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Private Costs of Electricity and Heat Generation

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1. Introduction

This deliverable is written in the framework of the CASES (Cost Assessment of Sustainable Energy Costs), which is an European Commission funded Coordination Action. In this project a comprehensive analysis of the examination of private and external costs is made. The objective of this paper is to present best predictions about the evolution of the private costs of different technologies of electricity and heat generation up to 2030. Chapter 2 illustrates the methodology for determination the private costs, on the basis of the Average Levelised Generating Costs (ALLGC). The energy price assumptions of the fossil nuclear energy systems are briefed in the following chapter of the report. Chapter 4 is a broad look at the current most important technologies and potentially future (most important) technologies of electricity and heat generation. Each of these technologies has been scrutinized, especially with regard to its potential for further development in the future. Chapter 5 represents analysis about the preliminary results of private costs of selective heat and electricity generation technologies.

2. Methodology – Private Cost Calculating

2.1. Average Lifetime Levelised Generating Costs

Objective of this chapter is to introduce briefly the approach followed, to provide the equations used for calculating levelised costs and to distinguish the essential parameters needed for calculations. The methodology calculates the generation costs on the basis of net power supplied to the station busbar, where electricity is fed to the grid. This cost estimation methodology discounts the time series of expenditures to their present values in a specified base year by applying a discount rate. A discount rate takes into account that the time value of money does not have the same value as the same sum earned or spent today. The levelised lifetime cost per kWh of electricity generated is the ratio of total lifetime expenses versus total expected outputs, expressed in terms of present value equivalent /IEA 2005/. This cost is equivalent to the average price that would have to be paid by consumers to repay exactly the investor/operator for the capital, fuel expenses and operation and maintenance expenses, inclusive the rate of return equal to discount rate. The date selected as base year is for the following calculations in chapter five year 2005. Hence the normal inflation is excluded from the calculations.

The formula to calculate for each power plant, the Average Lifetime Levelised Generating Costs is:

$$\sum_{t=0}^{T} \frac{\overline{p} \cdot E}{1+r_t} - \sum_{t=0}^{T} \frac{I_t + M_t + F_t}{(1+r)^t} = 0$$

From this follows the ALLGC to:

$$ALLGC = \frac{\sum_{t=0}^{T} \frac{[I_t + M_t + F_t]}{(1+r)^t}}{\sum_{t=0}^{T} \frac{[E_t]}{(1+d)^t}}$$

I_t	= Investment expenditures in year t
M_t	= Operation and Maintenance expenditure in year t
F_t	= Fuel expenditures in year t
E_t	= Electricity generation in year t
r	= Discount rate
ALLGC	= Average Lifetime Levelised Generating Costs ($\overline{p}$)

The capital (investment) expenditures in each year include construction, refurbishment and decommissioning expenses. A methodology which is widely adopted to assume capital costs, i.e. by OECD, is to define the specific overnight construction cost (OIC) in €/kW and the expense schedule from the construction period. The overnight construction cost is defined as the total of all costs incurred for building the plant immediately. Interest rate during construction can deviate from the general adopted discount rate, and the costs are expressed in terms of percentage of OIC. The capital costs are part of the levelised generation cost, which is the basis for cost comparisons and assessments.

The fuel price assumptions of fossil and nuclear plants are described in chapter 3.

Operating and Maintenance (O&M) costs contribute a small but no negligent fraction to the total cost.

- Fixed O&M costs [€/kWa] include cost of the operational staff, insurances, taxes etc.
- Variable O&M costs [€/MWh] include cost for maintenance, contracted personnel, consumed material (i.e. operating materials, operating fluids) and cost for disposal of normal operational waste (exclude radioactive waste)

The discount rate that is considered appropriate for the energy sector may differ from plant to plant. In this paper, two interest rates were used: 5% and 10%.

Private cost of generating electricity may include in addition to the ALLGC also other cost items that may vary from plant to plant. Possible items may be environmental taxes on fuels, carbon emission charges, system integration costs, etc.. For the purpose of comparison only the ALLGC costs are reported here as private costs.

3. Assumptions

3.1. Fuel prices

For the projection of future heat and electricity production costs fuel price assumptions of the used energy carriers are necessary. Fuel price assumptions are generally to be burdened with the restricted projection methodology, due to the high uncertainties by a given market and the law of demand and supply. Lignite and biomass (straw, wood chips, biogas) are local energy carriers, which are not included in an international price mechanism. Taking inflation into account the fuel prices of these two types of energy carriers will be constant. Of particular noteworthiness for nuclear power is that the total fuel cycle costs are considered (natural uranium, conversion, enrichment, intermediate and final disposal). In the projections, the oil price is gradually increasing at the beginning. Naturally gas is following a similar pattern. After 2030 constant prices for all energy carriers are assumed.

Table 1 Fuel price assumptions on plant level /EUSUSTEL 2006/; /NEEDS 2006/

Energy Carrier	Unit	2005	2010	2015	2020	2025	2030
Coal	[EUR/GJ]	1,96	1,86	1,97	2,07	2,14	2,19
Lignite	[EUR/GJ]	0,97	0,98	0,98	0,98	0,98	0,98
Natural gas	[EUR/GJ]	6,11	6,32	6,03	5,95	6,62	6,63
Oil	[EUR/GJ]	6,65	5,35	5,39	5,82	6,70	7,14
Light Oil	[EUR/GJ]	9,83	8,53	8,57	9,01	9,89	10,32
Nuclear Repository	[EUR/GJ]	0,62	0,62	0,62	0,62	0,62	0,62
Biomass (Wood chips)	[EUR/GJ]	6,00	6,00	6,00	6,00	6,00	6,00
Biomass (Straw)	[EUR/GJ]	6,00	6,00	6,00	6,00	6,00	6,00
Biogas	[EUR/GJ]	6,00	6,00	6,00	6,00	6,00	6,00

3.2. Heat credits for Combined Heat and Power

An important distinction needs to be made in comparing electricity power plants with combined heat and power plants (CHP`s), which use rejected heat with typical simple processes. The value of heat recovery can be measured by the cost avoided in using recovered thermal energy for a specific purpose, as opposed to using another source of energy. Most commonly, recovered heat replaces thermal energy output from some type of fuel-burning-equipment, usually a boiler. In this case, the value of recovered thermal energy is equivalent to the cost of fuel energy that would have otherwise been consumed. The displayed energy is commonly referred to as an energy credit or fuel credit. The amount of energy displaced by recovered heat is a function of the efficiency of the displaced boiler (or other heating equipment). The alternative heat generation technology in this report is given by a gas boiler with an efficiency of 90%.

3.3. Back-Up costs

The introduction of the intermittent renewable energies, like wind or solar power, affects the electricity generating system. The inflexibility, variability, and relative unpredictability of

intermittent energy sources are the most obvious barriers to an easy integration and widespread application of wind and solar power. Due to the fluctuation caused by producing energy with wind and solar plants, a back-up technology is necessary for compensating this. The back-up cost of not assured generating power of solar and wind plants can be calculated by means of the following equation /Friedrich 1989/.

$$C_{BU} = \frac{A_k}{h_v} - \frac{A_k \cdot P}{h_w} = A_k \cdot \left(\frac{1}{h_F} - \frac{P}{h_W} \right)$$

C_{BU} = Cost Back-Up

h_v = Full loading hours, supply

h_w = Full loading hours of the renewable power station

P = Power credit of the renewable energy plant

A_k = Annuity, incl. the annual fix costs of the Back-Up technology

In this equation, the provision of the back-up power is reduced by a capacity factor (P) for the renewable technologies /Kruck 2004/. Back-Up technologies here are a hard coal condensing power plant for minimum back-up costs, and a gas-fired CCGT plant for maximum back-up costs.

4. Technologies

Table 2 Heat and electricity generation technologies 2007

type of power plant	energy carrier	technology of electricity generation	max. net el. power (busbar)	net el. power at el. peak load	net el. power at thermal peak load	net thermal power at thermal peak load	el. efficiency at el. peak load	el. Efficiency at thermal peak load	thermal efficiency at thermal peak load	availability factor (full load hours)	technical life time	spec. Investment costs (overnight capital costs)	interest cost during construction period	guarding costs for period between shut-down and demolition	spec. demolition costs (greenfield)	fixed costs of operation	other variable costs
			[MW]	[MW]	[MW]	[MW]	[%]	[%]	[%]	[h/a]	[a]	[€/kW$_{el}$]	%	[Mio. €]	[€/kW$_{el}$]	[€/kW$_{el}$/yr]	[€/MWh$_{el}$]
nuclear power plant	nuclear power	PWR (Pressurized Water Reactor)	1000	1000			33			7500	40	1550	10,8	52,15	237,75072	38,55	0,98
		PBMR (Pebble Bed Modular Reactor)															
fossil fired power plant	heavy fuel oil	condensing power plant	350	350			43			7500	35	720	8,2		32,5	50,0	1,5
	light oil	gas turbine	50	50			36			7500	35	250	5,4		0,0	11,5	2,0
	hard coal	condensing power plant	600	600			46			7500	35	920	8,2		32,5	40,5	2,6
		IGCC	450	450			45			7500	35	1200	8,2		50,0	52,5	3,1
		IGCC power plant with CO2 sequestration															
	lignite	condensing power plant	965	965			44,5			7500	35	1300	8,2		30,0	38,0	1,0
		IGCC	450	450			44			7500	35	1200	8,2		50,0	52,5	3,1
		IGCC power plant with CO2 sequestration															
	natural gas	combined cycle	800	800			57,5			7500	35	440	5,4		15,0	19,0	1,5
		Combined Cycle plant with CO2 sequestration															
		gas turbine	50	50			38			7500	35	250	4		0,0	11,5	2,0
electricity generation based on renewables	hydro	run of river	0,01	0,01			85			5000	70	5850	10		0,0	59,0	0,0
			<0,1	<0,1			85			5000	70	5500	10		0,0	55,0	0,0
			>0,1	>0,1			85			5000	70	3500	10,8		0,0	45,0	0,0
		dam	0,1	0,1			83			3000	120	3500	10,8		0,0	45,0	0,0
		pump storage	0,5	0,5			72			3000	120	3500	10,8		0,0	45,0	0,0
		tidal power															
	wind	on-shore	2	2			100			2628	20	1000	0		0,0	40,0	0,0
		off-shore	2	2			100			4044	20	1650	0		0,0	60,0	0,0
	PV	poly cristalline, roof	0,00312	0,00312			15			1071	25	9400	0		0,0	94,0	0,0
		poly cristalline, open space	0,00312	0,00312			15			1071	25	6500	0		0,0	65,0	0,0
	solar thermal	solar trough	50	50			15,7			3820	30	3360	0		3,0	50,4	0,0
CHP with an extraction condensing turbine	natural gas	combined cycle	200	200	167	167	54	45	44	7500	35	570	5,4		15,0	30,0	1,5
		Combined cycle with CO2 sequestration															
	hard coal	condensing power plant	500	500	429	583	42,5	35	53	7500	35	1070	8,2		32,5	47,5	2,6
		IGCC with CO2 sequestration															
CHP back pressure turbine	natural gas	combined cycle	200	200		200		45	45	7500	35	550	5,4		15,0	27,5	1,5
	hard coal	CHP back pressure	200	200		285,7		35	50	7500	35	1200	8,2		32,5	56,0	2,6
Biomass CHP with an extraction condensing turbine	straw	power plant with an extraction condensing turbine	6,1	6,1		22,0		19,5	50,1	7500	30	2600	0		3,0	106,6	
	wood chips	power plant with an extraction condensing turbine	6,1	6,1		22,0		19,5	50,1	7500	30	1750	0		3,0	71,8	
fuel cells	natural gas	MCFC	2,5	0,25		0,175		48	34	7500	7	8000	0		3,0	440,0	14,0
		SOFC	0,2	0,2		0,176		44	38	7500	7	11000	0		3,0	605,0	14,0
	biogas	MCFC	2,5	0,25		0,175		48	34	7500	7	8000	0		3,0	440,0	14,0

Table 3 Heat and electricity generation technologies 2020

type of power plant	energy carrier	technology of electricity generation	max. net el. power (busbar)	net el. power at el. peak load	net el. power at thermal peak load	net thermal power at thermal peak load	el. efficiency at el. peak load	el. Efficiency at thermal peak load	thermal efficiency at thermal peak load	availability factor (full load hours)	technical life time	spec. Investment costs (overnight capital costs)	interest cost during construction period	guarding costs for period between shut-down and demolition	spec. demolition costs (greenfield)	fixed costs of operation	other variable costs
			[MW]	[MW]	[MW]	[MW]	[%]	[%]	[%]	[h/a]	[a]	[€/kW_{el}]	%	[Mio. €]	[€/kW_{el}]	[€/kW_{el}/yr]	[€/MWh_{el}]
nuclear power plant	nuclear power	PWR (Pressurized Water Reactor)	1000	1000			33			7500	40	1335	10,8	51	232,5	37,7	0,51
		PBMR (Pebble Bed Modular Reactor)															
fossil fired power plant	heavy fuel oil	condensing power plant	350	350			43			7500	35	720	8,2		32,5	50,0	1,5
	light oil	gas turbine	50	50			38			7500	35	225	5,4		14,8	0,0	0,0
	hard coal	condensing power plant	600	600			50			7500	35	895	8,2		32,5	40,5	2,6
		IGCC	450	450			54			7500	35	1100	8,2		50,0	52,5	3,1
		IGCC power plant with CO2 sequestration	450	450			48			7500	35	1370	8,2		55,0	65,0	3,6
	lignite	condensing power plant	965	965			50			7500	35	900	8,2		30,0	33,0	1,0
		IGCC	450	450			52			7500	35	1100	8,2		50,0	52,5	3,1
		IGCC power plant with CO2 sequestration	450	450			46			7500	35	1370	8,2		55,0	65,0	3,6
	natural gas	combined cycle	1000	1000			62			7500	35	385	5,4		15,0	18,0	1,5
		Combined Cycle plant with CO2 sequestration	1000	1000			56			7500	35	925	5,4		15,0	52,5	1,7
		gas turbine	50	50			39			7500	35	220	4		0,0	11,5	2,0
electricity generation based on renewables	hydro	run of river	0,01	0,01			85			5000	70	5850	10		0,0	59,0	0,0
			<0,1	<0,1			85			5000	70	5500	10		0,0	55,0	0,0
			>0,1	>0,1			85			5000	70	3500	10,8		0,0	45,0	0,0
		dam	0,1	0,1			83			3000	120	3500	10,8		0,0	45,0	0,0
		pump storage	0,5	0,5			72			3000	120	3500	10,8		0,0	45,0	0,0
		tidal power															
	wind	on-shore	2	2			100			2628	20	970	0		0,0	40,0	0,0
		off-shore	2	2			100			4044	20	1540	0		0,0	60,0	0,0
	PV	poly cristalline, roof	0,00312	0,00312			15			1071	25	3000	0		0,0	40,0	0,0
		poly cristalline, open space	0,00312	0,00312			15			1071	25	2500	0		0,0	29,4	0,0
	solar thermal	solar trough	50	50			20			3820	30	2710	0		3,0	40,7	0,0
CHP with an extraction condensing turbine	natural gas	combined cycle	200	200	159	148	58	46	43	7500	35	570	5,4		15,0	27,5	1,5
		Combined cycle with CO2 sequestration	200	200	137,9	148	52	40	43	7500	35	1070	5,4		15,0	60,0	1,7
	hard coal	condensing power plant	500	500	400	578	45	36	52	7500	35	1080	8,2		32,5	46,5	2,6
		IGCC with CO2 sequestration	450	450	331	434	45	35	46	7500	35	1520	8,2		60,0	70,0	3,6
CHP back pressure turbine	natural gas	combined cycle	200	200		191,3		46	44	7500	35	500	5,4		0,0	25,0	2,0
	hard coal	CHP back pressure	200	200		275,7		37	51	7500	35	1195	8,2		32,5	54,5	2,6
Biomass CHP with an extraction condensing turbine	straw	power plant with an extraction condensing turbine	6,1	6,1		22,0		19,5	50,1	7500	30	2200	0		3,0	106,6	
	wood chips	power plant with an extraction condensing turbine	6,1	6,1		22,0		19,5	50,1	7500	30	1600	0		3,0	71,8	
fuel cells	natural gas	MCFC	2,5	0,25		0,17		50	34	7500	7	1000	0		3,0	55,0	14,0
		SOFC	0,2	0,2		0,114		56	32	7500	7	1000	0		3,0	55,0	14,0
	biogas	MCFC	2,5	0,25		0,2075		46	38	7500	7	1000	0		3,0	55,0	24,0

Table 4 Heat and electricity generation technologies 2030

type of power plant	energy carrier	technology of electricity generation	max. net el. power (busbar)	net el. power at el. peak load	net el. power at thermal peak load	net thermal power at thermal peak load	el. efficiency at el. peak load	el. Efficiency at thermal peak load	thermal efficiency at thermal peak load	availability factor (full load hours)	technical life time	spec. Investment costs (overnight capital costs)	interest cost during construction period	guarding costs for period between shut-down and demolition	spec. demolition costs (greenfield)	fixed costs of operation	other variable costs
			[MW]	[MW]	[MW]	[MW]	[%]	[%]	[%]	[h/a]	[a]	[€/kW$_{el}$]	%	[Mio. €]	[€/kW$_{el}$]	[€/kW$_{el}$/yr]	[€/MWh$_{el}$]
nuclear power plant	nuclear power	PWR (Pressurized Water Reactor)	1000	1000			33			7500	60	1335	10,8	51	232,5	37,7	0,51
		PBMR (Pebble Bed Modular Reactor)															
fossil fired power plant	heavy fuel oil	condensing power plant	350	350			43			7500	35	720	8,2		32,5	50,0	1,5
	light oil	gas turbine	50	50			38			7500	35	225	5,4		14,8	0,0	0,0
	hard coal	condensing power plant	600	600			52			7500	35	895	8,2		32,5	40,5	2,6
		IGCC	450	450			54,5			7500	35	1100	8,2		50,0	52,5	3,1
		IGCC power plant with CO2 sequestration	450	450			48,5			7500	35	1370	8,2		55,0	65,0	3,6
	lignite	condensing power plant	965	965			50			7500	35	900	8,2		30,0	33,0	1,0
		IGCC	450	450			52,5			7500	35	1100	8,2		50,0	52,5	3,1
		IGCC power plant with CO2 sequestration	450	450			46,5			7500	35	1370	8,2		55,0	65,0	3,6
	natural gas	combined cycle	1000	1000			63			7500	35	385	5,4		15,0	18,0	1,5
		Combined Cycle plant with CO2 sequestration	1000	1000			57			7500	35	925	5,4		15,0	52,5	1,7
		gas turbine	50	50			40			7500	35	220	4		0,0	11,5	2,0
electricity generation based on renewables	hydro	run of river	0,01	0,01			85			5000	70	5850	10		0,0	59,0	0,0
			<0,1	<0,1			85			5000	70	5500	10		0,0	55,0	0,0
			>0,1	>0,1			85			5000	70	3500	10,8		0,0	45,0	0,0
		dam	0,1	0,1			83			3000	120	3500	10,8		0,0	45,0	0,0
		pump storage	0,5	0,5			72			3000	120	3500	10,8		0,0	45,0	0,0
		tidal power															
	wind	on-shore	2	2			100			2628	20	950	0		0,0	40,0	0,0
		off-shore	2	2			100			4044	20	1370	0		0,0	60,0	0,0
	PV	poly cristalline, roof	0,00312	0,00312			15			1071	25	2750	0		0,0	40,0	0,0
		poly cristalline, open space	0,00312	0,00312			15			1071	25	2000	0		0,0	19,4	0,0
	solar thermal	solar trough	50	50			22			3820	30	2500	0		3,0	37,5	0,0
CHP with an extraction condensing turbine	natural gas	combined cycle	200	200	159	142	59	47	42	7500	35	570	5,4		15,0	27,5	1,5
		Combined cycle with CO2 sequestration	200	200	139	142	53	41	42	7500	35	1070	5,4		15,0	60,0	1,7
	hard coal	condensing power plant	500	500	402	554	46	37	51	7500	35	1080	8,2		32,5	46,5	2,6
		IGCC with CO2 sequestration	450	450	336	420	45,5	36	45	7500	35	1520	8,2		60,0	70,0	3,6
CHP back pressure turbine	natural gas	combined cycle	200	200		187,1		46,5	43,5	7500	35	500	5,4		15,0	25,0	1,5
	hard coal	CHP back pressure	200	200		263,2		38	51	7500	35	1195	8,2		32,5	54,5	2,6
Biomass CHP with an extraction condensing turbine	straw	power plant with an extraction condensing turbine	6,1	6,1		22,0		19,5	50,1	7500	30	2200	0		3,0	106,6	
	wood chips	power plant with an extraction condensing turbine	6,1	6,1		22,0		19,5	50,1	7500	30	1600	0		3,0	71,8	
fuel cells	natural gas	MCFC	2,5	0,25		0,25		50	50	7500	7	1000	0		3,0	55,0	14,0
		SOFC	0,2	0,2		0,12		56	33	7500	7	750	0		3,0	41,3	14,0
	biogas	MCFC	2,5	0,25		0,25		50	50	7500	7	1000	0		3,0	55,0	24,0

4.1. Nuclear Power Plants

In 2004 in EU-25, nuclear energy represented 31 % of the electricity produced in the European Union and 15 % of the total energy consumed. Although until recently the public in some countries has had a rather negative attitude towards nuclear energy – which originates largely from the Chernobyl accident, a global comeback seems to be possible. Nuclear energy is one of the energy systems with the lowest greenhouse gas emissions and has a high price stability of the generated electricity. However, a pre-condition for further development of the nuclear power is the solution of the issues linked to the management of radioactive waste.

Current Technologies (2007)

Nuclear fission reactors produce and control the release of energy from splitting the atoms (like uranium 235 or 233 or plutonium 239) of certain elements. In a nuclear power reactor, the energy released is used as heat to make steam to generate electricity. Nowadays, the most commonly used reactor is the Light Water Reactor (LWR), which uses enriched uranium as fuel and water both as coolant and moderator. Two types of Light Water reactors are mostly used the Pressurized Water Reactor (PWR) and the Boiling Water Reactor (BWR). The electrical efficiency of nuclear power plants is restricted due to the low operating temperatures, so that efficiency is about 33%.

The availability of modern reactors varies from 80 to 95%. The output of power from large reactors can change with 30 to 40 MW per minute /MIT 2003/, but the technical minimum is 25%. A typical lifetime for current reactors is 40 to 60 years.

Future Technologies (2020, 2030)

The industry of nuclear power has been developing and improving reactor technology for almost five decades and is preparing for the next generations. The evolutions can be divided into two categories.

The first one is the further development of current standard reactors, which are called “generation III” reactors. Third-generation reactors are still thermal reactors, but with higher availability and longer operating lifetime (60 years), improved safety (reduced possibility of core melt accidents), higher burn-up to reduce fuel use and the amount of waste, smaller investment costs.

The second one is the “generation IV” reactors. An international workgroup is developing six nuclear reactors technologies for commercially deployment after 2030. Those types of reactors employ a closed fuel cycle to maximise the resource base and minimise high-level wastes to be sent to a repository. Most types of generation IV reactors will be fast reactors with a reinforced safety system. It is assumed that the mostly future reactor designs will not be cooled by light water, but by helium, sodium lead-bismuth and molten salt. One of the main issues is to be tackled with the costs, but one objective of the international work group is to present design concepts with lower investment costs than 1000 US-$/kW /GIF 2002/.

4.2. Fossil Power Plants

Fossil-fired energy technologies are very widely used worldwide. In 2005, more than 80% of the worldwide primary energy need and nearly two-thirds of the worldwide electricity demand is met by fossil energy carriers.

4.2.1. Hard coal- and Lignite-fired power plants

Among the existing technologies for electricity generation from fossil fuels, coal-fired power plants have dominated electricity production for several years. More than 40% of the worldwide electricity is generated by coal-fired power plants in 2005 /IEA 2007/. The fuel costs represent approximately 40% of the total electricity production cost. Technologies for electricity generation from coal can be applied for both hard coal and lignite. As there are large resources of lignite in Europe, lignite-fired plants will be discussed in this chapter as well.

Current Technologies (2007)

Pulverized Coal combustion (PCC):

One of the oldest technologies still dominating electricity production is the pulverized coal combustion (PCC). Thereby coal is crushed and milled to powder, which is fed to a burner. The combustion heat is used for the generation of steam, which is the working fluid in a steam cycle with steam turbine for electricity generation (Rankine cycle). This technology is very well known, has an excellent availability factor and features high fuel flexibility in terms of coal types. The PCC technology can be applied for lignite as well; however this will result in a somewhat lower efficiency due to the lower heat content of lignite. Recent development includes the application of supercritical pulverised coal combustion with supercritical steam conditions. These newer PCC power plants feature steam conditions above 221 bar and around 600°C. This results in an overall efficiency of 44.5% for lignite and 46% for hard coal

Integrated Gasification Combined Cycle (IGCC):

The integrated gasification combined cycle (IGCC) is the combination of a coal gasification unit and a gas fired combined cycle unit. First, the coal is gasified (by fixed bed gasification, fluidised bed or entrained flow gasification) to syngas which is a mixture of hydrogen and carbon monoxide. Subsequently, electricity is generated from syngas in a combined cycle power block consisting of a gas turbine process and a steam turbine process. The combined cycle technology is similar to the technology used in modern natural gas fired power plants (CCGT). In comparison to conventional steam power plants, IGCC power plants feature higher efficiencies and lower emissions. Lignite fuelled IGCC power plants have an efficiency of 44%, hard coal based IGCC plants 45%. IGCC features a high feedstock flexibility and can be designed for electricity generation from lignite, hard coal, waste or biomass. Furthermore IGCC technology offers promising conditions for CO_2-capture. The structure of an IGCC power plant is more complex than steam power plants. Thus, the investment costs are significantly higher compared to other coal power plants. The technical factors coal type, gasification technology, degree of the air

separation integration and the technology level of the gas turbine and turbine inlet temperature influence the efficiency of an IGCC plant /MIT 2005/.

Future Technologies (2020, 2030)

Future improvements and evolutions of the respective fossil fuelled electricity generation technologies strongly depend on the development of new materials. New materials for application at higher temperature and pressure levels are a prerequisite for further efficiency increases in new coal-fired power plants. Furthermore research on improved corrosion resistance of materials is necessary.

As the PCC-technology already exists for a long time and can be considered as mature technology, no major technical innovation or milestones can be expected in future. However by elevated steam parameters, installation of superheating steps and application of lower condenser pressures further increases in power plant efficiency up to 52% for the supercritical case can be achieved. In 2030 an efficiency of the IGCC power plants up to 55% can be expected. The progress in IGCC power plants depends not only on new materials, but also on the improvement of the reliability of system components. In the long term prospect, the IGCC technology has the potential to increase the efficiency considerably above 50%.

Integrated Gasification Combined Cycle (IGCC) with CCS

Within the context of this paper only a short description of the power plant technology with the capturing of CO_2 will be given. For a further discussion on the topics for capture, transport and storage of CO_2 see /VGB 2004/, /MIT 2005/ and /IPCC 2007/.

The sequestration of CO_2 implies adding infrastructure to a common fossil power plant. The CO_2 can be separated by three measures:

- Pre-combustion
- Post combustion
- Oxyfuel combustion

The power plant with CO_2-seperation more plant requires additional components. These components have an impact on the cost (about 1370 €/kW in 2020) and efficiency. The higher investment cost go in line with higher O&M cost. The cost of CO_2- storage and transportation are not included in specific investment costs of the IGCC power plant in the table of technology characterisation. Operational costs of CCS will be added to the fuel cost.

In this study, IGCC technology with CO_2 capture is considered to be available after 2010. The efficiency penalty due to CO_2 capture was assumed to be 6%, which is in accordance to /Hendriks 2007/.

4.2.2. Natural gas-fired power plants

Natural gas power plants became a very popular technology for the electricity production. Since 1973 the worldwide share of natural gas for the power generation increased from 12,3% to almost 20% worldwide /IEA 2007/.

Current Technologies (2007)

The initial point of gas-fired power plants is a gas turbine. This type of turbine can be adopted in a single configuration or in a combined cycle.

The simple cycle gas turbine is an open cycle, the air passes through a compressor before it enters into a combustion chamber. There, fuel is injected and a combustion reaction occurs. The resulting hot gasses enter a turbine, in which they expand, before being injected in the atmosphere. Single configuration units are very flexible and mainly serve in cycling and peak load. The efficiency of a single gas turbine amount 50%, but the capital cost are absolute low with 250 €/kW.

Combined Cycle Gas Turbines (CCGT`s) are based on the structure of the single gas turbine, but a second turbine (steam turbine) is added. The residual heat from the flue gasses from the simple gas turbine unit is recuperated in a heat recovery steam generator for making steam /VGB 2005/. The steam is finally used in a closed Rankine cycle. The efficiency of the gas cycle is approximately two-thirdly of the net efficiency. This is less than a simple single gas turbine plant, due to the combination of the Rankine and the gas turbine cycle the overall efficiency of a CCGT plant reaches 57,5%. In comparison to the simple gas turbine unit is the CCGT less flexible. The low construction costs (440 €/kW) and the short construction time of 2-3 years are the major advantages of the CCGT power plant.

Future Technologies (2020, 2030)

Compared to the coal power plants for gas turbine and CCGT`s are no real technical breakthroughs expected. Also costs are not expected to decrease a lot, because the capital costs are of a relative low level. But still some improvements can be reached by deployment of new materials. The new materials allow higher turbine inlet temperatures of the gas turbine and the option of supercritical steam parameters. By 2030, with the deployment of new materials and better cooling options for the gas turbine, an overall efficiency of 63% is assumed.

Combined Cycle Gas Turbine (CCGT) with CCS

The type of power plant with CCS for natural gas is the CCGT technology. The characterisations of the CCGT technology with CCS are shown in table 2-4. For the CCGT plants with separation of CO_2, there is a net efficiency loss of about 6%.

4.2.3. Oil-fired power plants

The oil-fired power plants are not anymore the standard state-of-the-art power plant for generating electricity in liberalised markets. Compared to 1973, the share of oil-fired power plants for the generation of electricity decreased worldwide from about 25% to 6,6% in 2005 /IEA 2007/. Italy is the exception in Europe with a relative high share of oil-fired power plants. The available oil reserves are mainly used for transport, domestic heat, industrial heat and the petrochemical industry. Sporadic peak power units run on oil. The technology of oil-fired plants can be condensing turbines (for large scale applications) or common gas turbines.

4.3. Combined Heat and Power plants (CHP)

Combined heat and power (CHP) or cogeneration is an energy conversion process, where electricity and useful heat are produced simultaneously in one process. To produce work is in contrast to heat more difficult. Two options for cogeneration are possible. Firstly, by electrochemical way, e.g. fuel cells, which convert chemical energy direct into electricity, with some irreversibilities where heat is produced. Secondly by the classical thermal route, which are based on conventional power generation systems.

Current Technologies (2007)

A number of mature electricity production technologies are well suited for CHP. The CHP power plants can be divided in three main typologies:

- Gas turbines with heat recovering
- Steam turbines (back-pressure or extraction-condensing)
- Reciprocating engines (basically gas- and diesel engines)

This chapter on CHP will not claim of detailed description of these five technologies of cogeneration.

Two types of production technologies (back pressure and extraction condensing) are shortly discussed below.

A back pressure CHP plant generates electrical power in the same way as a power plant, but instead of discharging the condensation heat from the steam together with the cooling water, the steam is cooled by a e.g. district heating distribution system and thus used for the generation of heat. Another type of cogeneration is the controlled (automatic) extraction operation of the steam turbine. This may also include either unfired or fired boiler operation. A controlled extraction steam turbine permits extraction steam flow to be matched to the steam demand. Varying amounts of steam can be used for heating or process purposes. The steam which will be not extracted is condensed.

In this present paper, gas and hard coal fuelled systems for fossil energy carriers, and straw and wood chips for biomass, have been considered. Data estimates assume 7500 h/a full load hours, a technical lifetime of 35 years for the fossil plants and 30 years for the biomass plants. As for the investment costs, there is a relative high discrepancy among the coal-fired and the gas-fired plants, due to the deployment of CCGT plants for natural gas and condensing plants for hard coal. No further high discrepancy on investment costs consists by the use of back pressure or an extraction turbine. Investment cost of biomass CHP plants are in the range of 1750 to 2600 €/kW.

Future Technologies (2020, 2030)

The technologies for combined heat and power are mature, but increased efficiency can be expected, similar the other fossil fuel technologies. CCS will play also in important role in future cogeneration plants. The investment cost of biomass CHP plants will continue be higher than fossil fired plants.

4.4. Renewable Plants

4.4.1. Hydro

One of the oldest methods for producing electricity is hydro. Currently water is the only renewable source which contributes substantially to the world electricity power, about 16% /IEA 2007/. The hydro power stations convert the potential/kinetic energy of water into electricity as a continuous flow of water through a turbine. The efficiency of hydro power stations is well, above 80 and up to 95%. Hydro power plants can serve as base load stations, but thanks to their fast response they could used as power control service plants. This chapter gives a short summary of hydro power stations, but cannot offer a detailed discussion of the various types of plants.

In general, the hydro power plants are distinguished in the following types:

- run of river
- dam/pump storage
- tidal power

Current Technologies (2007)

The existing technology is mature and well advanced, whereas the mechanical design is relatively simple. Hydro power units exist in a range from a few kW´s up to some GW`s. For the European Commission the split between large- and small-scale is conventionally set at 10 MW.

From a technical as well as an operational point of view, hydro power stations have a high efficiency and a well availability above 80% /EUSUSTEL 2006/. Although the investment cost of hydro power stations reach up to 5850 €/kW, the generation costs are very low.

Future Technologies (2020, 2030)

The currently reached efficiencies are already high. Small ameliorations could be made on some technical items, but from the economical standpoint the investment costs will be relatively high. Presently, various types of emerging technologies are being tested to extract energy from tides. But technical and economical assumptions are rather speculative.

4.4.2. Wind

At the end of 2006, worldwide capacity of wind-powered generators was 73.9 GW; although this thechnology currently produces just over 1% of world-wide electricity use, it accounts for approximately 20% of electricity production in Denmark, 9% in Spain, and 7% in Germany /WWEA 2007/. Within the last 15 to 20 years, wind energy has known an incredibly fast development on a global scale. The technology development started in the early 1980s with wind turbine ranging from 20 to 30 kW with simple fixed speed stall regulated turbines with basic asynchronous generators. At present wind turbines of sizes between 2 to 5 MW with advanced components (variable speed pitch turbines, new control systems and direct drive generator or gearless transmission systems) are commercially available. The generated wind energy can be supplied in grid-connected systems and in stand-alone systems. However, in most cases, the wind power plant is connected with the grid.

Current Technologies (2007)

Actual wind turbines are basically classified by the orientation of the drive shaft, which can be horizontal axis turbines or vertical axis turbines. Horizontal axis turbines with two or three blades are the dominant type and used today to nearly 100%. The wind turbine consists of 3 major components rotor, tower and the foundation. Modern wind turbines have an efficiency of 45 to 50%. But after the law of Betz only (16/27) 59% of the kinetic energy in the wind can be mechanically used. Over the last 15 years the efficiency increased 2-3% per year.

Especially in north-west countries of Europe the offshore development is rising steadily and begins to play an important role. Sites for onshore power plants are limited and onshore plants generate less electricity. Despite the higher investment costs, by about a factor two, the interest in offshore is increasing. By using the kinetic energy in the wind offshore, there is less turbulence and there are higher wind speeds, which result in expected utilisation times or more than 3000 h/a and up to 4000 full load hours per year. Inland wind power plants have an average availability of approximately 2000 to 2600 h/a. From an economical point of view, two parameters dominate the cost of generating electricity by wind: the investment cost of the plant and the electricity production rate of the turbine.

Future Technologies (2020, 2030)

In the future, the main expected trend of the wind technology is the further up-scaling of the turbines, in order to minimize the higher costs of foundation and cabling. Today offshore and

onshore wind turbines of 2 to 3 MW are commercially available. There are also some larger wind turbines, especially for offshore sites, but mostly they are still in prototype phase. The increasing of wind turbines is not limited by physical barriers, but the logistic of the material transport will be more and more a challenge. In summary, the size of wind turbines will increase up to or above 10 MW`s within the next decades /EUSUSTEL 2006/. A general change to gearless wind turbine is not expected, although this would solve many problems with the gearbox. As wind turbines grow in capacity, the size of the tower and the blades grow accordingly. The main challenge for constructing and design such large wind power plants is to reduce the weight of the blades (carbon fibres instead glass fibres) and of the foundation. The selection of the foundation type depends on the location of the wind turbine. In particular water depths of more than 30 metres exact other foundation design as the monopile-foundation.

4.4.3. Photovoltaic PV

Photovoltaic (PV) is a technology able to directly convert solar radiation in to electricity. The basic element of a PV system is a PV cell consisting of semiconductor material, which generates direct current from solar radiation. The peak capacity of one PV cell normally ranges from 50 to 150 Wp /EUSUSTEL 2006/. PV is a modular technology, thus PV systems consist of an interconnected series of PV cells, which altogether can feature peak capacities up to several megawatts.

The number of world-wide installed PV systems has considerable increased within the last decade and reached a capacity of around 5.7 GW in 2006. Thereby the most capacities had been manufactured in Japan, the US and Europe.

PV systems are generally distinguished into building-integrated systems (facade or roof installations) and centralized systems (ground mounted power plant). If the PV system is grid-connected, an inverter is necessary to invert direct current generated by the PV cell into alternating current.

There are different semiconductor materials used for the manufacturing of PV cells. The most common material applied in current installations is crystalline silicon /EPIA 2004/. There are two main types of crystalline, single-crystalline (sc) and multi-crystalline (mc) silicon. In this work mc-crystalline PV cells have been investigated, which currently are the most applied material for PV cells and feature an efficiency of around 15%.

The cost of electricity generation in PV systems is clearly higher than the cost of other technologies. This is due to the energy-intensive production of PV cells resulting into high specific investment costs. In consequence of low efficiencies and full load hours (electricity is only generated when the sun is shining), PV systems generate considerably less electricity compared to the same capacity of other electricity generation technologies.

Future Technologies (2020, 2030)

Improvement of PV systems will be primarily related to two aspects. Major improvements are anticipated to take place in the construction of PV cells. New materials and manufacturing

processes are under development aiming at a reduction of resource use and costs. Currently the learning curves of PV cell production are around 20% and still quite high. The second focus of future development lies on the improvements of the PV cell efficiencies. Currently the second generation of PV cells is on the market. An anticipated third generation is anticipated to approach a PV cell efficiency of around 20% /EPIA 2004/. Furthermore, a longer technical life times are expected in the third generation of PV cells.

4.4.4. Solar thermal (Solar trough)

Solar thermal electricity generation involves the capture of heat from solar radiation and conversion into electricity. Currently four main systems of solar thermal electricity generation can be distinguished:

- Parabolic trough systems dam/pump storage
- Central receiver systems
- Dish-engine systems
- Solar updraft tower

The first three systems concentrate the solar radiation by means of window systems in order to gain high temperature, which are used for the operation of a conventional steam cycle. The principle of a solar updraft tower is to collect air, which is heated up by solar radiation, and to use the effect of ascending heated air in a turbine for the generation of electricity. In this study, , parabolic trough systems have been investigated as an example of this class of technologies. Parabolic trough systems consist of solar collector arrays, which concentrate solar radiation to a heat transfer fluid, which is pumped through a pipe along the collector array. The heat of this transfer fluid is used to produce steam, which is converted into electricity in a steam turbine. First parabolic trough power plants with a capacity of 354 MW_e have been built between 1984 and 1989 in southern California. For base load electricity generation, these systems are co-fired by natural gas in hours without solar radiation.

Future Technologies (2020, 2030)

Starting from operational experiences of more than 20 years, parabolic trough technology is considered an approved and mature technology. A potential technological development, which is currently tested at pilot-scale, is the installation of a direct steam generation (DFG) instead of heat transfer via a heat transfer fluid /Luzzi et al. 2004/. This would avoid the use of toxic materials and considerable reduce the necessary infrastructure. Scaling to units with higher capacities is expected. Improvements in the steam cycle are in line with improvements in fossil fuelled condensing power plants.

4.5. Fuel Cells

The basic operating principle of a fuel cell is based on the controlled electrochemical reaction of hydrogen with oxygen forming water while using the electric energy output. The basic principle was already described in the 19th century by William Grove.

Conventional conversion of the chemical energy of a fuel into electricity is currently based on the deployment of heat engines. These machines work according to the principle of indirect energy conversion. At first heat must be produced which is then converted into mechanical and finally into electric energy by a generator. The maximum energetic efficiency is given by the Carnot factor and depends on in- and outlet temperature.

Unlike the conventional power generating concepts, the electrochemical basic concept of fuel cells produce direct electricity and heat and is not limited by the Carnot factor. Nevertheless, the fuel cell process is subject to the second law of thermodynamics.

Fuel cells are generally connected in series to achieve the desired power output. The assembly of several cells together with the necessary equipment (separators, cooling plates, manifolds and supporting structure) is called fuel cell stack. When one or more stacks are assembled together then a fuel cell module is obtained. There exist several fuel cell technologies and systems, which can serve for several small-scale, to large scale applications. In this paper fuel cell systems are addressed for CHP applications. Due to heat as by-product fuel cells are perfectly suitable for CHP applications.

Current Technologies (2007), Future technologies (2020, 2030)

For stationary applications, numerous demonstration plants and some field tests have been already implemented /Adamson 2005/. Nowadays, fuel cells exist in different types, distinguished mainly by the electrode material and the corresponding operating temperature. For stationary applications, the most important fuel cell types are /FZJ 2007/:

- MCFC – Molten Carbonate Fuel Cells
- SOFC – Solid Oxide Fuel Cells
- PEMFC – Polymer Electrolyte (or Proton Exchange Membrane) Fuel cells
- PAFC – Phosphoric Acid Fuel Cells

In this chapter only the MCFC and SOFC will be described. The SOFC operates at temperatures from 650 to 1000°C. As a result of the high temperature SOFCs can be used for a broad range of CHP applications. In general, fuel cells are characterized by their electrolyte material and, as the name implies, the SOFC has a solid oxide, or ceramic, electrolyte. The efficiency of a SOFC is about 44% and the efficiency can be significant increased in combination with a down streamed micro gas turbine. The other type of fuel cell for stationary application is the MCFC, which operates above 600°C. The Molten Carbonate Fuel Cell offer the advantage of high (electrical and thermal) efficiencies, high temperature of the exhaust heat (which makes the production of steam feasible) and the straight-forward use of carbon containing synthesis gases.

Correspondingly, MCFC are developed for use of different fuels. In our study MCFC is used for biogas and natural gas.

Also, due to the relatively high operating temperature, expensive catalysts are not required, whereas compared to the SOFC, which operates at higher temperatures, expensive ceramics can be avoided. The investment cost of a SOFC is approximately 30% higher than for the MCFC. Compared to other cogeneration plants the capital cost is very high, due to the use of new and cost intensive materials. Fuel cells have a part load efficiency and are reliable. The power output can be changed easily, due to the modular construction.

5. Private Costs

Before going into detail and depict the private costs of electricity and heat generation, this section describes the main general trends, results and emphasizes which conclusions can be found in this report. It is important to realise that this paper gives a snapshot of the existing situation.

The results, as can be found in chapter 5.1 (year 2007), 5.2 (year 2020) and 5.3 (year 2030), can be divided into two parts. The first part depicts the influence of the discount factor (5 versus 10%) and assumes a constant available factor. To illustrate the effect of the availability factor (expressed in Full Load Hours) on production cost, the cost of generation in 2007, 2020 and 2030 of the various technologies over a range of plant factors is shown in each chapter. The second part discusses the results of the respective energy carrier and point of time.

5.1. Private Costs 2007

5.1.1. Fossil and Nuclear Power 2007

Capital cost repayments and fuel costs tend to be the two largest components of the cost of electricity. In this case the nuclear PWR and the lignite condensing power plant have the lowest specific private costs per MWhel. The higher capital costs make the nuclear power more expensive than the lignite condensing plant. An advantage of the gas power plant is its low investment costs. On the other hand, fuel costs amount to more than 80% of the total electricity production costs. This makes the gas technology very dependent on the gas prices, which are is as volatile as the prices of oil and of which is following the trend of long term price increasing. Gas power plants can serve in base, cycling and peak load with acceptable production costs. Oil power plants are completely uncompetitive due to the fuel price. Figure 2 depicts the effect of the availability factor and emphasis the deployment of nuclear, coal and lignite plants as base load plants. For current (2007) fossil and nuclear technologies, lignite condensing plants have the lowest production costs at a discount rate of 5 and 10%. To come to a close, the nuclear plant at a 5% discount rate and the coal condensing plant at a 10% discount rate have the lowest generating cost.

Table 5 Fossil/Nuclear private costs with a discount rate of 5 and 10% (2007)

		Invest Costs	Fuel Costs	O&M Costs	Total
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
Nuclear PWR	5%	15,84	6,76	6,72	29,33
	10%	27,80	6,76	6,24	40,81
Oil Condensing	5%	6,60	50,84	8,21	65,66
	10%	11,21	49,11	8,18	68,51
Light Oil Gas Turbine	5%	2,20	92,56	3,58	98,33
	10%	3,74	90,48	3,58	97,80
Coal Condensing	5%	8,72	15,86	8,00	32,58
	10%	14,80	15,52	7,97	38,29
Coal IGCC	5%	11,37	16,22	10,14	37,72
	10%	19,31	15,86	10,09	45,26
Lignite Condensing	5%	12,83	7,92	6,08	26,83
	10%	21,78	7,92	6,05	35,75
Lignite IGCC	5%	11,84	8,01	10,14	29,99
	10%	20,10	8,01	10,09	38,20
Gas CCGT	5%	3,88	39,41	4,09	47,38
	10%	6,58	39,07	4,07	49,72
Natural Gas Turbine	5%	2,16	59,64	3,58	65,38
	10%	3,67	59,11	3,58	66,36

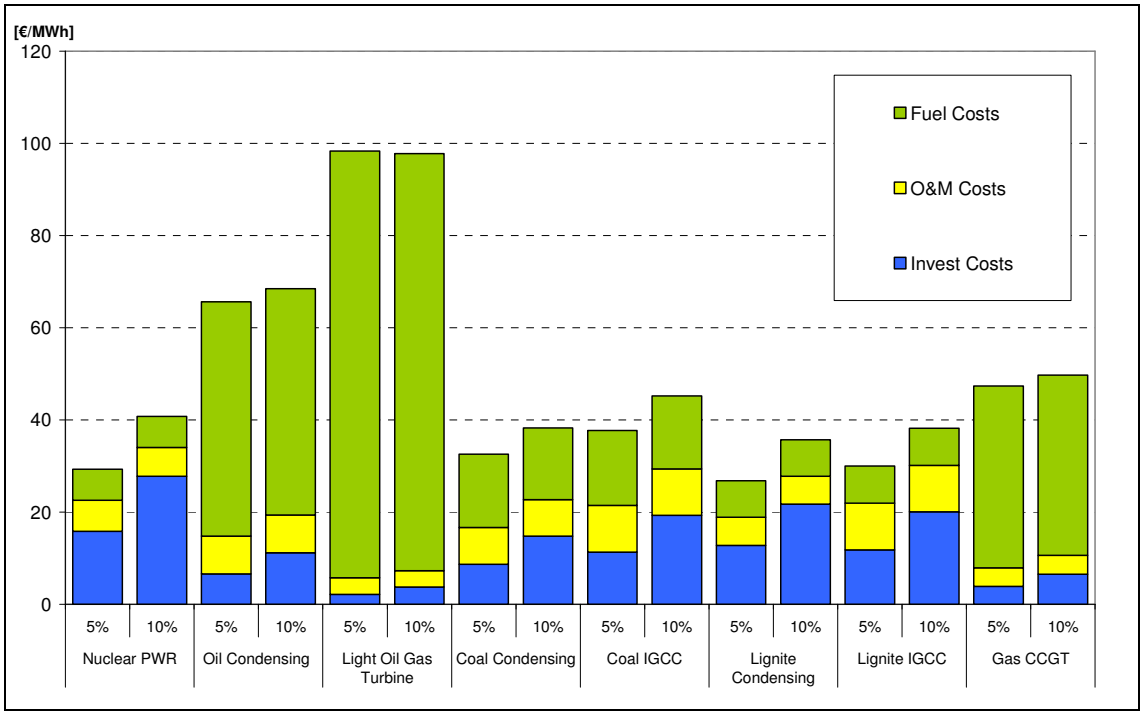


Figure 1 Fossil/Nuclear private costs with a Discount rate of 5 and 10% (2007)

Table 6 Fossil/Nuclear effect of availability with a 5% discount rate (2007)

	Full Load Hours [h/a]														
	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500
Technology	[€/MWh$_{el}$]														
Nuclear PWR	115,65	88,67	72,49	61,70	53,99	48,21	43,71	40,12	37,17	34,72	32,65	30,87	29,33	27,98	26,79
Oil condensing power plant	118,92	102,28	92,29	85,63	80,88	77,31	74,54	72,32	70,50	68,99	67,71	66,61	65,66	64,83	64,09
Light Oil gas turbine	113,29	108,61	105,81	103,94	102,61	101,61	100,83	100,21	99,70	99,27	98,91	98,60	98,34	98,10	97,90
Coal condensing power plant	89,24	71,53	60,91	53,83	48,77	44,98	42,03	39,66	37,73	36,12	34,76	33,59	32,58	31,70	30,92
Coal IGCC	111,49	88,44	74,61	65,39	58,80	53,86	50,02	46,95	44,43	42,34	40,56	39,04	37,72	36,57	35,56
Lignite condensing power plant	98,58	76,15	62,70	53,73	47,33	42,52	38,79	35,80	33,35	31,31	29,59	28,11	26,83	25,71	24,72
Lignite IGCC	105,64	82,00	67,81	58,36	51,60	46,54	42,60	39,45	36,87	34,72	32,90	31,34	29,99	28,81	27,77
Gas CCGT	73,11	65,07	60,25	57,03	54,73	53,01	51,67	50,60	49,72	48,99	48,37	47,84	47,38	46,98	46,62
Natural Gas turbine	80,15	75,53	72,76	70,92	69,60	68,61	67,84	67,22	66,72	66,30	65,94	65,64	65,38	65,15	64,94

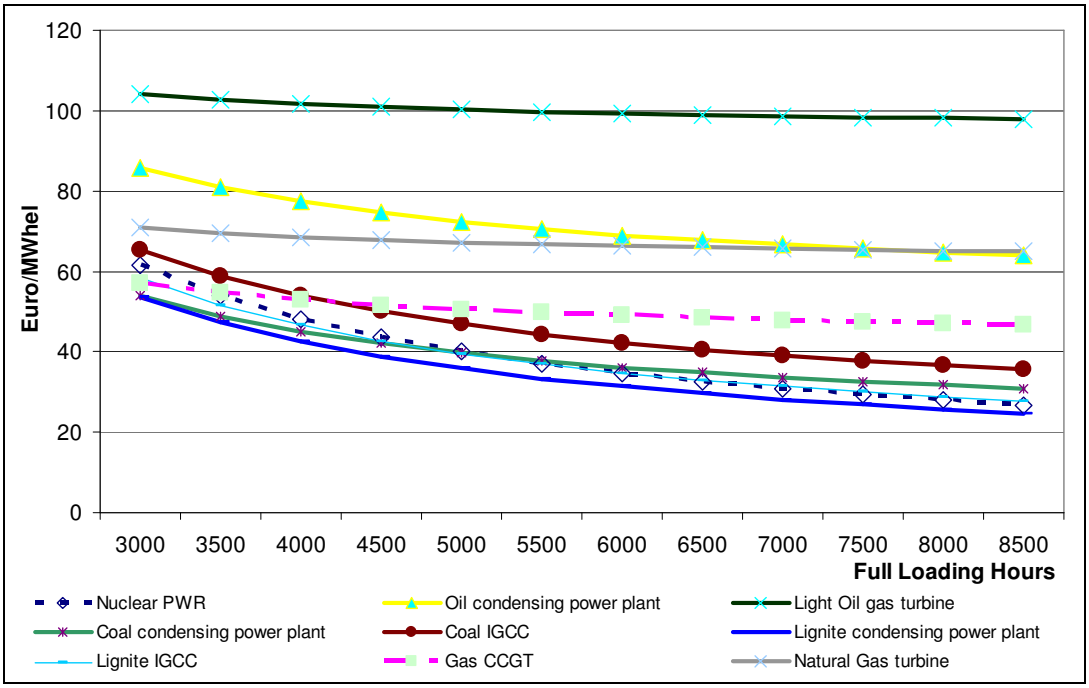


Figure 2 Fossil/Nuclear effect of availability (Full loading hours) with a 5% discount rate

Table 7 Fossil/Nuclear effect of availability with a 10% discount rate (2007)

	Full Load Hours [h/a]														
	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500
Technology	[€/MWh$_{el}$]														
Nuclear PWR	173,05	131,73	106,93	90,40	78,59	69,74	62,85	57,34	52,83	49,07	45,89	43,17	40,81	38,74	36,92
Oil condensing power plant	140,08	117,71	104,29	95,35	88,96	84,16	80,43	77,45	75,01	72,98	71,26	69,78	68,51	67,39	66,40
Light Oil gas turbine	118,90	112,31	108,35	105,72	103,83	102,42	101,32	100,44	99,72	99,12	98,62	98,18	97,80	97,47	97,18
Coal condensing power plant	119,15	93,88	78,72	68,62	61,40	55,98	51,77	48,40	45,64	43,35	41,40	39,74	38,29	37,03	35,91
Coal IGCC	150,57	117,66	97,92	84,75	75,35	68,30	62,81	58,42	54,83	51,84	49,31	47,14	45,26	43,62	42,16
Lignite condensing power plant	143,19	109,61	89,47	76,04	66,45	59,25	53,66	49,18	45,52	42,46	39,88	37,67	35,75	34,07	32,59
Lignite IGCC	146,71	112,80	92,45	78,89	69,20	61,94	56,29	51,77	48,07	44,98	42,38	40,14	38,20	36,51	35,01
Gas CCGT	86,22	74,82	67,97	63,41	60,15	57,71	55,81	54,29	53,04	52,01	51,13	50,38	49,72	49,15	48,65
Natural Gas turbine	87,16	80,66	76,76	74,16	72,30	70,91	69,82	68,96	68,25	67,66	67,16	66,73	66,36	66,03	65,74

5.1.2. Combined Heat and Power 2007

Combined Heat and Power is a mature technology with high potential for the heat and electricity markets. Table 5 present the results for the very optimal availability from more than 85 per cent. Typical availability factors for CHP`s varies from 3500 hours to 6000 hours depending on the weather and size of the plant compared to the heat sink. In the present review coal and gas combined heat and power plants are the most competitive. In the simplified approach for the heat credits the minimal electricity costs are absolutely low. For combined heat and power the total production costs of generating electricity are highly dependent on the use an value of co-product, the heat, and thereby very site-specific. In comparison to the fossil fuel CHP`s the CHP`s which uses biomass (straw, wood) are the costs two to three times higher. Beside the Fuel Cell Technologies the ordinaries CHP`s are highly resistant against an increasing discount rate. At a 5% discount rate, the maximum production costs range between 32 and 60 €/MWhel for fossil energy carriers and for biomass the costs range between 135 and 146 €/MWhel.

Table 8 CHP private costs with a discount rate of 5 and 10% (2007)

		Invest Costs	Fuel Costs	O&M Costs	Heat Credits	Total (min)	Total (max)
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
CHP-CCGT-Gas	5%	4,81	50,36	5,53	21,03	39,68	60,70
	10%	7,76	49,92	5,53	20,84	42,37	63,21
CHP Cond.-Coal	5%	3,78	20,85	8,89	29,36	4,16	33,52
	10%	6,07	20,40	8,89	29,10	6,26	35,36
CHP-CCGT-Gas (BP)	5%	4,64	50,36	5,51	21,26	39,25	60,51
	10%	7,49	49,92	5,50	21,23	41,68	62,91
CHP Cond.-Coal (BP)	5%	10,53	20,85	10,02	35,97	5,43	41,40
	10%	17,00	20,40	10,02	35,65	11,77	47,42
CHP Cond.-Straw	5%	21,48	110,77	14,21	90,50	55,97	146,47
	10%	33,43	110,77	14,21	89,88	68,53	158,42
CHP Cond.-Wood	5%	14,46	110,77	9,57	90,50	44,30	134,80
	10%	22,50	110,77	9,57	89,88	52,96	142,84
CHP MCFC-Gas	5%	175,61	46,77	72,67	17,46	277,58	295,04
	10%	199,22	46,77	72,67	17,46	301,20	318,66
CHP SOFC-Gas	5%	259,85	51,02	94,67	21,95	383,59	405,54
	10%	316,36	51,03	94,67	21,95	440,10	462,06
CHP MCFC-Biogas	5%	175,61	45,00	72,67	17,46	275,82	293,28
	10%	199,22	45,00	72,67	17,46	299,42	316,89

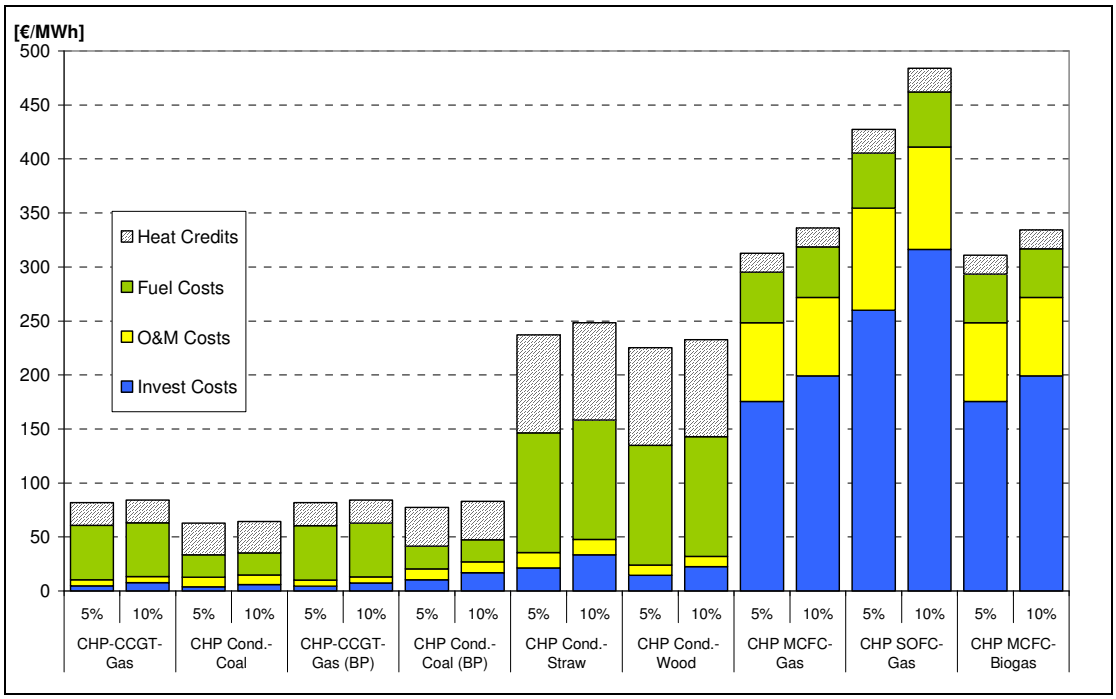


Figure 3 CHP private costs with a discount rate of 5 and 10% (2007)

Table 9 CHP effect of availability with a 5% discount rate, with heat credit (2007)

			Full Load Hours [h/a]					
			3500	4000	4500	5000	5500	6000
Technology			[€/MWh$_{el}$]					
CHP extraction condensing turbine	natural gas	Gas CCGT	49,74	47,38	45,55	44,08	42,88	41,88
		CCGT_CO2						
	hard coal	Condensing	15,73	13,02	10,91	9,22	7,84	6,69
		IGCC_CO2						
CHP back pressure turbine	natural gas	Gas CCGT BP	49,10	46,79	45,00	43,56	42,38	41,40
	hard coal	Coal CHP BP	25,99	21,17	17,42	14,43	11,97	9,93
CHP extraction condensing	straw	Straw Cond.	96,76	87,20	79,76	73,81	68,95	64,89
	wood chips	Wood chips Cond.	71,76	65,32	60,32	56,31	53,03	50,30
fuel cells	natural gas	Gas MCFC	545,33	482,58	433,77	394,72	362,78	336,15
		Gas SOFC	772,75	681,54	610,60	553,85	507,41	468,72
	biogas	MCFC	543,56	480,81	432,00	392,95	361,01	334,39

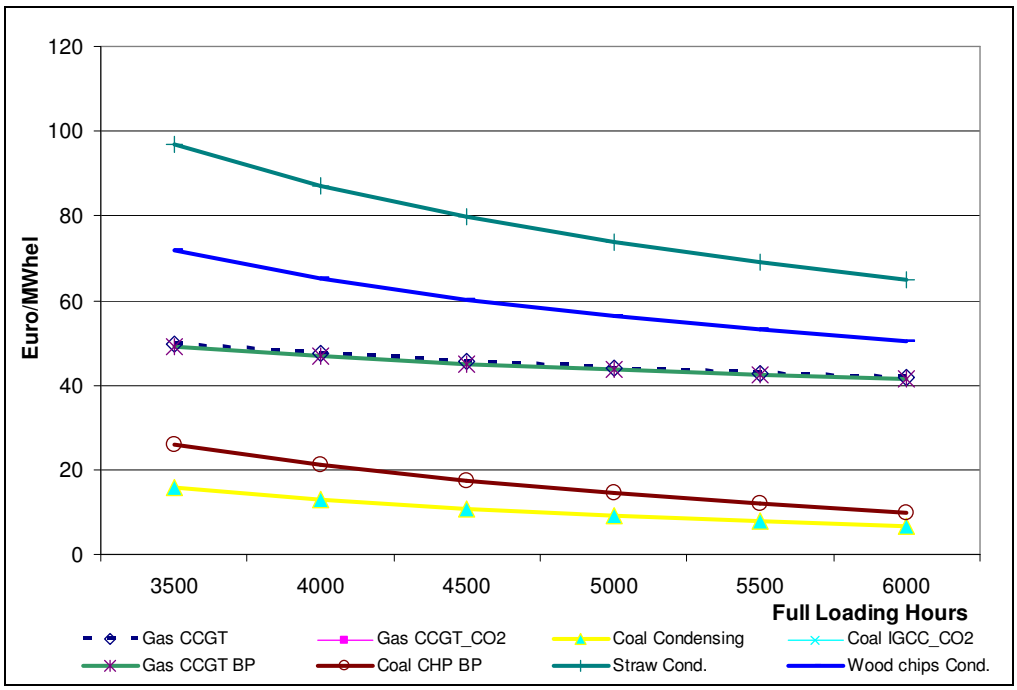


Figure 4 CHP effect of availability (Full loading hours) with a 5% discount rate (2007, with heat credit)

Table 10 CHP effect of availability with a 10% discount rate, with heat credit (2007)

			Full Load Hours [h/a]					
			3500	4000	4500	5000	5500	6000
Technology			[€/MWh$_{el}$]					
CHP extraction condensing turbine	natural gas	Gas CCGT	55,81	52,66	50,21	48,25	46,65	45,31
		Gas CCGT_CO2						
	hard coal	Coal Condensing	16,56	13,74	11,55	9,79	8,36	7,16
		Coal IGCC_CO2						
CHP back pressure turbine	natural gas	Gas CCGT BP	54,78	51,71	49,32	47,41	45,85	44,55
	hard coal	Coal CHP BP	39,72	33,16	28,07	23,99	20,66	17,88
CHP extraction condensing	straw	Straw Cond.	123,46	110,64	100,67	92,69	86,16	80,72
	wood chips	Wood chips Cond.						
fuel cells	natural gas	Gas MCFC	546,71	490,78	446,03	409,42	378,91	353,10
		Gas SOFC	732,76	656,12	594,82	544,66	502,86	467,49
	biogas	MCFC	544,94	489,00	444,26	407,65	377,14	351,32

5.1.3. Renewable Sources 2007

For the renewable sources the generic framework and assumptions adopted to calculate private costs for those plants have been adapted to reflect their specific characteristics. The lifetimes of renewable technologies, with the exception of hydro power, are maximum 30 years (solar thermal). The average full loading hours of volatile generating technologies (wind and solar) are significantly lower than the generic assumption of 7.500 h/a for nuclear, coal and gas plants. Three types of run of river hydro plants (small, medium and large), a hydro dam and hydro pump storage are considered in the category hydro power generation. The production costs of hydroelectricity are depicting in table 11. At a discount rate of 5%, the electricity production costs of hydro range between 45 and 72 €/MWhel. By calculations with a discount rate of 10% the hydroelectricity production costs varies between 80 and 130 €/MWhel. For wind power plants only a marginal production cost difference exists, although the investment cost for offshore turbines is considerably higher. Thanks to the more stable wind conditions and higher availability of the offshore plant yield nearly the same costs. At a 5% discount rate, the production costs for wind power plants are about 40 €/MWhel. Figure 5 shows that the electricity production costs of solar generated electricity, in particular PV, are absolute uncompetitive in relation to the other renewable technologies or fossil and nuclear generated electricity.

Table 11 **Private costs of electricity generation technologies by renewable sources with a discount rate of 5 and 10% (2007)**

		ALLGC	Back-Up, min	Add. Back-Up, max	Total (min)	Total (max)
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
Hydro Run of river small	5%	72,29			72,29	72,29
	10%	128,95			128,95	128,95
Hydro Run of river medium	5%	67,87			67,87	67,87
	10%	121,14			121,14	121,14
Hydro Run of river large	5%	45,19			45,19	45,19
	10%	79,09			79,09	79,09
Hydro dam	5%	73,50			73,50	73,50
	10%	131,67			131,67	131,67
Hydro Pump storage	5%	73,50			73,50	73,50
	10%	131,67			131,67	131,67
Wind On-shore	5%	45,75	8,86	6,49	48,83	55,32
	10%	59,82	11,92	9,62	67,50	77,12
Wind off-shore	5%	47,58	9,26	6,78	50,64	57,42
	10%	62,76	12,46	10,05	70,57	80,63
PV roof	5%	710,51	8,84	6,47	719,34	725,81
	10%	1054,70	11,88	9,59	1066,58	1076,18
PV Open space	5%	491,31	8,79	6,43	500,10	506,53
	10%	729,31	11,82	9,54	741,14	750,68
Solar through	5%	127,64	9,66	7,07	137,31	144,38
	10%	199,81	13,00	10,49	212,81	223,30

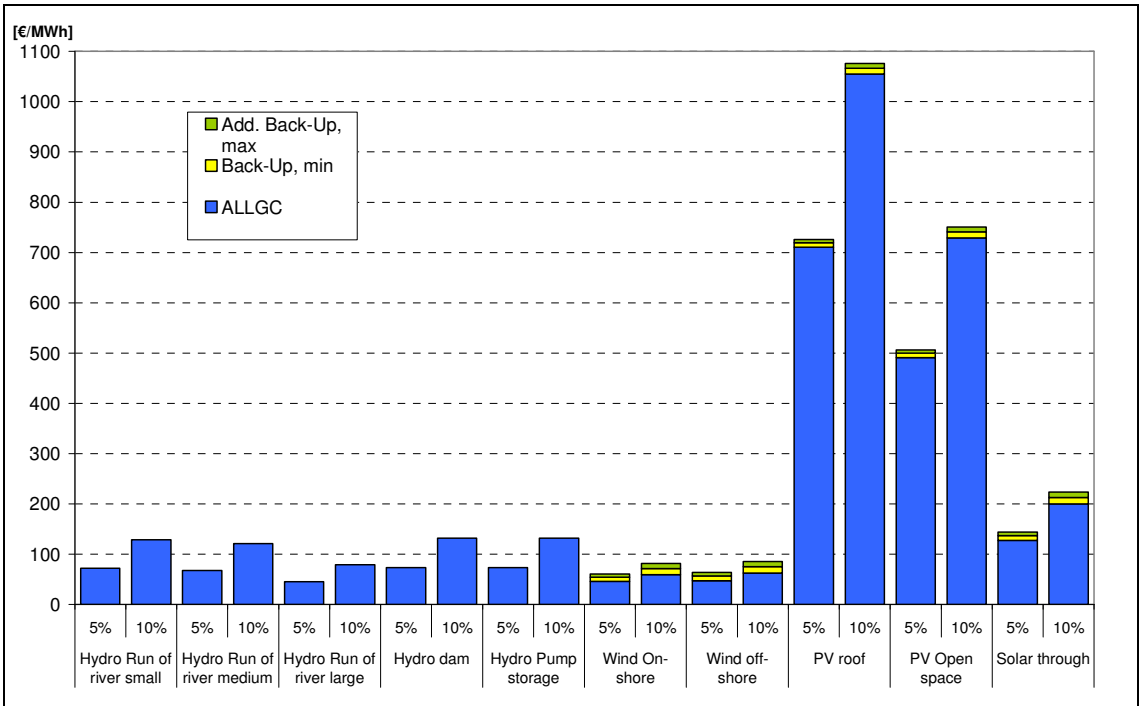


Figure 5 **Private costs of electricity generation technologies by renewable sources with a discount rate of 5 and 10% (2007)**

Table 12 Renewable effect of availability (Full loading hours) with a 5% discount rate (2007)

	Full Load Hours [h/a]										
Technology	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
	[€/MWh$_{el}$]										
Wind Onshore	157,46	143,15	131,22	121,12	112,47	104,97	98,41	92,62	87,48	82,87	78,73
	2500	**2600**	**2700**	**2800**	**2900**	**3000**	**3100**	**3200**	**3300**		
	[€/MWh$_{el}$]										
Wind Offshore	101,52	97,62	94,00	90,65	87,52	84,60	81,87	79,32	76,91		
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV roof	1613,69	1411,98	1255,09	1129,58	1026,89	941,32	868,91				
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV open space	1115,85	976,37	867,88	781,10	710,09	650,91	600,84				
	2500	**3000**	**3500**	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**	**7500**
	[€/MWh$_{el}$]										
Solar trough	305,32	254,43	218,08	190,82	169,62	152,66	138,78	127,22	117,43	109,04	101,77

Table 13 Renewables effect of availability (Full loading hours) with a 10% discount rate (2007)

	Full Load Hours [h/a]										
Technology	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
						[€/MWh$_{el}$]					
Wind Onshore	157,46	143,15	131,22	121,12	112,47	104,97	98,41	92,62	87,48	82,87	78,73
	2500	**2600**	**2700**	**2800**	**2900**	**3000**	**3100**	**3200**	**3300**		
	[€/MWh$_{el}$]										
Wind Offshore	101,52	97,62	94,00	90,65	87,52	84,60	81,87	79,32	76,91		
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV roof	1613,69	1411,98	1255,09	1129,58	1026,89	941,32	868,91				
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV open space	1115,85	976,37	867,88	781,10	710,09	650,91	600,84				
	2500	**3000**	**3500**	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**	**7500**
	[€/MWh$_{el}$]										
Solar trough	305,32	254,43	218,08	190,82	169,62	152,66	138,78	127,22	117,43	109,04	101,77

5.2. Private Costs 2020

5.2.1. Fossil and Nuclear Power 2020

The dominant position of lignite and nuclear is also confirmed in 2020. The costs of known fossil and nuclear fuel based technologies decrease mainly by two factors: higher efficiency and lower investment costs. At a 5% discount rate the electricity production costs of lignite-based power plants decrease by approximately 5 €/MWhel between 2007 and 2020 and the costs of nuclear-based technologies by approximately 3 €/MWhel. Another interesting result is the strong increase of the production costs of oil power plants, which increase to more than 40% due to the higher price of oil. Despite the oil-gas price coupling mechanism the production costs of IGCC gas plants remain at a constant level. This development can be explained firstly by the increasing efficiency factor (57.5 to 62%) and secondly by the lower overnight capital costs. The natural gas and coal CCS enter the market in 2020 with costs ranging from 33.51 €/MWhel for lignite, to 41.50 €/MWhel for coal and to 58.75 €/MWhel for natural gas at a discount rate of 5%. In line with the differences in average availability (figure 8) full load hours, the electricity production costs of the nuclear power are constant below 40 €/MWhel. This result is mainly driven by the lower nuclear investment costs. The use of CCS-technology increase the production costs by more than 20%.

Table 14 Fossil/Nuclear private costs with a Discount rate of 5 and 10% (2020)

		Invest Costs	Fuel Costs	O&M Costs	Total
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
Nuclear PWR	5%	13,65	6,76	6,12	26,53
	10%	23,94	6,76	5,66	36,36
Oil Condensing	5%	6,60	57,12	8,21	71,94
	10%	11,21	55,91	8,18	75,30
Light Oil Gas Turbine	5%	1,98	94,80	0,02	96,81
	10%	3,37	93,44	0,01	96,82
Coal Condensing	5%	8,48	15,54	8,00	32,03
	10%	14,40	15,44	7,97	37,81
Coal IGCC	5%	10,42	14,39	10,14	34,95
	10%	17,70	14,30	10,09	42,09
Coal IGCC with CO2 seq.	5%	12,98	16,19	12,32	41,50
	10%	22,04	16,09	12,27	50,40
Lignite Condensing	5%	8,88	7,06	5,41	21,35
	10%	15,08	7,06	5,38	27,52
Lignite IGCC	5%	10,85	6,78	10,14	27,78
	10%	18,43	6,78	10,09	35,30
Lignite IGCC with CO2 seq.	5%	13,52	7,67	12,32	33,51
	10%	22,95	7,67	12,27	42,89
Gas CCGT	5%	3,39	37,84	3,95	45,19
	10%	5,76	37,49	3,94	47,19
Gas CCGT with CO2 seq.	5%	8,15	41,89	8,71	58,75
	10%	13,84	41,51	8,69	64,04
Natural Gas Turbine	5%	1,90	60,15	3,58	65,63
	10%	3,23	59,60	3,58	66,40

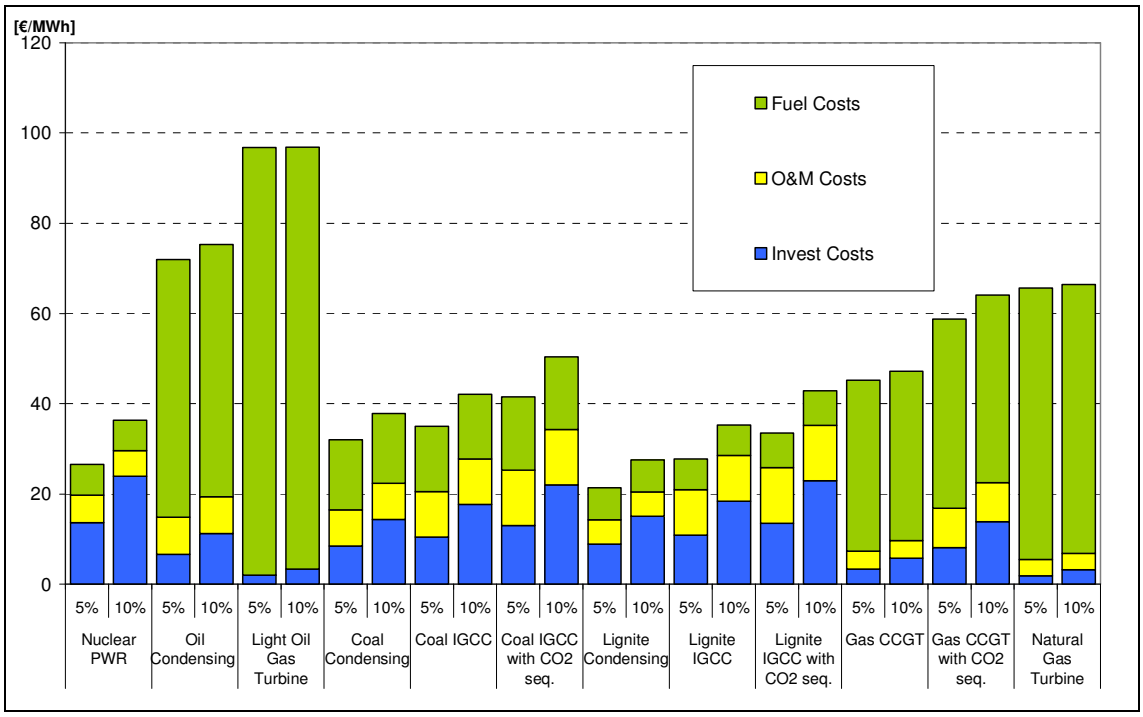


Figure 6 Fossil/Nuclear private costs with a discount rate of 5 and 10% (2020)

Table 15 Fossil/Nuclear effect of availability with a 5% discount rate (2020)

	Full Load Hours [h/a]														
	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500
Technology	[€/MWh$_{el}$]														
Nuclear PWR	103,56	79,49	65,05	55,42	48,54	43,38	39,37	36,16	33,53	31,35	29,49	27,91	26,53	25,33	24,27
Oil condensing power plant	125,20	108,56	98,57	91,91	87,16	83,59	80,82	78,60	76,78	75,27	73,99	72,89	71,94	71,11	70,37
Light Oil gas turbine	104,82	102,32	100,82	99,81	99,10	98,56	98,14	97,81	97,54	97,31	97,12	96,95	96,81	96,68	96,57
Coal condensing power plant	87,73	70,32	59,88	52,92	47,94	44,21	41,31	38,99	37,09	35,51	34,17	33,02	32,03	31,16	30,39
Coal IGCC	104,93	83,06	69,94	61,19	54,95	50,26	46,62	43,70	41,32	39,33	37,65	36,20	34,95	33,86	32,90
Coal IGCC CO2 seq.	128,40	101,24	84,95	74,08	66,33	60,51	55,98	52,36	49,40	46,93	44,84	43,05	41,50	40,14	38,94
Lignite condensing power plant	74,64	57,99	48,00	41,33	36,58	33,01	30,23	28,01	26,19	24,68	23,40	22,30	21,35	20,52	19,78
Lignite IGCC	99,47	77,07	63,63	54,66	48,26	43,46	39,73	36,74	34,29	32,26	30,53	29,06	27,78	26,66	25,67
Lignite IGCC CO2 seq.	122,56	94,73	78,03	66,90	58,95	52,99	48,35	44,64	41,61	39,08	36,94	35,10	33,51	32,12	30,89
Gas CCGT	68,44	61,18	56,81	53,91	51,83	50,27	49,06	48,09	47,30	46,64	46,08	45,60	45,19	44,82	44,50
Gas CCGT CO2 seq.	119,45	100,48	89,10	81,51	76,09	72,03	68,87	66,34	64,27	62,55	61,09	59,84	58,75	57,80	56,97
Natural Gas turbine	79,36	75,07	72,50	70,78	69,55	68,63	67,92	67,35	66,88	66,49	66,16	65,87	65,63	65,41	65,23

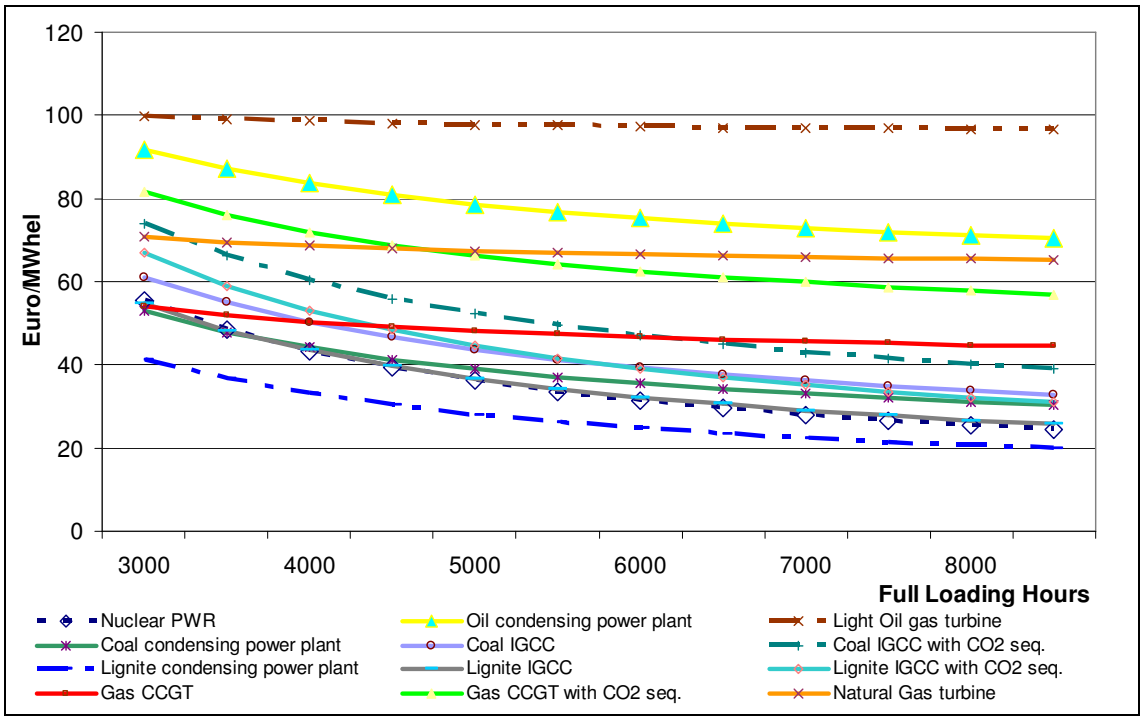


Figure 7 Fossil/Nuclear effect of availability with a 5% discount rate (2020)

Table 16 Fossil/Nuclear effect of availability with a 10% discount rate (2020)

	Full Load Hours [h/a]														
	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500
Technology	[€/MWh$_{el}$]														
Nuclear PWR	152,72	116,36	94,54	80,00	69,61	61,82	55,76	50,91	46,94	43,64	40,84	38,44	36,36	34,55	32,94
Oil condensing power plant	146,87	124,51	111,09	102,14	95,75	90,96	87,23	84,25	81,81	79,77	78,05	76,58	75,30	74,18	73,20
Light Oil gas turbine	110,31	106,09	103,56	101,88	100,67	99,77	99,07	98,50	98,04	97,66	97,34	97,06	96,82	96,61	96,42
Coal condensing power plant	117,07	92,30	77,44	67,53	60,46	55,15	51,02	47,72	45,02	42,77	40,86	39,23	37,81	36,58	35,48
Coal IGCC	140,96	110,07	91,53	79,17	70,34	63,72	58,57	54,45	51,08	48,27	45,89	43,85	42,09	40,54	39,18
Coal IGCC CO2 seq.	173,33	134,91	111,86	96,50	85,52	77,29	70,89	65,76	61,57	58,08	55,13	52,59	50,40	48,48	46,78
Lignite condensing power plant	105,48	81,12	66,50	56,76	49,79	44,57	40,51	37,26	34,61	32,39	30,52	28,91	27,52	26,30	25,23
Lignite IGCC	137,11	105,29	86,20	73,48	64,39	57,57	52,27	48,03	44,56	41,67	39,22	37,12	35,30	33,71	32,31
Lignite IGCC CO2 seq.	169,46	129,91	106,18	90,36	79,05	70,58	63,99	58,71	54,40	50,80	47,76	45,15	42,89	40,91	39,17
Gas CCGT	79,86	69,65	63,53	59,44	56,53	54,34	52,64	51,28	50,16	49,23	48,45	47,78	47,19	46,68	46,23
Gas CCGT CO2 seq.	147,44	121,38	105,74	95,32	87,87	82,29	77,94	74,47	71,62	69,26	67,25	65,53	64,04	62,74	61,59
Natural Gas turbine	85,44	79,49	75,92	73,54	71,84	70,57	69,58	68,78	68,13	67,59	67,14	66,74	66,40	66,11	65,84

5.2.2. Combined Heat and Power 2020

The production costs of the several mature combined heat and electricity technologies (coal condensing, natural CCGT) are in nearly the same range as 2007. In comparison to the fossil-fuel based CCS-plants the costs are approximately 20% lower. At a discount rate of 5%, the costs of common fossil CHP´s range between 40,11 and 61,86 €/MWhel (at maximum level, without heat credit). For a coal CCS plant the production costs are 48.74 €/MWhel and for a gas-

fired CCS plant 74.12 €/MWhel. Contrary to 2007, fuel cells are not any more the most cost intensive CHP-technology. This depends on the learning curve of the various fuel cell plants. The biomass-fired cogeneration plants are uncompetitive due to the high share of fuel costs. Over three fourths of the biomass production costs are devoted by the high fuel prices.

Table 17 CHP private costs with a discount rate of 5 and 10% (2020)

		Invest Costs	Fuel Costs	O&M Costs	Heat Credits	Total (min)	Total (max)
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
CHP-CCGT-Gas	5%	4,79	51,89	5,20	19,62	42,25	61,88
	10%	7,76	51,89	5,20	19,62	45,22	64,84
CHP-CCGT-Gas (CO2)	5%	8,99	59,67	5,46	19,62	54,50	74,12
	10%	14,56	59,67	5,62	19,62	60,23	79,85
CHP Cond.-Coal	5%	9,45	21,90	8,76	30,66	9,45	40,11
	10%	15,29	21,90	8,76	30,66	15,29	45,95
CHP Cond.-Coal (CO2)	5%	13,30	22,53	12,91	34,06	14,68	48,74
	10%	21,52	22,53	12,91	34,06	22,90	56,96
CHP-CCGT-Gas (BP)	5%	4,20	51,89	5,21	19,96	41,34	61,30
	10%	6,80	51,89	5,22	20,17	43,74	63,91
CHP Cond.-Coal (BP)	5%	10,45	21,31	9,82	36,56	5,03	41,58
	10%	16,92	21,31	9,82	36,56	11,49	48,05
CHP Cond.-Straw	5%	18,17	110,77	14,21	95,65	47,51	143,16
	10%	28,29	110,77	14,21	95,65	57,62	153,27
CHP Cond.-Wood	5%	13,22	110,77	9,57	95,65	37,91	133,55
	10%	20,57	110,77	9,57	95,65	45,26	140,91
CHP MCFC-Gas	5%	21,96	47,74	21,33	18,03	73,00	91,03
	10%	24,90	47,74	21,33	18,03	75,94	93,97
CHP SOFC-Gas	5%	21,96	42,62	21,33	15,12	70,80	85,92
	10%	24,90	42,62	21,33	15,12	73,74	88,86
CHP MCFC-Biogas	5%	21,96	46,96	31,33	22,01	78,24	100,25
	10%	24,90	46,96	31,33	22,01	81,18	103,19

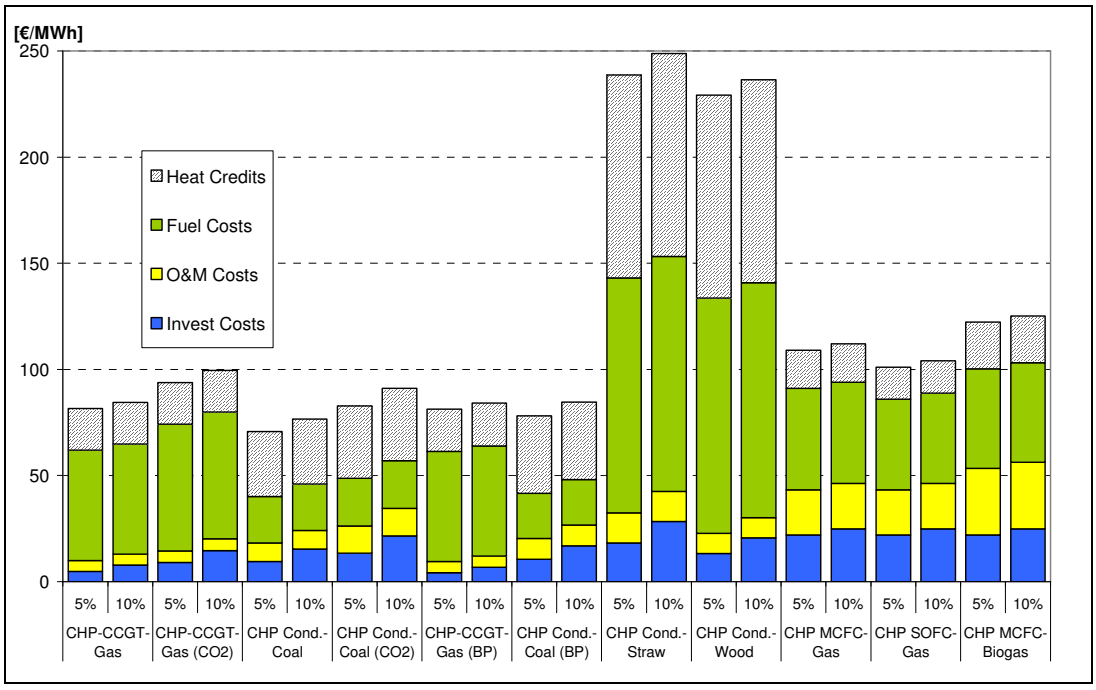


Figure 8 CHP private costs with a discount rate of 5 and 10% (2020)

Table 18 CHP effect of availability with a 5% discount rate, with heat credit (2020)

			Full Load Hours [h/a]					
			3500	4000	4500	5000	5500	6000
Technology			[€/MWh$_{el}$]					
CHP extraction condensing turbine	natural gas	Gas CCGT	51,92	49,66	47,89	46,48	45,33	44,37
		Gas CCGT_CO2	69,25	65,79	63,10	60,95	59,19	57,72
	hard coal	Coal Condensing	27,33	23,14	19,88	17,27	15,14	13,36
		Coal IGCC_CO2	40,55	34,49	29,77	26,00	22,91	20,34
CHP back pressure turbine	natural gas	Gas CCGT BP	50,30	48,20	46,57	45,26	44,19	43,30
	hard coal	Coal CHP BP	25,28	20,53	16,84	13,89	11,47	9,46
CHP extraction condensing	straw	Straw Cond.	84,53	65,79	63,10	60,95	59,19	57,72
	wood chips	Wood chips Cond.	63,95	57,85	53,10	49,30	46,19	43,60
fuel cells	natural gas	Gas MCFC	106,48	98,63	92,53	87,64	83,65	80,32
		Gas SOFC	104,28	96,43	90,33	85,45	81,45	78,12
	biogas	MCFC	111,72	103,87	97,77	92,89	88,89	85,56

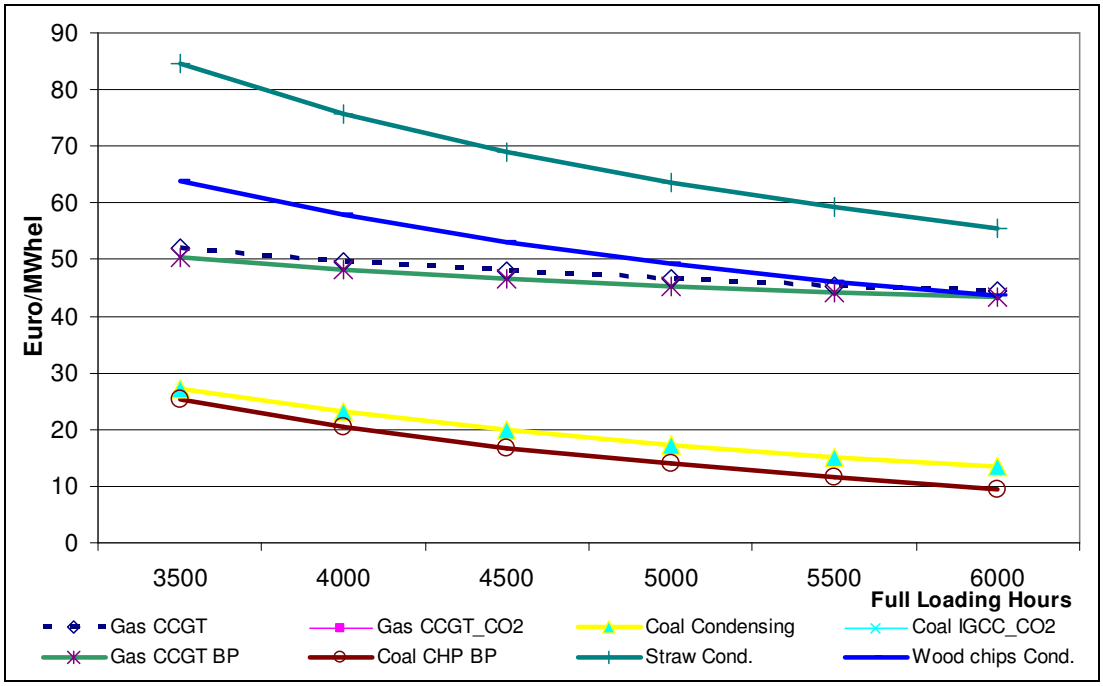


Figure 9 CHP effect of availability (Full loading hours) with a 5% discount rate (2020, with Heat credit)

Table 19 CHP effect of availability by 10% discount rate, with heat credit (2020)

			Full Load Hours [h/a]					
			3500	4000	4500	5000	5500	6000
Technology			**[€/MWh$_{el}$]**					
CHP extraction condensing turbine	natural gas	Gas CCGT	58,27	55,21	52,83	50,93	49,37	48,07
		Gas CCGT_CO2	69,25	65,79	63,10	60,95	59,19	57,72
	hard coal	Coal Condensing	39,85	34,09	29,62	26,04	23,10	20,66
		Coal IGCC_CO2	40,55	34,49	29,77	26,00	22,91	20,34
CHP back pressure turbine	natural gas	Gas CCGT BP	55,67	52,87	50,70	48,96	47,54	46,35
	hard coal	Coal CHP BP	39,13	32,65	27,62	23,58	20,29	17,54
CHP extraction condensing	straw	Straw Cond.	106,20	94,81	85,96	78,88	73,08	68,25
	wood chips	Wood chips Cond.	79,71	71,64	65,36	60,33	56,22	52,80
fuel cells	natural gas	Gas MCFC	112,78	104,14	97,43	92,06	87,66	84,00
		Gas SOFC	110,58	101,95	95,23	89,86	85,46	81,80
	biogas	MCFC	118,02	109,39	102,67	97,30	92,90	89,24

5.2.3. Renewable Sources 2020

With exception of the solar technologies (PV and solar through) the production costs of nearly all renewable energies in 2020 are in the same range as 2007. At a 5% discount rate, the cost of PV decreases of about a factor two. The lower investment costs are essential for this development. But in comparison to the other electricity technologies PV remains the most expensive electricity generating technology with more than 200 €/MWhel at a 5% discount rate.

Table 20 Private costs of renewable electricity generation technologies with a discount rate of 5 and 10% (2020)

		ALLGC	Back-Up, min	Back-Up, max	Total (min)	Total (max)
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
Hydro Run of river small	5%	72,29			72,29	72,29
	10%	128,95			128,95	128,95
Hydro Run of river medium	5%	67,87			67,87	67,87
	10%	121,14			121,14	121,14
Hydro Run of river large	5%	45,19			45,19	45,19
	10%	79,09			79,09	79,09
Hydro dam	5%	73,50			73,50	73,50
	10%	131,67			131,67	131,67
Hydro Pump storage	5%	73,50			73,50	73,50
	10%	131,67			131,67	131,67
Wind On-shore	5%	44,84	8,86	6,49	48,09	54,58
	10%	58,58	11,92	9,62	66,29	75,91
Wind off-shore	5%	45,39	9,26	6,78	48,87	55,65
	10%	59,57	12,46	10,05	67,69	77,74
PV roof	5%	236,10	8,84	6,47	244,93	251,40
	10%	345,94	11,88	9,59	357,83	367,42
PV Open space	5%	193,07	8,79	6,43	201,86	208,29
	10%	284,61	11,82	9,54	296,43	305,97
Solar through	5%	102,95	9,66	7,07	112,62	119,69
	10%	161,16	13,00	10,49	174,16	184,65

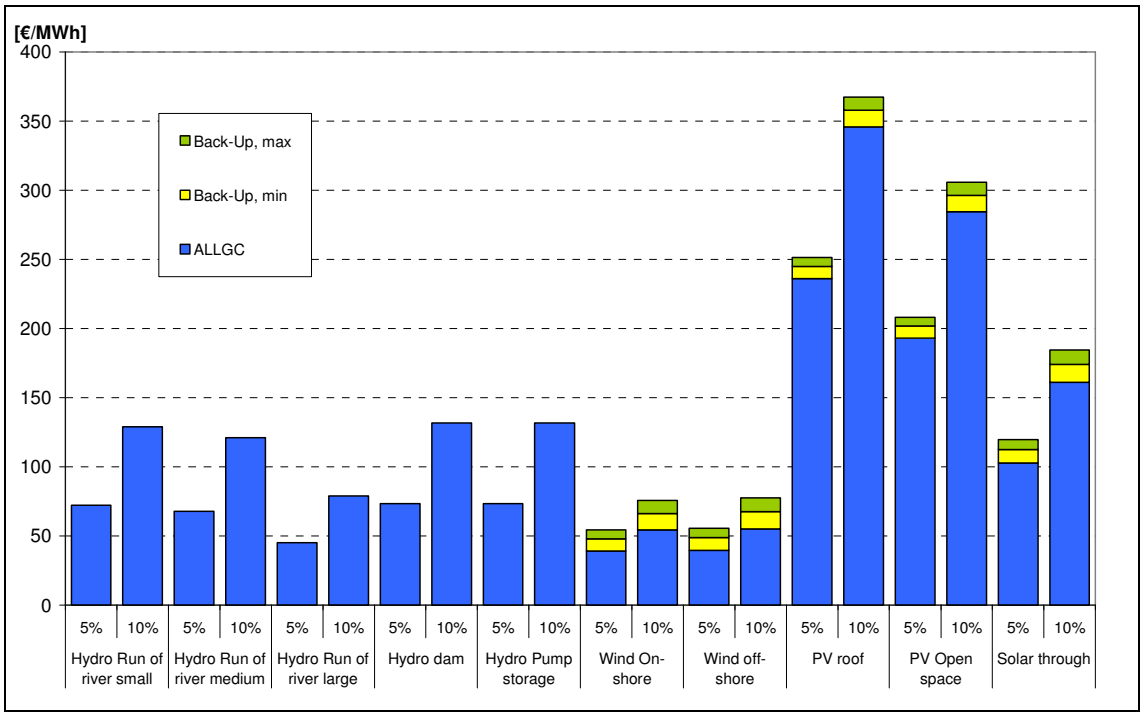


Figure 10 Private costs of renewable electricity generation with a discount rate of 5 and 10 % (2020)

Table 21 Renewables effect of availability with a 5% discount rate (2020)

	Full Load Hours [h/a]										
Technology	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
	[€/MWh$_{el}$]										
Wind Onshore	153,94	139,94	128,28	118,41	109,95	102,62	96,21	90,55	85,52	81,02	76,97
	2500	**2600**	**2700**	**2800**	**2900**	**3000**	**3100**	**3200**	**3300**		
	[€/MWh$_{el}$]										
Wind Offshore	96,36	92,65	89,22	86,03	83,07	80,30	77,71	75,28	73,00		
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV roof	529,29	463,13	411,67	370,51	336,82	308,75	285,00				
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV open space	435,46	381,03	338,69	304,82	277,11	254,02	234,48				
	2500	**3000**	**3500**	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**	**7500**
	[€/MWh$_{el}$]										
Solar trough	246,25	205,21	175,90	153,91	136,81	123,13	111,93	102,61	94,71	87,95	82,08

Table 22 Renewables effect of availability with a 10% discount rate (2020)

	Full Load Hours [h/a]										
Technology	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
	[€/MWh$_{el}$]										
Wind Onshore	153,94	139,94	128,28	118,41	109,95	102,62	96,21	90,55	85,52	81,02	76,97
	2500	**2600**	**2700**	**2800**	**2900**	**3000**	**3100**	**3200**	**3300**		
	[€/MWh$_{el}$]										
Wind Offshore	96,36	92,65	89,22	86,03	83,07	80,30	77,71	75,28	73,00		
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV roof	529,29	463,13	411,67	370,51	336,82	308,75	285,00				
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV open space	435,46	381,03	338,69	304,82	277,11	254,02	234,48				
	2500	**3000**	**3500**	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**	**7500**
	[€/MWh$_{el}$]										
Solar trough	246,25	205,21	175,90	153,91	136,81	123,13	111,93	102,61	94,71	87,95	82,08

5.3. Private Costs 2030

5.3.1. Fossil and Nuclear Power 2030

The lowest private costs of generating electricity by fossil-fired and nuclear technology are below 28 €/MWhel. The private costs and the ranking of technologies are more or less similar to the years 2007 and 2020. The nature of low fuel costs affects the minimal private costs for fossil-fired lignite and nuclear power plants. The markets for coal power plant technology are undergoing substantial changes towards CO_2-sequestration, which leads to higher private costs. At a 5% discount rate, the costs range between 33 and 58 €/MWhel for most plants with CO_2-sequestration. Within this fossil/nuclear framework (2007-2030oil-fired power plants appear as the most expensive generating technology, with up to 100 €/MWhel.

Table 23 Fossil/Nuclear private Costs with a Discount rate of 5 and 10% (2030)

		Invest Costs	Fuel Costs	O&M Costs	Total (min)
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
Nuclear PWR	5%	12,37	6,76	5,74	24,87
	10%	23,49	6,76	5,56	35,81
Oil Condensing	5%	6,60	59,78	8,21	74,59
	10%	11,21	59,78	8,18	79,17
Light Oil Gas Turbine	5%	1,98	97,77	0,02	99,77
	10%	3,37	97,77	0,01	101,14
Coal Condensing	5%	8,48	15,16	8,00	31,64
	10%	14,40	15,16	7,97	37,53
Coal IGCC	5%	10,42	14,47	10,14	35,03
	10%	17,70	14,47	10,09	42,25
Coal IGCC with CO2 seq.	5%	12,98	16,26	12,32	41,56
	10%	22,04	16,26	12,27	50,57
Lignite Condensing	5%	8,88	7,06	5,41	21,35
	10%	15,08	7,06	5,38	27,52
Lignite IGCC	5%	10,85	6,72	10,14	27,71
	10%	18,43	6,72	10,09	35,24
Lignite IGCC with CO2 seq.	5%	13,52	7,59	12,32	33,43
	10%	22,95	7,59	12,27	42,81
Gas CCGT	5%	3,39	37,89	3,95	45,23
	10%	5,76	37,89	3,94	47,59
Gas CCGT with CO2 seq.	5%	8,15	41,87	8,71	58,74
	10%	13,84	41,87	8,69	64,41
Natural Gas Turbine	5%	1,90	59,67	3,58	65,15
	10%	3,23	59,67	3,58	66,48

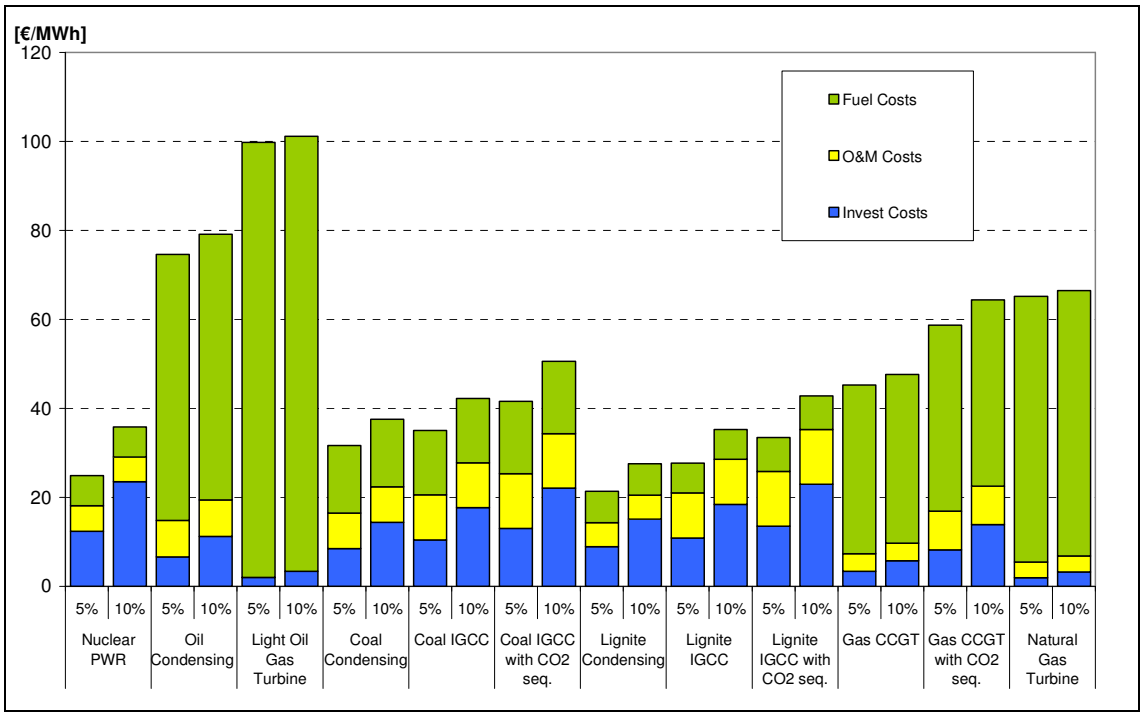


Figure 11 Fossil/Nuclear private costs with a discount rate of 5 and 10 % (2030)

Table 24 Fossil/Nuclear effect of availability with a 5% discount rate (2030)

	Full Load Hours [h/a]														
	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500
Technology	[€/MWh$_{el}$]														
Nuclear PWR	95,26	73,26	60,06	51,27	44,98	40,27	36,60	33,67	31,27	29,27	27,58	26,13	24,87	23,77	22,80
Oil condensing power plant	127,86	111,21	101,23	94,57	89,81	86,24	83,47	81,25	79,44	77,92	76,64	75,54	74,59	73,76	73,03
Light Oil gas turbine	107,79	105,28	103,78	102,78	102,06	101,53	101,11	100,77	100,50	100,27	100,08	99,92	99,77	99,65	99,54
Coal condensing power plant	87,35	69,94	59,50	52,53	47,56	43,83	40,93	38,61	36,71	35,13	33,79	32,64	31,64	30,77	30,01
Coal IGCC	105,00	83,13	70,01	61,27	55,02	50,33	46,69	43,77	41,39	39,40	37,72	36,28	35,03	33,93	32,97
Coal IGCC CO2 seq.	128,46	101,31	85,01	74,15	66,39	60,57	56,04	52,42	49,46	46,99	44,90	43,11	41,56	40,20	39,00
Lignite condensing power plant	74,64	57,99	48,00	41,33	36,58	33,01	30,23	28,01	26,19	24,68	23,40	22,30	21,35	20,52	19,78
Lignite IGCC	99,41	77,00	63,56	54,60	48,20	43,40	39,66	36,67	34,23	32,19	30,47	28,99	27,71	26,59	25,60
Lignite IGCC CO2 seq.	122,48	94,65	77,95	66,82	58,87	52,91	48,27	44,56	41,52	38,99	36,85	35,02	33,43	32,04	30,81
Gas CCGT	68,49	61,22	56,86	53,96	51,88	50,32	49,11	48,14	47,35	46,69	46,13	45,65	45,23	44,87	44,55
Gas CCGT CO2 seq.	119,43	100,46	89,08	81,50	76,08	72,01	68,85	66,32	64,25	62,53	61,07	59,82	58,74	57,79	56,95
Natural Gas turbine	78,88	74,59	72,02	70,30	69,07	68,15	67,44	66,87	66,40	66,01	65,68	65,39	65,15	64,93	64,74

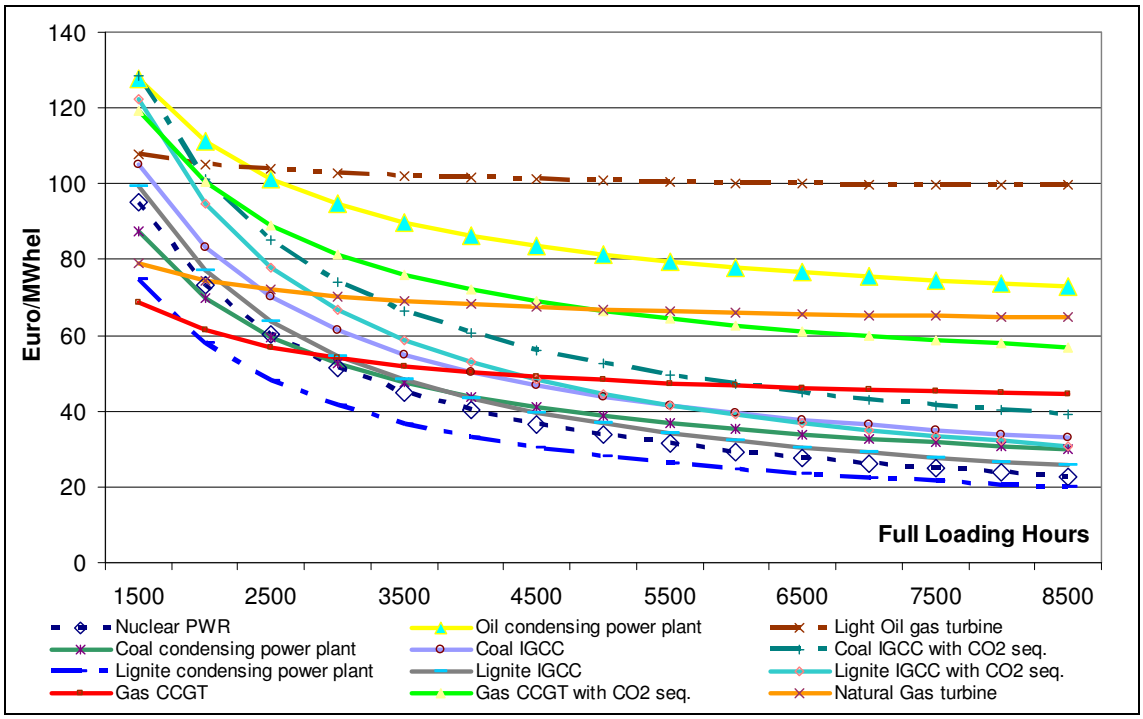


Figure 12 Effect of availability (Full loading hours) with a 5% Discount rate (2030)

Table 25 Fossil/Nuclear effect of availability with a 10% discount rate (2030)

	Full Load Hours [h/a]										
Technology	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
	[€/MWh$_{el}$]										
Wind Onshore	153,94	139,94	128,28	118,41	109,95	102,62	96,21	90,55	85,52	81,02	76,97
	2500	**2600**	**2700**	**2800**	**2900**	**3000**	**3100**	**3200**	**3300**		
	[€/MWh$_{el}$]										
Wind Offshore	96,36	92,65	89,22	86,03	83,07	80,30	77,71	75,28	73,00		
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV roof	529,29	463,13	411,67	370,51	336,82	308,75	285,00				
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV open space	435,46	381,03	338,69	304,82	277,11	254,02	234,48				
	2500	**3000**	**3500**	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**	**7500**
	[€/MWh$_{el}$]										
Solar trough	246,25	205,21	175,90	153,91	136,81	123,13	111,93	102,61	94,71	87,95	82,08

5.3.2. Combined Heat and Electricity 2030

In 2030, the production costs of CHP plants are nearly equivalent to their values in 2020. With the sole exception of the lower investment costs of the SOFC fuel cells, the different fuel price trends entail discrepancies in private costs.

Table 26 CHP private costs with a Discount rate of 5 and 10% (2030)

		Invest Costs	Fuel Costs	O&M Costs	Heat Credits	Total (min)	Total (max)
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
CHP-CCGT-Gas	5%	4,79	50,78	5,20	18,83	41,95	60,78
	10%	7,76	51,89	5,20	19,62	45,22	64,84
CHP-CCGT-Gas (CO2)	5%	8,99	58,21	5,46	18,83	53,84	72,67
	10%	14,56	59,67	5,62	19,62	60,23	79,85
CHP Cond.-Coal	5%	9,45	21,31	8,76	29,38	10,13	39,51
	10%	15,29	21,90	8,76	30,66	15,29	45,95
CHP Cond.-Coal (CO2)	5%	13,30	21,90	12,91	32,65	15,47	48,12
	10%	21,52	22,53	12,91	34,06	22,90	56,96
CHP-CCGT-Gas (BP)	5%	4,20	51,33	5,18	19,18	41,54	60,71
	10%	6,80	51,89	5,22	20,17	43,74	63,91
CHP Cond.-Coal (BP)	5%	10,45	20,75	9,82	34,90	6,12	41,02
	10%	16,92	21,31	9,82	36,56	11,49	48,05
CHP Cond.-Straw	5%	18,17	110,77	14,21	95,65	47,51	143,16
	10%	28,29	110,77	14,21	95,65	57,62	153,27
CHP Cond.-Wood	5%	13,22	110,77	9,57	95,65	37,91	133,55
	10%	20,57	110,77	9,57	95,65	45,26	140,91
CHP MCFC-Gas	5%	21,96	47,74	21,33	26,52	64,51	91,03
	10%	24,90	47,74	21,33	18,03	75,94	93,97
CHP SOFC-Gas	5%	16,47	42,62	19,50	15,91	62,68	78,60
	10%	18,68	42,62	19,50	15,91	64,89	80,80
CHP MCFC-Biogas	5%	21,96	43,20	31,33	26,52	69,97	96,49
	10%	24,90	46,96	31,33	22,01	81,18	103,19

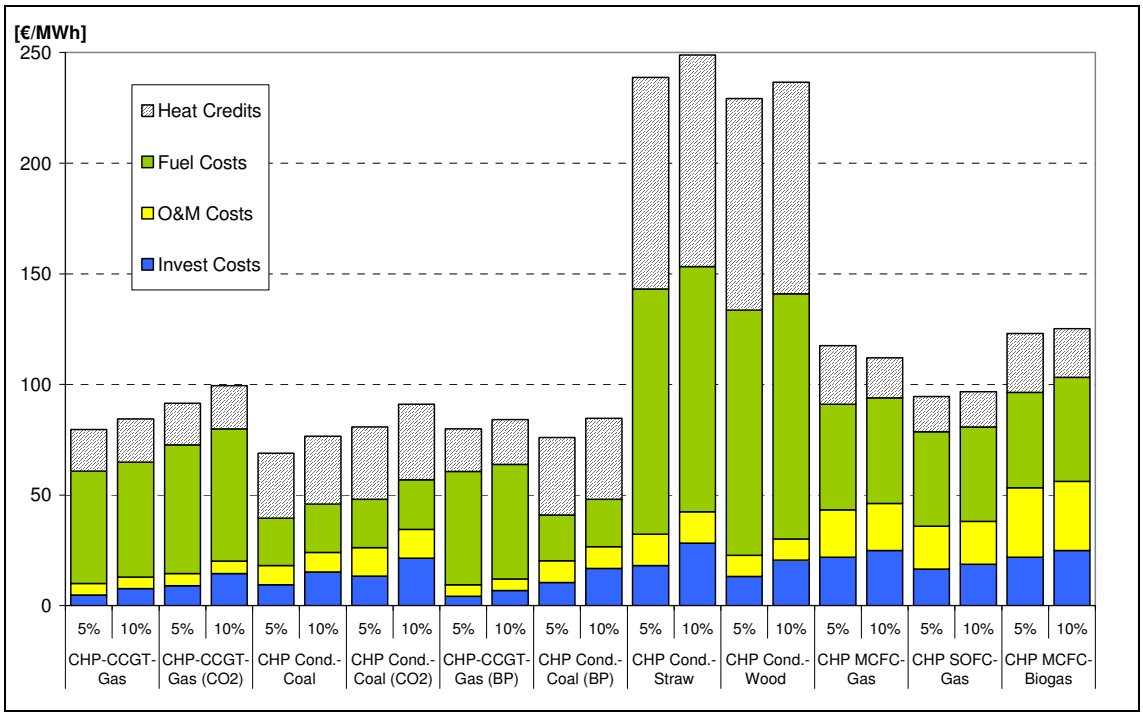


Figure 13 CHP private costs with a discount rate of 5 and 10 % (2030)

Table 27 CHP effect of availability with a 5% discount rate, with heat credit (2030)

			Full Load Hours [h/a]					
			3500	4000	4500	5000	5500	6000
Technology			**[€/MWh$_{el}$]**					
CHP extraction condensing turbine	natural gas	Gas CCGT	51,61	49,35	47,59	46,18	45,02	44,06
		Gas CCGT_CO2	68,59	65,13	62,44	60,29	58,53	57,06
	hard coal	Coal Condensing	28,01	23,82	20,56	17,95	15,82	14,04
		Coal IGCC_CO2	41,34	35,28	30,56	26,79	23,70	21,13
CHP back pressure turbine	natural gas	Gas CCGT BP	50,51	48,41	46,77	45,46	44,39	43,50
	hard coal	Coal CHP BP	26,37	21,63	17,94	14,98	12,57	10,55
CHP extraction condensing	straw	Straw Cond.	84,53	75,85	69,10	63,71	59,29	55,61
	wood chips	Wood chips Cond.	63,95	57,85	53,10	49,30	46,19	43,60
fuel cells	natural gas	Gas MCFC	97,99	90,14	84,04	79,16	75,16	71,83
		Gas SOFC	87,80	81,91	77,33	73,67	70,67	68,18
	biogas	MCFC	103,45	95,61	89,50	84,62	80,63	77,30

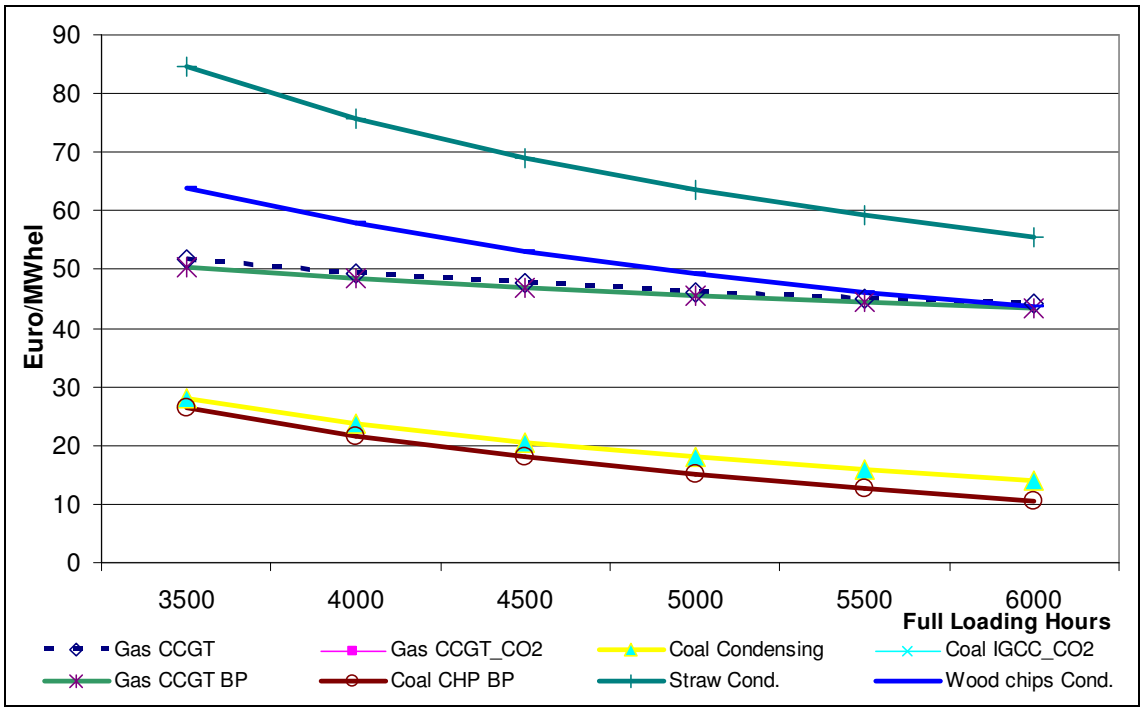


Figure 14 **Effect of availability (Full loading hours) with a 5% discount rate (2030, with Heat credit)**

Table 28 **CHP effect of availability with a 10% discount rate, with heat credit (2030)**

			Full Load Hours [h/a]					
			3500	4000	4500	5000	5500	6000
Technology			[€/MWh$_{el}$]					
CHP extraction condensing turbine	natural gas	Gas CCGT	58,27	55,21	52,83	50,93	49,37	48,07
		Gas CCGT_CO2	68,59	65,13	62,44	60,29	58,53	57,06
	hard coal	Coal Condensing	39,85	34,09	29,62	26,04	23,10	20,66
		Coal IGCC_CO2	41,34	35,28	30,56	26,79	23,70	21,13
CHP back pressure turbine	natural gas	Gas CCGT BP	55,67	52,87	50,70	48,96	47,54	46,35
	hard coal	Coal CHP BP	39,13	32,65	27,62	23,58	20,29	17,54
CHP extraction condensing	straw	Straw Cond.	106,20	94,81	85,96	78,88	73,08	68,25
	wood chips	Wood chips Cond.	79,71	71,64	65,36	60,33	56,22	52,80
fuel cells	natural gas	Gas MCFC	112,78	104,14	97,43	92,06	87,66	84,00
		Gas SOFC	110,58	101,95	95,23	89,86	85,46	81,80
	biogas	MCFC	118,02	109,39	102,67	97,30	92,90	89,24

5.3.3. Renewable Sources 2030

In 2030, the private costs calculated for renewable technologies do not undergo the same price reduction as from 2020 to 2007. At a discount factor of 5%, the wind energy production costs are in the range of 46 to 47 €/MWhel (incl. Back-up), against private costs of 49 €/MWhel in 2020. For solar plants, the installation site is the crucial factor of the private costs. Solar power roof systems are more expensive than open space systems. For roof solar energy systems the

private costs reach around 230 €/MWhel at 5% discount rate and above 330 €/MWhel at 10% discount rate.

Table 29 Private costs of electricity generation technologies by renewable sources with a discount rate of 5 and 10% (2030)

		ALLGC	Back-Up, min	Back-Up, max	Total (min)	Total (max)
		[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]	[Eur/MWh$_{el}$]
Hydro Run of river small	5%	72,29			72,29	72,29
	10%	128,95			128,95	128,95
Hydro Run of river medium	5%	67,87			67,87	67,87
	10%	121,14			121,14	121,14
Hydro Run of river large	5%	45,19			45,19	45,19
	10%	79,09			79,09	79,09
Hydro dam	5%	73,50			73,50	73,50
	10%	131,67			131,67	131,67
Hydro Pump storage	5%	73,50			73,50	73,50
	10%	131,67			131,67	131,67
Wind On-shore	5%	44,23	8,86	6,49	47,60	54,08
	10%	57,68	11,92	9,62	65,49	75,11
Wind off-shore	5%	42,02	9,26	6,78	46,14	52,91
	10%	54,63	12,46	10,05	63,23	73,28
PV roof	5%	219,53	8,84	6,47	228,37	234,84
	10%	320,23	11,88	9,59	332,11	341,70
PV Open space	5%	150,61	8,79	6,43	159,40	165,83
	10%	223,84	11,82	9,54	235,67	245,21
Solar through	5%	94,98	9,66	7,07	104,64	111,71
	10%	148,67	13,00	10,49	161,67	172,16

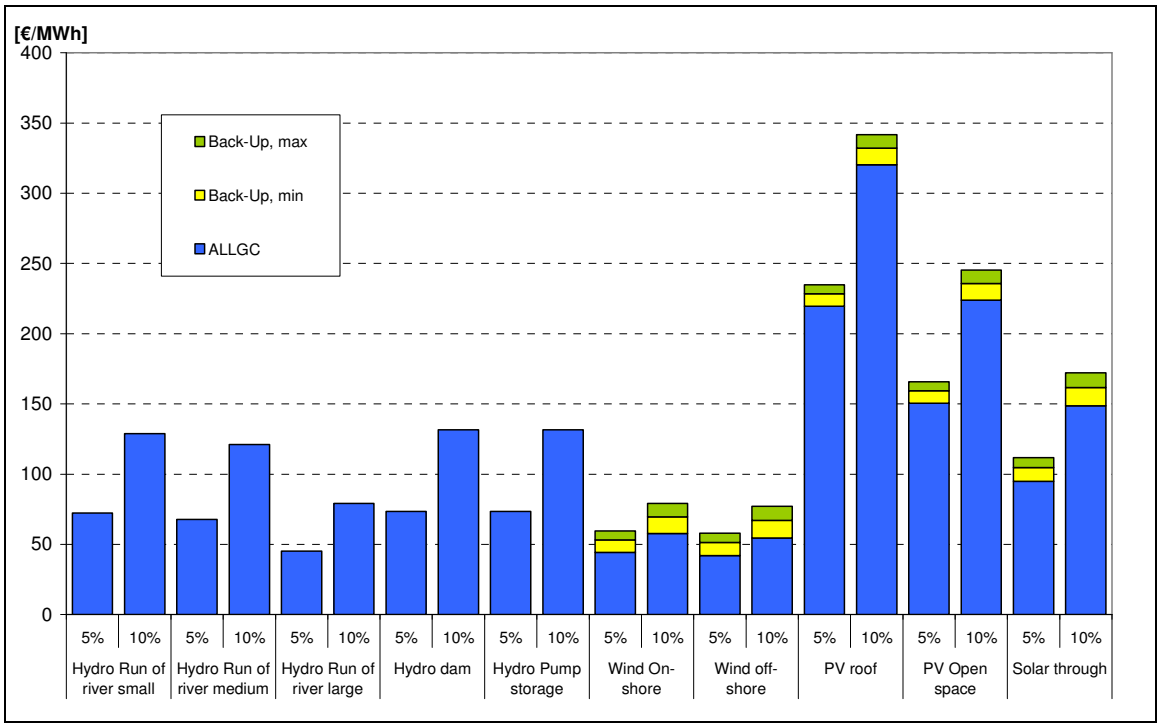


Figure 15 Renewables private costs with a discount rate of 5 and 10 % (2030)

Table 30 Renewables effect of availability with a 5% discount rate (2030)

	Full Load Hours [h/a]										
Technology	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
	[€/MWh$_{el}$]										
Wind Onshore	151,59	137,81	126,32	116,61	108,28	101,06	94,74	89,17	84,22	79,78	75,79
	2500	**2600**	**2700**	**2800**	**2900**	**3000**	**3100**	**3200**	**3300**		
	[€/MWh$_{el}$]										
Wind Offshore	88,37	84,97	81,82	78,90	76,18	73,64	71,26	69,04	66,95		
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV roof	489,95	428,70	381,07	342,96	311,78	285,80	263,82				
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV open space	342,48	299,67	266,37	239,74	217,94	199,78	184,41				
	2500	**3000**	**3500**	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**	**7500**
	[€/MWh$_{el}$]										
Solar trough	227,17	189,31	162,27	141,98	126,21	113,59	103,26	94,65	87,37	81,13	75,72

Table 31 Renewables effect of availability with a 10% discount rate (2030)

	Full Load Hours [h/a]										
Technology	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
	[€/MWh$_{el}$]										
Wind Onshore	151,59	137,81	126,32	116,61	108,28	101,06	94,74	89,17	84,22	79,78	75,79
	2500	**2600**	**2700**	**2800**	**2900**	**3000**	**3100**	**3200**	**3300**		
	[€/MWh$_{el}$]										
Wind Offshore	88,37	84,97	81,82	78,90	76,18	73,64	71,26	69,04	66,95		
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV roof	489,95	428,70	381,07	342,96	311,78	285,80	263,82				
	700	**800**	**900**	**1000**	**1100**	**1200**	**1300**				
	[€/MWh$_{el}$]										
PV open space	342,48	299,67	266,37	239,74	217,94	199,78	184,41				
	2500	**3000**	**3500**	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**	**7500**
	[€/MWh$_{el}$]										
Solar trough	227,17	189,31	162,27	141,98	126,21	113,59	103,26	94,65	87,37	81,13	75,72

6. Summary

The lowest private costs of generating electricity from the traditional main generating technologies (nuclear, hard coal, lignite and hydro) are within the range of 25 to 45 €/MWhel. The private costs for renewable energy sources remain at a high level up to 2030. At a discount rate of 5% the costs for generating electricity with renewable energies are between 55 €/MWhel for wind turbines and about 150 €/MWhel for PV systems. Combined Heat and Power plants are already today very competitive with private costs ranging from 40 to 60 €/MWhel. The choice of the discount rates of 5 and 10% reflects an assessment of power generation investment strategies.

Within this framework and limitations, the paper suggests that none of the traditional electricity technologies can be expected to be the cheapest in all situations. Also, the chosen generating technology will depend on the specific circumstances of each project.

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