses and steam cooling) when it passes from the steam generator to the turbine; these represent about 10%.

At the turbine input	
CPST - Calorific power transmitted in the input steam to the turbine	(= **90**)

The "Turbine" efficiency is the most influential factor of a power plant's efficiency, and takes into account the fundamental heat rejected in the condenser (cold source). This efficiency is the difference between the ideal efficiency of the turbine and the sum of the losses – internal and external – of the turbine.

At the generator input	
MPG - Mechanical power transmitted to the generator	(= **40**)

The efficiency of a large electrical generator is typically 99%.

At the generator output	
GEP - Gross electric power at the generator terminals	(= **39**)

From the gross output without electrical power consumed by the station auxiliaries and the losses in "generator transformers" it is possible to obtain the net value.

At the transmission grid input	
NEP - Net electric power supplied to the grid	(= **36**)

η - Power station efficiency η = NEP/CV (= 36%)
Losses CV-NEP (= 64%)

3.2 Power plant efficiency

This section indicates efficiency values for converting fuels into electricity in today's average thermal power plant. It is important to note that these values do not represent fuel or power plant availability, but efficiency as defined in part 3.1.

3.2.1 Converting oil into electricity

Steam turbine fuel-oil power plant	**38 to 44%**

Ref: Figures agreed through peer review between EURELECTRIC and VGB experts

3.2.2 Converting coal into electricity

An appropriate coal to be used in a thermal power station is "steam coal". Conventional power plants with pulverized coal firing have efficiencies as follows:

Steam turbine coal-fired power plant	**39 to 47%**

Ref: VGB

3.2.2.1 CONVERTING COAL IN NEW COAL COMBUSTION TECHNOLOGIES INTO ELECTRICITY

Coal and other non-gaseous fossil fuels can also be converted into electricity (and heat in CHP power plants) in combined gas-steam-cycle if the fuel is gasified in advance. Such IGCC (Integrated Gasification Combined Cycle) power plants offer large potential for higher efficiencies. On the other hand, these plants are very complex and difficult to operate, which reduces flexibility and availability. Other advanced techniques concentrate on special firing systems like fluidised bed combustion (FBC; attractive for medium scale and low-quality coal) and increased steam parameters (600°C, 270 bar and more; affords new materials). Currently, there are four main available "Clean Coal Combustion Technologies" [28] in various sizes:

Pulverised coal boilers with ultra-critical steam parameters	**Up to 47%**

Ref.: Nordjyllandsvaerket power plant 47% with sea water cooling (Denmark)

Atmospheric Circulating Fluidised Bed Combustion (CFBC)	**> 40%**

Ref: Gardanne power plant (France)

Pressurised Fluidised Bed Combustion (PFBC)	**> 40%**

Ref: Cottbus: 74 MWe. 220 th. (Germany)

Coal fired IGCC	**> 43%**

Ref: Buggenum: 43% (Netherlands); Puertollano (330 MWe); 45% (Spain)

3.2.3 CONVERTING NATURAL GAS INTO ELECTRICITY

In the case of gas turbines:

Large gas turbine (MW range)	**up to 39%**

Ref: Gas turbine World Handbook, 2000/2001

3.2.3.1 CONVERTING NATURAL GAS INTO ELECTRICITY IN COMBINED CYCLE

In the case of CCGT (Combined Cycle Gas Turbine processes) power is generated more efficiently than in a simple gas turbine cycle: the hot exhaust gases of the gas turbine are used to produce steam that generates electricity in a steam turbine cycle.

Large gas fired CCGT power plant	**up to 58%**

Ref.: Mainz-Wiesbaden "GuD" plant ("GuD" – Gas and Steam / Siemens)

3.2.4 CONVERTING BIOMASS AND BIOGAS INTO ELECTRICITY

Biomass results from the joint combustion of organic materials of vegetal or animal origin, and also including materials resulting from their transformation. Biogas is a mixture resulting from the anaerobic fermentation of organic materials.

Biomass and biogas	**30-40%**

Biomass gasification combined cycle power plant	**40%**

Ref: Energy from Biomass, Principles and Applications [15]

We may consider as main sources of biomass the following: forest; waste materials from forestry and sewage; skin and residues from agro-industrial activities; residues from agricultural plantation; sewage from animal wastes; urbane waste; energy farm.

Waste-to-energy
Utilisation of waste for power generation should be treated as "Renewable" because it prevents the use of exhaustible fuels. Moreover, it reduces the need for waste landfills and related methane emissions.

The incineration of biomass and organic waste is CO_2 neutral, because the carbon dioxide that is released into the atmosphere practically offsets the CO_2 absorbed by biomass during its growth.

Waste-to-electricity power plant	**22 to 28%**

Ref: VGB

3.2.5 CONVERTING NUCLEAR ENERGY INTO ELECTRICITY

As far as nuclear energy is concerned, the fact that the fission of one gram of U235 releases approximately 24 MWh or 1 MWday (MWd) of thermal energy makes it convenient to use the concept of combustion rate, also known as "burn-up", which is expressed in MWdays per tonne of heavy metal[4] (MWd/tHM). Over the past 30 years, burn-up has steadily increased: for light water reactors, the most common type in the western world, it has moved from 33,000 to around 65,000 MWd/tHM and is expected to increase further.

The total thermal energy released by nuclear fuel is proportional to the burn-up it reaches at the end of its reactor life[5]. One fuel assembly containing typically 460 kg of uranium and reaching a burn-up of 65,000 MWd/tU would therefore release 65,000 MWd/tU x 0.46 tU x 24h/d = 717,600 MWh of thermal energy over its reactor life. The thermal efficiency of a nuclear power station is defined in exactly the same way as for any other thermal plant: it is the efficiency of the thermodynamic cycle by which the heat generated by the fuel is converted into steam through steam generators. The thermal efficiency of a conventional nuclear power station is around 33%.

Nuclear power plant	**33% to 36%**

Ref: Figures agreed through peer review between EURELECTRIC and VGB experts

Therefore, to generate 1,000 MW of electrical power (MWe) in a nuclear plant it is needed around 3,000 MW of thermal power from the fission reaction.

<u>One day generating and fuel consumption:</u>

For a generating capacity of 1,000 MWe, the energy output in one day is:
$(1 \times 10^9 J/s) \times (86,400 s) = 0,864 \times 10^{14} J$

Each day fuel consumption:
1,000 MWe coal-fired power plant burns about 8,000 tons of coal;
1,000 MWe nuclear power plant has to undergo fission of about 3.2 kg mass of U235.

[4] Heavy metal referring to the fissionable material composing the fuel
[5] The relation between the burn-up achievable and the initial heavy metal content of the fuel assembly is more complex

3.2.6 CONVERTING GEOTHERMAL ENERGY INTO ELECTRICITY

Geothermal energy comes from the thermal earth inner activity, mainly where there is volcano activity. The deposits of heat may be exploited with almost constant power supply. Once steam reaches earth surface through wells, it is used to produce electricity, in some cases used for non-electric purposes (e.g. building heating), or saving energy otherwise produced through conventional methods. Inside geothermal plants steam supplies power to move the turbines producing electricity. Waste water derived from steam is then injected in deep wells in order to keep a constant pressure level and to avoid steam pollution. In some areas of the world, including Europe, geothermal energy plays a leading role. The type of use – heating or power generation – depends on the quantity and quality (level of temperature) of the geothermal source. In some regions, it has been produced commercially in the range of hundreds of MW for many decades [EU Blue Book on Geothermal Resources].

Geothermal power plant	**up to 15%**	for 190°C

Ref: EGEC / Geothernet

The efficiency of existing organic Rankine Cycle plants generally range from 10% to 15.5% for resources at 100°C to 160°C and is slightly higher (17%) for temperatures up to 190°C with a two-phase geothermal fluid [quote from EGEC / Geothernet]. Advanced cycles like the Kalina Cycle offer large potential but are not commercially available. Regarding the high density and the constant availability of the energy source – that is, for a renewable technology, only comparable with hydro – the focus is not on increasing efficiencies but at reducing costs. Just for heating purposes the use of heat pumps is very attractive, especially if the temperature of the geothermal source is not very high (low quality). Heat pumps require external energy input like electricity but are able to generate much more heat (at medium quality) than the quantity included in the fuel for generating this electricity. For domestic heating, even the upper ground or ambient air suffices as geothermal source.

3.2.7 CONVERTING THERMAL ENERGY INTO ELECTRICITY AND USEFUL HEAT IN CHP UNITS

In the case of Combined Heat and Power (CHP), or co-generation, part of the converted thermal energy is used for generating useful heat: either by utilising the low-temperature steam at the steam-turbine exit for district heating or branching off a certain amount of steam directly from the steam turbine i.e. for process heat. This reduces the electrical efficiency slightly (~14 % of extracted heat for district heating), but the input fuel energy is better used in total. The loss of electrical output results from the pressure difference by condensing steam at back pressure instead of vacuum conditions. For high temperature steam extraction, the loss is higher.

For example, a 112 MW (electric) plant operating in a mode without heat extraction has an electrical efficiency of 36.3%. By producing 152 MW additional heat the overall efficiency increases to 84.9%.

Example:	
Power of gas turbine	69,100 kW
Power of back-pressure steam turbine	44,700 kW
Auxiliary power consumption	1,400 kW
Net power output of plant	112,400 kW
Heat input gas turbine	230,000 kW
Heat input supplementary firing	79,600 kW
Process steam output	152,000 kW
Electrical efficiency	36.3 %
Thermal efficiency of heat production (only)	48.6 %
Overall efficiency	84.9 %

The “overall efficiency” is higher than the electrical efficiency and results from adding the efficiency of the generated heat (= useful heat / energy of fuel supplied). The overall efficiency is therefore defined as:

Overall efficiency = (Electrical Power Output + Useful Heat Output) / Total Fuel Input. Comparing separated heat and power supply to CHP or two different CHP solutions on the basis of overall efficiencies is possible with the same amount of electricity and heat at uniform temperature levels[6]. CHP applications provide potential for better fuel utilisation especially if the volume of heat demand is high and relatively constant (in the summer period too), as in industry or in some northern regions of Europe. Examples for CHP power stations in Finland show highest figures for heat output and overall efficiency compared to others and in contrast to other countries, without any subsidies being provided.

IV. EFFICIENCY IN NON-THERMAL ELECTRICITY GENERATION BASED ON RENEWABLE RESOURCES

4.1 INTRODUCTION

Renewable energies are sources of energy that renew themselves constantly through natural processes and, seen on a human-time scale, will never run out. Renewable energies come from three primary sources: solar radiation; heat from inner earth; tidal power.

These three sources can be used either directly or indirectly, in particular the form of biomass, wind, wave energy and ambient heat. Renewable energy sources (RES) can be converted into electricity, heat and also fuel.

4.2 CONVERTING SOLAR ENERGY INTO ELECTRICITY

Solar systems for electricity generation purposes are based on the concentration of sunlight. There are three different concentration solar power systems: parabolic trough systems; solar power tower; parabolic dish technology using a stirling motor

Their efficiency values are the following:

Parabolic trough	**14 – 18%**
Power tower	**14 – 19%**
Dish stirling	**18 – 23%**

Ref: Figures agreed through peer review between EURELECTRIC and VGB experts

Solar energy may also be used directly to produce electricity (photovoltaic effect) that involves photovoltaic cells and, sometimes, grouped on photovoltaic panels. Although it is difficult to generate a high output solar energy compared with fossil fuel or nuclear energy, solar energy is of major importance because it is a non-polluting and renewable energy source. The efficiency value of photovoltaic cells is the ratio of the electrical energy produced by the cells to the incident solar radiant energy.

Photovoltaic cells	**Up to 15%**

Ref: VGB

[6] Directly comparing different CHP applications, or comparing CHP with separate heat and power generation could be misleading, if the quality of the energy converted is not taken into account (2nd law of thermodynamics). For pure electricity production, the thermodynamic limits have to be considered and for pure heat production this comparison does not show a benefit for CHP, since simple heating boilers, i.e. for domestic heating, have a comparable or even higher quality in “overall efficiency” than CHP units.

4.3 CONVERTING WIND ENERGY INTO ELECTRICITY

Energy derived from the wind results from the solar energy on the different stratum of the atmosphere. A typical turbine with 40 meters blade diameter and an 8 m/s wind speed, extract about 400 kW from the air of which about 35% can be converted into electric power.

Wind turbine	**Up to 35%**

Ref: VGB - this figure is a maximum because it does not increase with the total performance. Even 4 MW off-shore converters will not exceed 35%. Example: German coast on-shore: up to 2,500 hours per year; off-shore: up to 4,500 hours per year.

4.4 CONVERTING HYDRO ENERGY INTO ELECTRICITY

The electrical efficiency of a hydroelectric power station depends mainly on the type of water turbine. The electricity generated by moving water comes from large hydroelectric power plants and also from smaller ones, such as: mini-power and micro-power plants. It is worth mentioning that more than 90% of total hydro power generated in the EU comes from large hydro. The installed capacity of a small hydroelectric power plant is generally a few MW (<5 MW with an efficiency between 80 and 85 %).

Large hydro power plant	**Up to 95%**
Small hydro power plant	**Up to 90%**

Ref: VGB

4.5 CONVERTING ENERGY FROM THE OCEAN INTO ELECTRICITY

Tidal energy results from submarine turbines moving from the rise and fall of sea level due to the gravitational forces of the moon and sun. A dam is used to store the water and a turbine to enable useful energy production.

Tidal power plant	**Up to 90%**

Ref: Electricité de France (EDF)

V. EFFICIENCY IN DECENTRALISED GENERATION TECHNOLOGIES

Short-term energy-storage technologies such as mechanical flywheel, chemical batteries and fuel cells, magnetic superconducting, electric ultra-capacitor, can be incorporate in a multi-energy system[7]. Applications with high electrical demands and lower heat demands will be suited to fuel cells. Electrical efficiencies are as follows:

Protons Exchange Membrane Fuel Cell (PEMFC)	**40 %**
Phosphoric Acid Fuel Cell (PAFC)	**40 %**
Solid Oxide Fuel Cell (SOFC)	**46 % (aimed > 60%, pressurized)**
Melted Carbonates Fuel Cell (MCFC)	**52 % (aimed: 65 %)**

Ref: VGB

[7] A study [35] considered the following storage technology: batteries (lead-acid and advanced), flywheels (low speed and high speed), ultracapacitors, compressed air energy storage, superconducting magnetic energy storage, pumped hydro electric storage, and hydrogen storage.

Fuel cells produce electricity, heat and water. The waste heat recovered from the fuel cells may be used (e.g. for building heating) with effects in the increase of overall efficiency of the system. The overall efficiency is at around 85 to 95%.

Microturbines

Small and micro-turbines (up to 100 kW)	**17 to 22%**

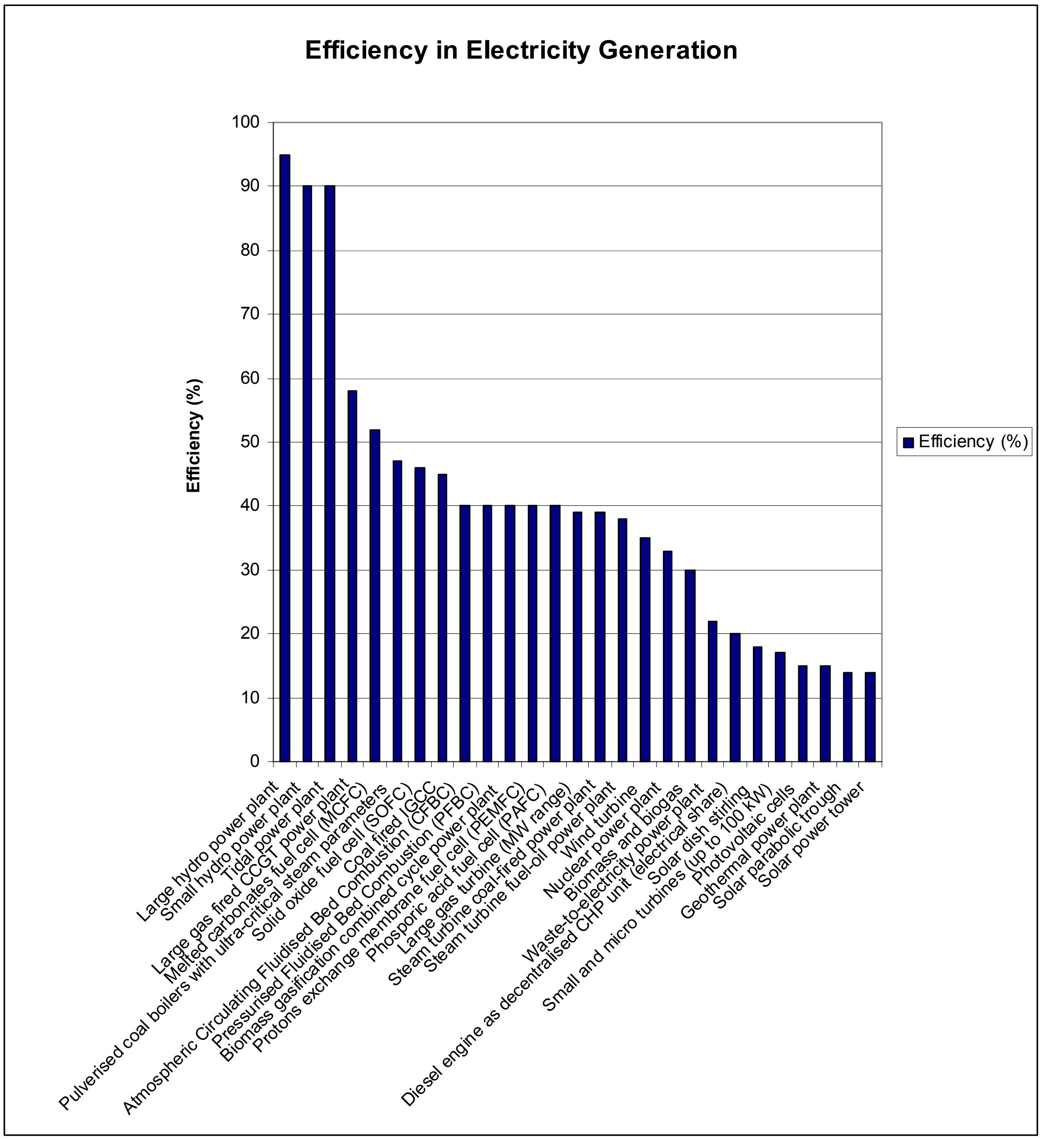
Ref: Capstone

As micro turbines, diesel/gas motors are often used for decentralised CHP applications:

Diesel engine as decentr. CHP unit, electrical share	**20% to 40% and above**	45% at large scale

Ref: Figures agreed through peer review between EURELECTRIC and VGB experts

The graph below summarises the efficiency in various generation technologies:



VI. IMPACTS ON THE ENVIRONMENT

6.1 Fossil and Nuclear fuels

The impacts on the environment due to the use of fossil fuels in thermal power plants are the following: emissions of gases causing acidification (e.g. sulphur dioxides and nitrogen oxides), greenhouse gas emissions (e.g. carbon dioxide, methane, sulphur hexafluoride, etc), ashes and dust emissions to air.

Example: 1,000 MW of generation capacity, 6,600 full load hours per annum = 6.6 TWh electricity production per annum result in the following emissions (the diversity of fuel mixes in each country gives different average values):

	Hard Coal	Lignite	Oil	Gas-CC	Nuclear
El. Efficiency %	42.0%	40.0%	44.0%	57.0%	34.0%
Fuel Consumpt. t/a	2,000,000	7,600,000	1,289,768	920,000	20
Oxygen Cons. t/a	3,800,000	4,800,000	3,270,047	1,600,000	0
CO_2 emiss. t/a	5,200,000	6,600,000	4,496,314	2,200,000	0
SO_2 emiss t/a	3,800	4,300	3,134	1,200	0
NO_x emiss t/a	3,800	4,300	3,134	3,500	0
Dust emiss t/a	600	640	470	200	0
Radioactivity kBq/a	80	90	0	0	52,800
Ash t/a	150,000	950,000	2,000	0	0
Gypsum t/a	75,000	110,000	220,000	0	0

Ref: VGB

The table below shows relative power plant emissions per unit of electricity generated in the UK [29]:

Fuel Source	SO_2	NOx	CO_2
Coal (average UK)	1.00	1.00	1.00
Coal (typically imported)	0.55	1.00	1.00
Coal (incorporating fuel emission control)	0.10	0.60	1.05
Heavy Fuel-Oil	1.20	0.75	0.85
Natural Gas	0.00	0.25	0.50

For example, considering the CO_2 intensity[8], the values may range from 32 gCO_2/kWh – in a system with Nuclear + Hydro + Biomass + Wind – to 1,000 gCO_2/kWh – in a system based exclusively on coal.

The table below contains the total SO_2, NOX and CO_2 emissions in the European Union.

Gas (kt)	1980	1990	2000	2005	2010	2020
SO_2	12,214	8,424	3,115	2,259	1,736	1,059
NOx	3,214	2,672	1,653	1,400	1,268	1,053
CO_2	894,342	888,562	862,676	832,352	847,068	891,369

Ref: Eurprog, EURELECTRIC

[8] Pulverised coal plant with desulphurisation – assuming CO_2 emissions of 961 gCO_2/kWh; a co-generation installation with CO_2 emissions of 399-434 gCO_2/kWh [26]

6.2 Renewable energy sources

To illustrate the environmental benefits associated with a non-polluting source an example is provided. Considering a 10 MW wind farm with an average production of 23.5 GWh/year, compared with an alternative thermal production, the avoided emissions of SO_2, NOx, CO_2 and ashes, are as follows:

Wind Farm 10 MW; 6,5-7 m/s; 23,5 GWh/year - avoided emissions:				
Considering an alternative thermal production:	SO_2	NOx	CO_2	Ashes and particles
Based on fuel-oil	127 t	60 t	19,000 t	6.5 t
Based on Coal	183 t	122 t	25,000 t	1,400 t

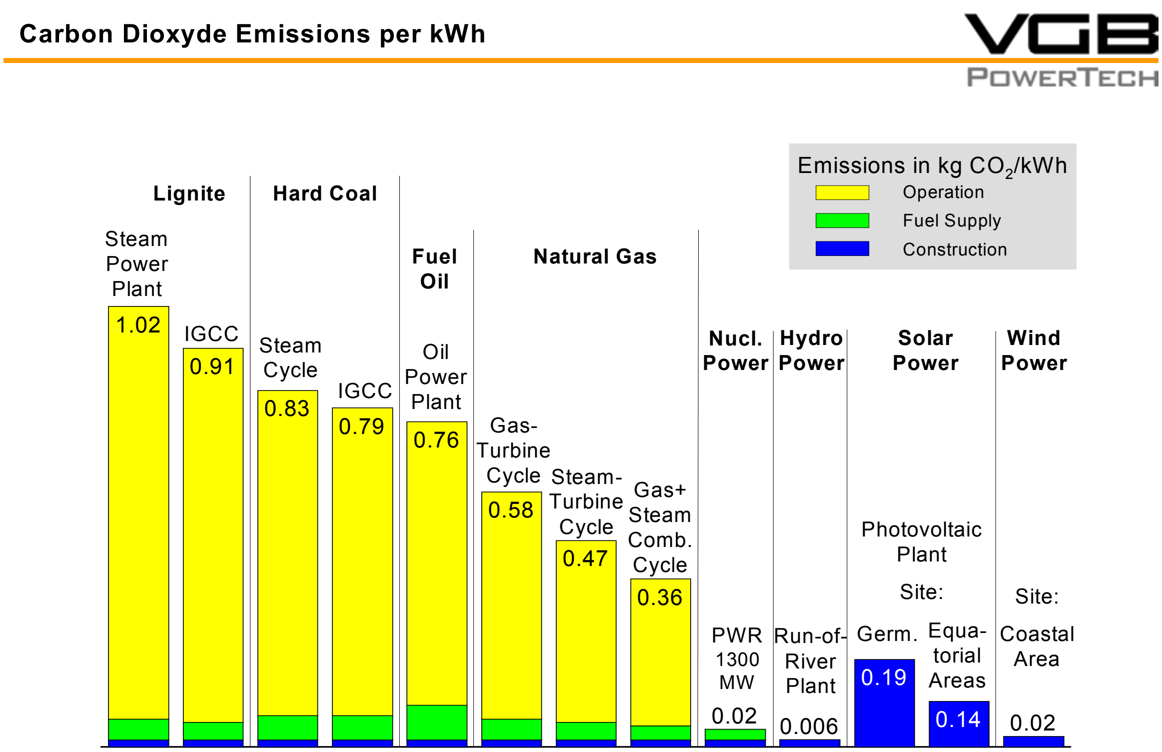
Ref: Jorge A Gil Saraiva, 1996 [10]

Power plants using renewable energy sources do not emit greenhouse gases and other emissions during operation. On the other hand, except for hydro and geothermal power, the net output of such a plant is comparably small, because the energy input (e.g. solar radiation, wind) is not constant and its density is low. Therefore, the expenditure of energy and materials for plant construction per electricity generated is high.

6.3 Comparison of specific CO_2 emissions

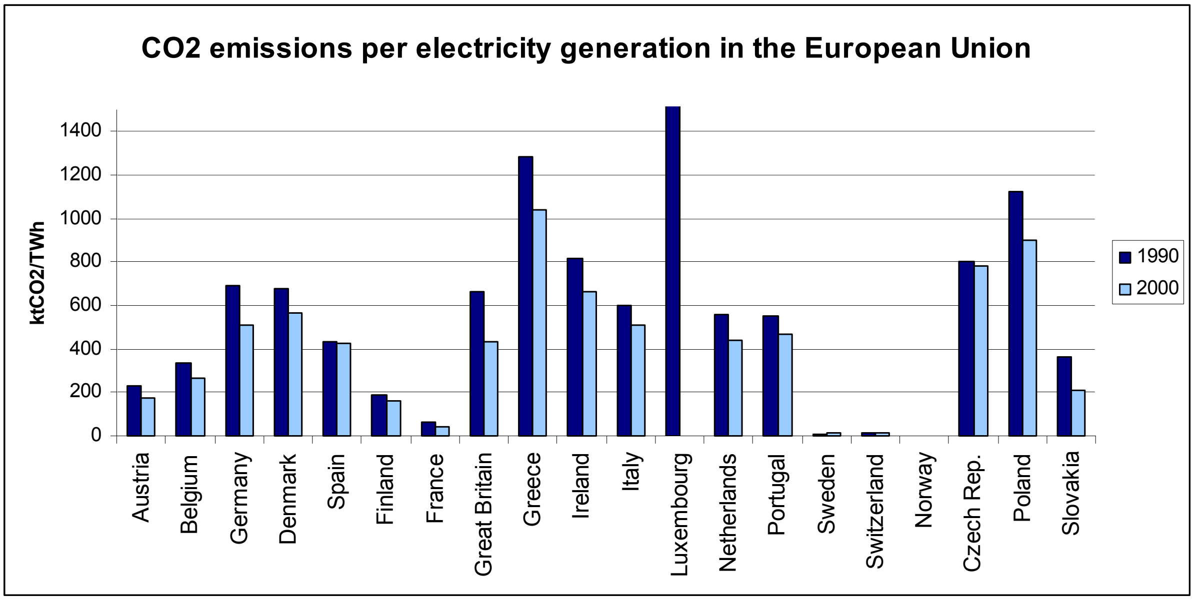
For an overall comparison of specific CO_2 emissions (i.e. kg CO_2/kWh) a full "Life-Cycle Balance", including site erection and fuel supply, is necessary. The graph below shows that the specific emissions cannot be neglected for solar power; on the other hand, nuclear power is very competitive in this sense.

Finally, carbon dioxide emissions are not the only criterion for climate change issues. Some other greenhouse gases like methane have higher Global Warming Potential (GWP) than CO_2. Therefore, gas pipeline leakages for example could have a considerable impact on the Life-Cycle Balance of gas-based power supply, but they are difficult to assess (2% to 8%).



according to Siemens / Voss / VDI-GET 1999

Note that the values presented in the graph below differ from the values "Intensity CO_2 emissions from Thermal Electricity Generation" in the table in page 18, because they refer to specific CO_2 emissions not only per thermal electricity generation but per total electricity generation.



Ref: Eurprog, EURELECTRIC [Luxembourg, 1999 = 7,197 $ktCO_2/TWh$, data from 2000 not available]

VII. POWER PLANT SCALES AND GENERATION COSTS

The following table gives an idea of the typical power plant scale.

Type	Scale (kW)
Nuclear Plant	1,300,000
Coal Plant	500,000
Gas Turbine, Combined-cycle	250,000
Gas Turbine, Single-cycle	100,000
Industrial Co-generation Plant	50,000
Wind Turbine	1,000
Micro-turbine	50
Residential Fuel Cell	7
Household Solar Panel	3
Stirling Engine	1

Ref: Figures agreed through peer review between EURELECTRIC and VGB experts

Total costs of electricity generation per kWh generated comprise the specific costs for capital investment, operation & maintenance and fuel. Regarding full life-cycle balance decommissioning and external effects of emissions (e.g. health, climate) have to be included, although external costs are difficult to assess:

- The total costs of fossil based power generation vary from 3 to 4 eurocent/kWh at current fuel prices, even for natural gas in combined cycle generation. Although investment costs are very low for gas based plants, gas prices vary considerably from time to time in comparison to hard coal and lignite (in some countries fuel tax has to be added). External costs: significant emission reductions are being achieved, but there still remains a negative impact, especially CO_2, that studies show to be 20%, and in some pessimistic view up to 60% of the total costs.

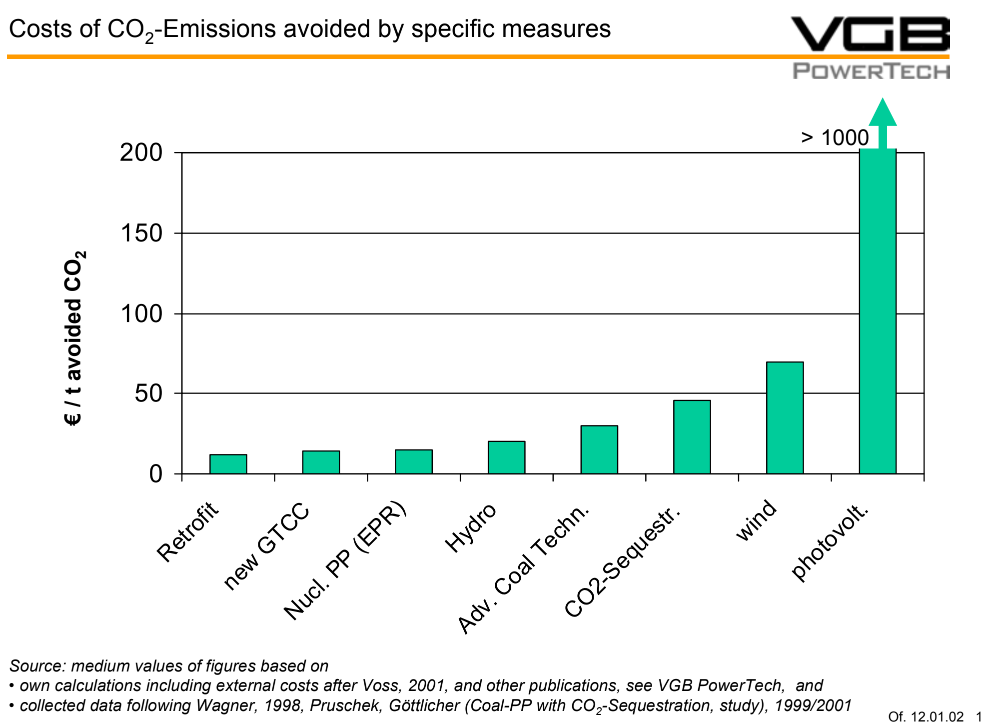
- In general, nuclear systems have in total, competitive costs when compared with fossil fuel generation systems. The investment costs are higher, but today most of these plants only produce for fuel costs and therefore are attractive. The latest design studies like the European Pressurised Water Reactor [EPR] have been completed under the prerequisite to be competitive to coal and even gas at total costs. The external costs are low due to near zero emissions; however, the nuclear waste issue should also be taken into account.

- Hydro and geothermal power are – if at large scale – the only renewable sources providing sufficient energy density and availability to generate power at attractive costs. If investments are paid, large hydro power plants have the lowest total costs, i.e. less than 2 eurocent/kWh. External costs are difficult to estimate (i.e. displacing CO_2-emitting plants) but comparatively low.

- Wind turbines, biomass and solar thermal power plants have total costs of at least 5 eurocent/kWh under optimum conditions. At normal conditions, 10 eurocent/kWh can easily be exceeded. This counts as well for small hydro plants (< 5 MW).

- Total costs from photovoltaic power generation are high: 35 eurocent/kWh can be exceeded even under sunny conditions. To give an example: in Germany photovoltaic power is subsidised around 50 eurocent/kWh, which covers approximately only half of the total costs for photovoltaic application in this country. External costs are relatively small compared to this dimension, but comparable to those of gas-fired power plants.

A key factor for a sustainable – that means ecologically, economically and socially compatible – power supply is the cost of saved $kgCO_2/kWh$. Several studies show [Wagner, Munich, 1997] that this can be done through measures that are relatively cheap to realise – i.e. retrofitting advanced turbine blades – when related to increased power output. In comparison, erecting wind converters could cost up to 10 times more per tCO_2 reduced and photovoltaic systems over 100 times more (see graph below). Consequently, the most cost-effective CO_2 abating technique is improving conventional power supply.



Source: medium values of figures based on
• own calculations including external costs after Voss, 2001, and other publications, see VGB PowerTech, and
• collected data following Wagner, 1998, Pruschek, Göttlicher (Coal-PP with CO_2-Sequestration, study), 1999/2001

VIII. ELECTRICITY GENERATION INDICATORS IN THE EU

The following table presents indicators that characterise some electricity generation aspects in the EU Member States.

Two series of values are presented in the table below: one related to 1985 and the other to 1999.

Some indicators 1985 > 1999	Energy intensity (Gross Inland Consumption/ GDP) toe/1990 MEUR		Import dependency (%)		Electricity Generated/ Capita kWh/inhabitant		Intensity CO_2 emissions from Thermal Electricity Generation tCO_2 emissions from power generation/ GWh Non-Nuclear thermal electricity generated	
AUSTRIA 1985>**1999**	220.5	**186.5**	65.3	**66.1**	5,913.9	**7,458.8**	541	**619**
BELGIUM 1985>**1999**	329.6	**313.3**	69.3	**76.5**	5,813.5	**8,263.8**	838	**590**
DENMARK 1985>**1999**	213.8	**160.2**	77.6	**-13.6**	5,679.6	**7,305.9**	928	**748**
FINLAND 1985>**1999**	297.2	**261.2**	59.2	**51.7**	10,139.7	**13,439.3**	699	**587**
FRANCE 1985>**1999**	251.5	**230.9**	54.1	**51.9**	6,226.7	**8,856.8**	846	**740**
GERMANY 1985>**1999**	315.0	**228.1**	42.1	**59.2**	6,706.5	**6,768.4**	944	**809**
GREECE 1985>**1999**	308.4	**341.9**	60.7	**66.1**	2,791.8	**4,725.6**	1,009	**852**
IRELAND 1985>**1999**	322.4	**202.7**	60.1	**83.1**	3,414.1	**5,888.5**	757	**733**
ITALY 1985>**1999**	182.9	**180.3**	82.0	**80.9**	3,281.4	**4,607.6**	672	**580**
LUXEMBOURG 1985>**1999**	448.1	**269.6**	99.0	**97.3**	2,560.2	**2,374.1**	1,205	**385**
NETHERLANDS 1985>**1999**	320.9	**260.6**	5.8	**29.7**	4,342.1	**5,480.9**	599	**600**
PORTUGAL 1985>**1999**	297.2	**351.3**	75.2	**89.9**	1,908.3	**4,331.7**	697	**655**
SPAIN 1985>**1999**	235.9	**238.9**	60.6	**76.6**	3,314.4	**5,302.4**	907	**761**
SWEDEN 1985>**1999**	290.6	**244.8**	42.2	**35.1**	16,421.4	**17,535.3**	1,105	**455**
UNITED KINGDOM 1985>**1999**	312.9	**252.6**	-15.4	**-20.3**	5,257.7	**6,163.5**	886	**618**

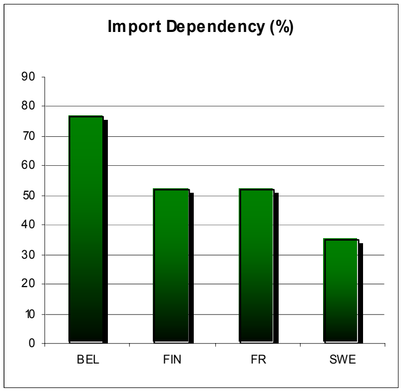
Ref: 2001-Annual Energy Review, January 2002 – European Commission [9]

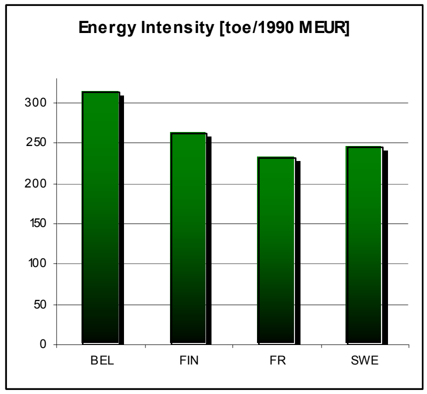
Data from 1999	**EU-15**	**USA**	**Japan**
Average Thermal Efficiency	**39.9%**	**33.3%**	**44.9%**
Consumption/GDP [toe/MEUR]	**231.3**	**396.2**	**198.2**
CO2 emissions/capita [tCO2/inhabitant]	**8.2**	**20.7**	**9.1**
Import dependency	**47.6% [686.6 Mtoe]**	**24.9% [565.2 Mtoe]**	**79.4% [409.2 Mtoe]**

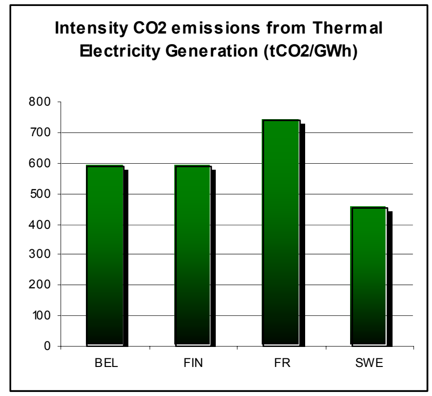
Ref: 2001-Annual Energy Review, January 2002 – European Commission [9]

Reference Year: 1999

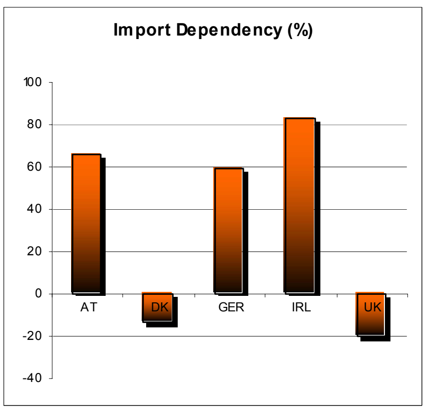
Countries with electricity generated/capita >7500 kWh/inhabitant

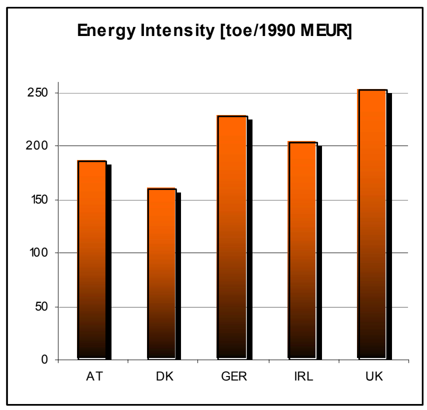


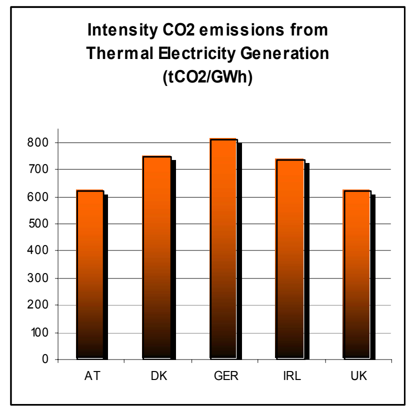




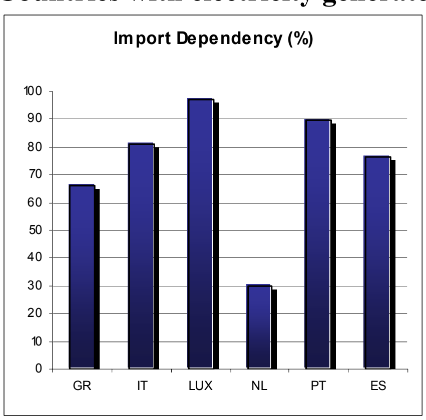
Countries with electricity generated/capita 5500-7500 kWh/inhabitant

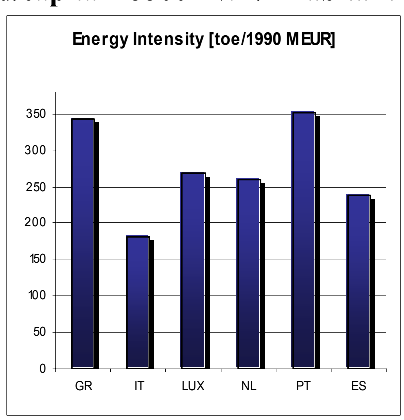


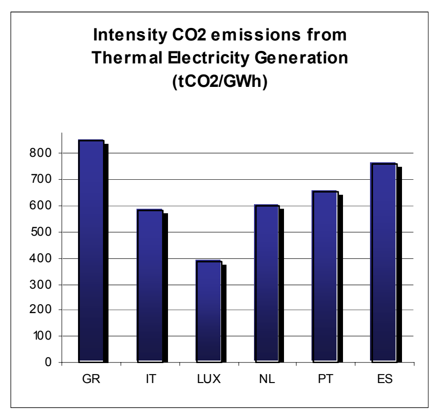




Countries with electricity generated/capita < 5500 kWh/inhabitant







Ref: 2001-Annual Energy Review, January 2002 – European Commission [9]

8.1 EU-15 ELECTRICITY GENERATION MIX

The thermal power plants based on non-renewable resources represent 85.2% of the total electricity generation in the European Union.

Electricity Generation in the EU-15	Year 2000
Conventional thermal	51.8%
Nuclear	33.4%
Hydro & other renewables	14.8%
EU-15 Electricity Generation in the year 2000 = 2,448.6 TWh	

Ref: Eurostat

8.2 ACCESSION COUNTRIES ELECTRICITY GENERATION MIX

The generation mix of the future EU Members States (e.g. Estonia, Latvia, Lithuania, Malta, Cyprus, Czech Republic, Slovakia, Hungary, Poland, Slovenia) which will enter the European Union in 2004, is the following:

Electricity Generation in future 10 EU Member States	Year 2000
Conventional thermal	75.9%
Nuclear	17.9%
Hydro & other renewables	6.2%
Future 10 EU Member States Electricity Generation in the year 2000 = 302,1 TWh	

Ref: Eurprog (data from Malta and Estonia was not available)

IX. THE BENEFITS OF IMPROVING EFFICIENCY

Considering the scarcity of non-renewable energy resources such as: gas-oil, light fuel-oil, heavy fuel-oil, anthracite, coal, butane, natural gas - and the environmental impacts associated with the use of such resources, such as acidification and climate change, there is a need to consider the analysis of the following resources:

– Renewable energy sources: Solar energy, hydro power, tidal power, geothermal power, biomass, wind energy

– Direct energy conversion: Fuel cells, magneto hydrodynamic generators, thermionic converters, semiconductor thermoelectric converters

– CHP supply and combined cycle: Combined Heat and Power, Combined Cycle Power Station

– Multi-energy systems: combining traditional grid power with new technologies (fuel cells, others)[9]

– Advanced combustion technologies and efficient process: Integrated Gasification Combined Cycle, Fluidised bed combustion, Flue Gas desulphurisation process

– Bio-fuel: Methane, Biogas, Bio-diesel

– Nuclear

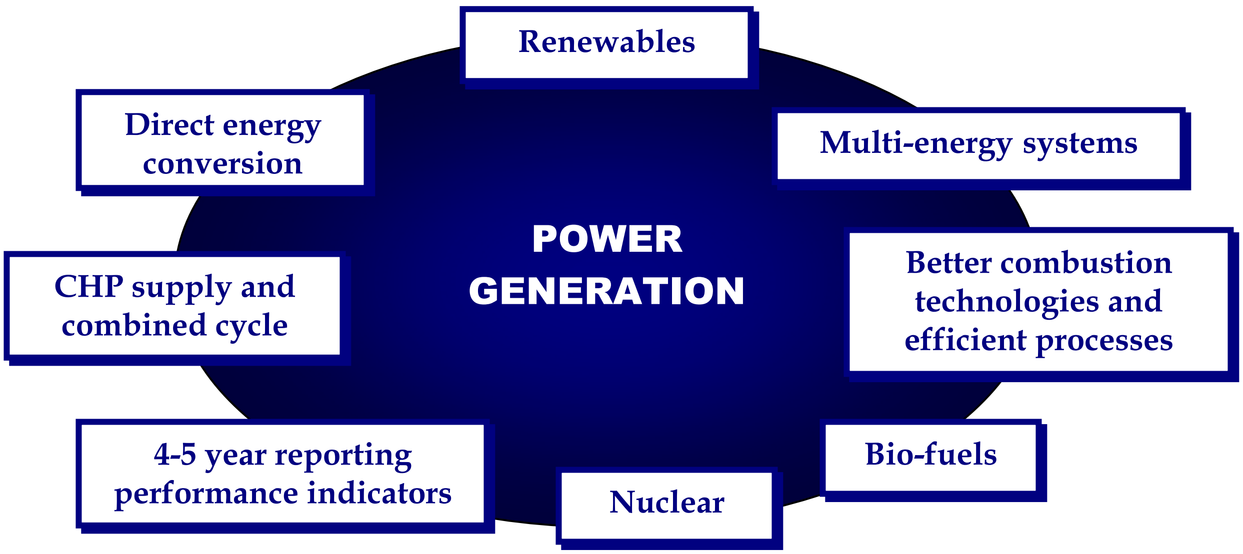
For these resources it is necessary to identify their availability, their potential for technical improvement and the way to promote their implementation.

[9] One example of a multi-energy system could be a combination of a grid power, fuel cells, flywheel energy storage, and diesel engine generator for achieving the quality, availability, and system efficiency desired by the customer from its energy source [4]

It is also important to measure the progress for each country on a regular basis, i.e. every four-five years, with performance indicators, concerning the efficiency process, renewable and combined heat and power contributions, greenhouse gas reductions, such as:

- – Overall efficiency of power plants (%)
- – Electricity RES and CHP as share of total electricity production (%)
- – Overall CO_2 emissions

Main Issues on Preservation of Resources on the Supply-Side



9.1 EFFECTS OF SLIGHT EFFICIENCY IMPROVEMENT

Increasing efficiency even at a very small scale has a remarkable impact on emissions reductions and on fuel consumption. The following table gives an overview on the main figures of fuel consumption and emissions for state-of-the-art power plants and different types of fuel including figures for increased efficiency of +0.1%. Emissions of SO_2, NOx follow the latest EU Directive on Large Combustion Plants.

	Hard Coal	+ 0.1% efficiency	Lignite	+ 0.1% efficiency	Oil	+ 0.1% efficiency	Gas-CC	+ 0.1% efficiency	Nuclear	+ 0.1% efficiency
Output MWel	800		900		500		300		1,000	
Load factor h-peak/a	6,000		7,500		1,000		4,500		7,500	
Energy output MWh_{el}/a	4,800,000		6,750,000		500,000		1,350,000		7,500,000	
El. Efficiency %	42.0%	42.1%	40.0%	40.1%	44.0%	44.1%	57.0%	57.1%	34.0%	34.1%
Fuel Consupt t/a	1,400,000	-3,382	7,790,000	-19,400	98,000	-200	189,000	-331	22	-0.067
Oxygen cons t/a	2,700,000	-6,500	4,900,000	-12,220	248,000	-600	328,000	-574		0
CO_2 emiss. t/a	3,800,000	-8,938	6,750,000	-16,800	341,000	-800	451,000	-790		0
SO_2 emiss t/a	2,700	-7	4,400	-11	240	-1	250	0		0
NO_x emiss t/a	2,700	-7	4,400	-11	240	-1	720	-1		0
Dust emiss t/a	400	-1	700	-2	40	0	40	0		0
Ash t/a	107,000	-254	970,000	-2,400	150	0	0	0		

Ref: Calculations made by VGB following the Emission Limit Values (ELV) required by the Directive on Large Combustion Plant

The table below includes two specific examples, gas fired CHP and a coal fired power plant located in Finland. Here, the efficiency improvement of +0.1% result in 1,000 to 1,500 tons of reduced CO_2 emissions per year.

Reference year 2000	480 MW Natural Gas-fired CHP station	160 MW Coal-fired CHP station
	Vuosaari B	**Salmisaari B**
Capacity MWel	480	160
District heat MW	420	270
Maximum fuel effect MW	974	510
Electricity generation GWh	3,137	710
District heat generation GWh	2,877	1,299
Fuel input GWh	6,635	2,469
Load Factor (h as peak) (*)	6,812	4,841
Improved global efficiency	From 90.6% to 90.7%	From 88.0% to 88.1%
Reduce fuel burn	540t of natural gas	367t of coal
Reduce environmental emissions		
tCO_2	1,487	892
tSO_2	-	1.21
tNO_2	0.93	1.15
tDust	-	0.1
tFly ash	-	41
tBottom ash	-	8
tLime	-	5
tFlue gas end product	-	10

Ref: Helsinki Energy
(*) Fuel input (MWh) / Maximum fuel effect (MW)

There are many different technologies to meet future energy demand *inter alia*:

- Improving efficiencies of established processes,
- Developing and commissioning of advanced and new techniques, some in more decentralised supply structures,

- Fuel switching and replacing old power plants with stations state-of-the-art.

To estimate the impacts on the environment, not only fuel consumption and emissions at the operating period of a power plant need to be calculated, but also construction of the site, fuel supply and decommissioning have to be taken into account. A full Life-Cycle Balance may show in detail that not every new or advanced technique is of advantage.

X. FINAL REMARKS AND NEXT STEPS

- Coal and other fossil fuels dominate world-wide power supply due to their cost-effective usage in large central units – both industrialised countries and developing countries. Though a high standard of fossil fuel conversion techniques has been achieved up to now, further improvement of classical processes is possible, i.e. through advanced steam parameters with new materials. Emission abatement through efficiency improvement at coal fuelled power plant is comparably cheap and therefore has great effects on fuel consumption and environmental impacts.

- Nuclear power avoids large-scale greenhouse gas emissions. Consequently, expanding its use may compensate for fossil fuel power emissions, especially in industrialised countries, which are typically able to raise high capital costs.

- Renewable energy and advanced conversion techniques such as fuel cells will be the future pillar of the fuel mix for power supply – with considerable potential for resource preservation. Much effort will have to be made to reduce costs and to optimise the full life cycle.

- CHP applications have great potential for better fuel utilisation. However, extending CHP has to be calculated carefully for every individual case in comparison to efficient but separate power and heat generation, especially if there is no constant heat demand for the heat load generated.

- Distributed power plants of small scale, especially fuel cells, will contribute more and more to power supply and might contribute to fuel preservation due to their specific high efficiency. Large units will be necessary for economically feasible long term base power supply. Therefore, the two power supply concepts are not competitors but rather complementary.

- For some fuels such as coal, large power plants represent the only way for ecological and economically efficient utilisation. In contrast to gas and oil, coal resources are distributed over many regions of the world and there are vast reserves which could last for hundreds of years.

XI. GLOSSARY

[1][19][30]

Battery	A DC voltage source containing two or more cells that directly convert chemical energy into electrical energy.
Co-generation	A process that generates two different types of usable energy. However, co-generation is in most cases used to describe a process in which waste heat from power generation (such as gas turbine, micro-turbine and fuel cells) is captured and used for other purposes. For example, exhaust heat from a gas turbine can be transferred directly through a heat exchanger and used to heat water for residential or commercial use.
Combined heat and power (CHP)	Another term for co-generation. See above.
Distributed generation (DG)	Any power generation capability at the point of use rather than a central power generation facility. Types of DG include conventional combustion generators as well as micro-turbines, fuel cells, photovoltaics and wind generators.
Efficiency	Useable energy output divided by energy input.
Emission	Discharge of substances into the atmosphere, water or soil. The point or area from which the discharge takes place is called the "source". The term is used to describe the discharge, the amount of discharge, and the rate of discharge (per m^3 or kWh), which can be indicated as concentration or specific emission. The term can also be applied to noise, heat, etc.
Energy indicator	Indicator used either to chart trends in the energy or economic situation of a given geographical or economical unit over a period of time, or to compare the energy situations of different units. Energy indicators may also be used to chart macroeconomic trends or changes in the standard of living, given the importance of energy to a country's economy on the one hand and to household expenditure on the other. Note: Energy consumption per capita, frequently used as a standard of living indicator, must be used for this purpose with great care, as a high level of consumption may be the result of bad management (and vice-versa), and differences in accounting systems and procedures may conceal major differences.
Energy intensity	Ratio between gross energy domestic consumption (see Gross Inland Consumption) or final energy consumption (see Final Energy Consumption) and gross domestic product (see Gross Domestic Product). Note: The indicator is very important for charting trends in the energy content of an economic system or of a country's energy efficiency.
Energy sources	All sources (primary or derived) from which useful energy can be recovered directly or by transformation. The terms "energy sources", "forms of energy", "energy agents", "energy" and "energy vectors" are interchangeable in many contexts. Note: It is recommended that each source of energy be called by its specific name, as the generic terms can lead to confusion. For

	example, "new energy" can be applied to energy sources that have been exploited more systematically or with the help of more sophisticated techniques. Likewise, "conventional energy" which often refers to fossil fuels and partly to electrical energy is a very relative concept, and one which changes with time. As for "renewable energy sources", they may be continually renewable (permanent flux), renewable in short cycles (annual, for example), over a period of one or more generations; or may be partly or completely renewable. The names "energy flux" and "energy stock" are sometimes used to distinguish between "renewable energy sources" and "non-renewable energy sources. Furthermore, some terms such as "soft energy sources" or "hard energy sources" which do not correspond to any physical reality have a sociological rather than technical or economic meaning. All these generic terms can thus be used validly with a very indicative and qualitative meaning.
Final energy consumption	Energy consumed by the final user for all energy purposes (1)
Fuel cell	A device that generates a relatively small amount of electricity from fuels through an electro-chemical process rather than from combustion. In the most common case, a catalyst strips electrons from hydrogen proton and oxygen in the air to produce water and heat as a by-product. Hydrogen fuel cells are characterised as having high electrical efficiencies with zero harmful emissions.
Gas turbine	An engine (based upon the jet engines used on aircraft) used to power electrical generators in major power plants. Gas turbines run on natural gas and are characterised by having low investment costs, short construction time, no need for thermal cycle cooling, low environmental impact and very low maintenance requirements. Power output can vary from a couple of megawatts to several hundred megawatts.
Gross domestic product	Total production of goods and services by the subjects of a country and foreigners within national borders (2)
Gross inland energy consumption	Gross consumption minus bunkers: final energy consumption plus energy sector's own consumption and losses.
Higher heating value (Gross calorific value)	Quantity of heat liberated by the complete combustion of a unit volume or weight of a fuel in the determination of which the water produced is assumed completely condensed and the heat recovered.
Level of energy dependency	Quotient of net energy imported and the total amount of energy consumed within a given geographical or economic unit, for a given time period, e.g. one year. It is also possible to calculate this ratio for a specific energy source. It is also possible to work out the level of energy independence, which is the quotient of primary energy production divided by total energy consumption within a geographic or economic unit. This gives a rough indication of the coverage of needs by primary energy production. a) These two levels are not complementary in that changes in stocks may mean that the two percentages, when added together, do not equal 100%. b) When a country is a net exporter of energy, the level of energy dependency may be negative.
Lower heating value (net calorific	Quantity of heat liberated by the complete combustion of a unit

value)	volume or weight of a fuel in the determination of which the water produced is assumed to remain as a vapour and the heat not recovered.
Micro-grid	A group of power generators, connected with intelligent switchgear and remote controls to supply the electricity demands of local users. A typical micro-grid might have an output of about 10 MW.
Micro-turbine	A small turbine-engine powered electric generation plant. Like the larger gas turbine used in major power generating facilities, micro-turbines also have one moving part: the turbine shaft. Micro-turbines are very low maintenance, efficient, fairly quiet and come in various outputs ranging from 30kW to 75 kW. Micro-turbines can run on numerous fuels and can also be linked together to provide outputs of several megawatts.
Net energy of an energy-producing installation	The gain in energy obtained from an energy-production installation during an assumed lifespan; in other words, the amount of energy produced during that period, all the energy required for the construction, operation and subsequent dismantling of the installation.
Performance of consumer equipment	The ratio of the useful energy produced by the consumer equipment to the energy supplied to it. Note: A distinction is made between theoretical performance in set conditions and actual performance in real conditions. The second level of performance is generally lower than the first.
Photovoltaic(s) (PVs)	Pertains to the direct conversion of light into electricity.
Photovoltaic cell	Component commonly called a solar cell that can convert light energy into electrical energy. Cells can be combined to form an array to provide greater overall output.
Pollutant	Any physical or chemical characteristic or material present in environmental media (air, water, soil), emitted either by human activities or by natural processes, and adversely affecting man or the environment.
Photovoltaic module	A number of photovoltaic cells electrically interconnected in either series or parallel and mounted together, usually in a sealed unit of convenient size for shipping, handling and assembling into panels and/or arrays. The term “module” is often used interchangeably with the term “panel”.
Uninterruptible power supply (UPS)	A device that supplies back-up power to electronic equipment. When an electrical surge, sag or outage is sensed, can instantly switch from grid-supplied power to a back-up power supply such as a battery. The end result is a constant, clean supply of power to the end-using equipment. UPS’s come in sizes ranging from units that can supply a couple of hundred watts to a laptop, to units that supply megawatts of power to entire data centres.

NOTES:

1. Own consumption by energy industries: The consumption of self-produced and of purchased energy by energy producers and transformers in operating their installations, (e.g. heating, light).

Note: For hydraulic pumping, the balance resulting from pumping (difference between electricity produced and electricity consumed for pumping) is generally ascribed to the consumption by the electricity sector; the consumption by auxiliaries is included in this entry.

2. Gross National Product (GNP): Total productions of goods and services by the subject of a country at home and abroad. In national income accounting, it is a measure of the performance of nation's economy, within a specific accounting period (usually a year).

    2.1 The concepts and measuring relevance are increasingly being brought into question because, as a monetary measure, many welfare transactions are not taken into account (such as the shadow economy, exchange of goods or services, household work).

    2.2 As a rule the GNP is simultaneously drawn up and presented in three aspects: its formation, distribution, and consumption.

    2.3 The nominal GNP (market price) is fundamentally distinguished from the real GNP (prices of the base year), with the sole purpose of recording the quantitative changes.

Equivalences
Typical reference values

1 kWh = 0,860 Mcal	Heat equivalent of 1 kWh	Electricity equivalent of 1 tonne of Fuel
1 cal = 4,1868 Joules	1 kWh = 86 gram Oil equivalent	1 tonne of Oil <> 11 628 kWh
1 tonne of Oil = 10 000 Mcal	1 kWh = 123 gram Coal equivalent	1 tonne of Coal <> 8 140 kWh
1 tonne of Coal = 7 000 Mcal	1 kWh = 79.7 gram Natural Gas equivalent	1 tonne of Natural Gas <> 12 547 kWh
1 tonne of Natural Gas = 10 790 Mcal		

Note: The unit "toe" (tonne of oil equivalent) is commonly used to compare the energy content of different fuels.

References

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