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Development of a set of full cost estimates of the use of different energy sources and its comparative assessment in EU countries

This report on full cost of electricity generation in EU is divided in two parts.

Part one provides a literature review on methodology and results on private and external cost calculation. The literature review assesses costs of electricity generation for each EU-25 country, plus Romania and Norway. For some countries a brief overview of electricity production in the country and a foreseen on electricity production evolution until 2030 introduces the cost assessment.

Part two provides new estimates on full costs of electricity generation in Europe. Results are obtained by summing external costs due to impacts on human health, environment, crops and materials and to climate change impacts, to private generation costs. Results are provided for present (period 2005-2010), 2020 and 2030. In this report, a wide set of technologies is analysed, including nuclear and fossil fired power plants, renewables and combined heat and power plants.

PART 2
FULL COST: LEVELISED EUROPEAN ESTIMATES
RESULTS AND ASSESSMENT

Development of a set of full cost estimates of the use of different energy sources and its comparative assessment in EU countries

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1. Introduction

This report provides new estimates on full costs of electricity generation in Europe. Results are obtained by summing external costs due to impacts on human health, environment, crops, materials and to climate change impacts, to private generation costs. This exercise results in levelised and homogenous values for all EU27 countries. Data are levelised since European average values for private costs, emissions inventory and external cost of greenhouse gases and heavy metals are considered. However country-specific levels of emissions for air pollutants are taken into account, hence regional assessment is admitted for external costs. Data are homogeneous since the same set of technologies, which includes nuclear and fossil fired power plants, renewables and combined heat and power plants, is considered for the whole analysis. Results are provided for present (period 2005-2010), 2020 and 2030.

Chapter 2 gives an overview of the methodology adopted for private and external costs calculation. Chapter 3 provides the European average results of the estimates for a wide set of technologies and their evolution from 2005 until 2030. Chapter 4 provides an assessment on full cost composition detailed for technology and an assessment of results across countries.

2. CASES methodology for cost estimation – EU levelised values

2.1 Private costs

In the framework of the CASES project private costs of electricity production have been calculated with the *Average Levelised Generating Costs* (ALLGC) methodology[1]. The methodology calculates the generation costs (in EuroCents/kWh) 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 2005, which is the specified base year, by applying a discount rate. According to the methodology used in the IEA study in 2005[2], 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. The total lifetime expenses include the value of the capital, fuel expenses and operation and maintenance expenses, inclusive the rate of return equal to discount rate.

The formula to calculate the average lifetime levelised generating cost is:

$$\text{Average Lifetime Levelised Generating Cost} = \sum_{t=0}^{T} \frac{[I_t + M_t + F_t]}{(1+r)^t} \Bigg/ \sum_{t=0}^{T} \frac{[E_t]}{(1+r)^t}$$

Where I_t is the investment expenditures in year t; M_t is the operation and maintenance expenditure in year t; F_t is the fuel expenditures in year t; E_t is the electricity generation in year t and r is the discount rate.

The ***capital (investment)*** expenditures in each year include construction, refurbishment and decommissioning expenses. As suggested by OECD the methodology used defines the specific overnight construction cost 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.

The ***operating and maintenance costs (O&M)*** contribute by a small but no negligible fraction to the total cost. Fixed O&M costs include costs of the operational staff, insurances, taxes etc. Variable O&M costs include cost for maintenance, contracted personnel, consumed material and cost for disposal of normal operational waste (excluding radioactive waste).

[1] The methodology used and the results obtained are explained in the CASES report 4.1 "Private Costs of Electricity and Heat Generation", IER University Stuttgart.
[2] IEA, OECD, NEA "Projected Costs of Generating Electricity", Paris, 2005.

The ***fuel price*** assumptions for fossil and nuclear plants are described in Figure 2.1. Since lignite and biomass are local energy carriers, which are not included in an international price mechanism, then the fuel prices of these two types of energy carriers are assumed to be constant. The price projections for the other fuels are determined by taking into account the international market mechanism. Of particular noteworthiness for nuclear power is that the total fuel cycle costs are considered (natural uranium, conversion, enrichment, intermediate and final disposal).

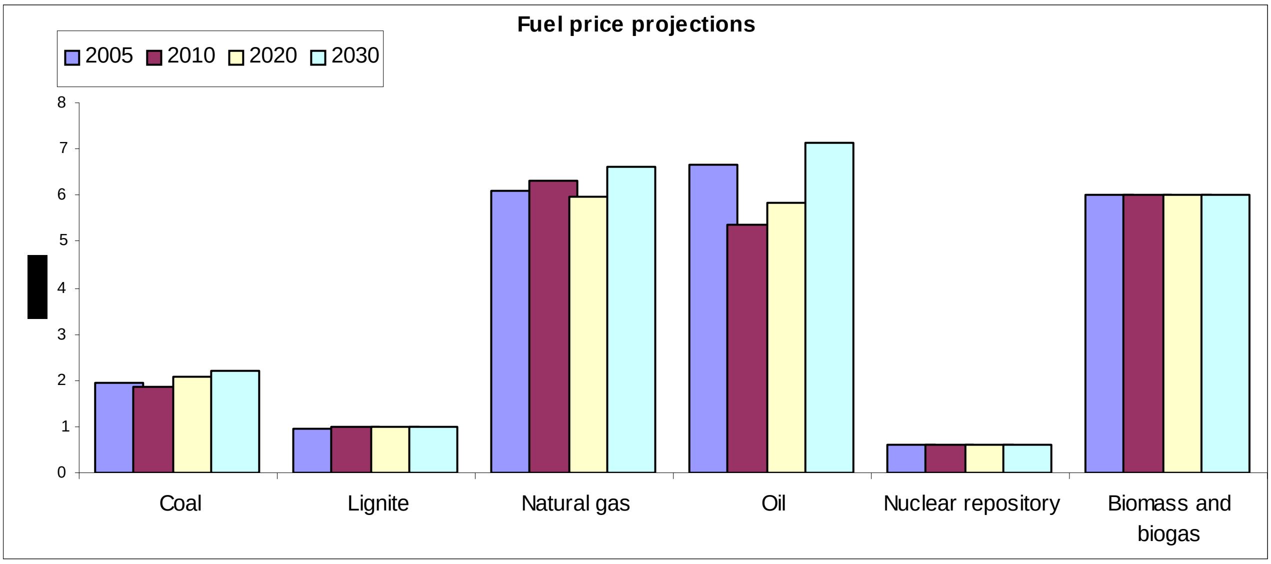

Figure 2.1 Fuel price assumptions on plant level (EUSUSTEL, 2006[3])

To assess full costs of electricity production a ***discount rate*** of 5 percent is considered.

The basis year for the analysis is 2005.

Table 2—1 reports the assumption on ***technical lifetime***, which are on the base of the cost estimation.

type of power plant	energy carrier	technology of electricity generation	technical life time (years) for construction year		
			2007	2020	2030
Nuclear power plant	PWR (Pressurized Water Reactor)		40	40	60
Fossil fired power plant			35	35	35
Electricity generation based on renewables	hydro	run of river	70	70	70
		dam and pump storage	120	120	120
	Wind		20	20	20
	PV		25	25	25
	solar thermal		30	35	40
CHP with an extraction condensing turbine	natural gas and hard coal		35	35	35
Biomass CHP			30	30	30
Fcuel cells			7	7	7

Table 2—1 Technical life time for type of power plant

The variables listed above are used to estimate the average lifetime levelised generating cost (ALLGC). However, to make private costs comparable across technologies some adjustments are introduced for Combined Heat and Power plants and for wind and solar technologies.

[3] EU, European Sustainable Electricity; Comprehensive Analysis of Future European Demand and Generation of European Electricity and its Security of Supply, Leuven 2006.

The ALLGC for combined heat and power plants (CHP) does not take into account the fact that the plant is used also to produce heat, in addition to electricity. 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. The value of recovered thermal energy is equivalent to the cost of fuel energy that would have otherwise been consumed, which is referred to as an energy credit or ***fuel credit***. A gas boiler, with an efficiency of 90 percent, gives the alternative heat generation technology in this report. Then in the computation of full cost the fuel credit is subtracted from the ALLGC.

An adjustment of the ALLGC should be made also for wind and solar technologies. Due to the fluctuation caused by producing energy with wind and solar plants, which are intermittent energy sources, a back-up technology is necessary for compensating this. The ***back-up cost*** of uncertain generating power of solar and wind plants is calculated with the equation estimated by Friedrich in 1989[4]. In this equation, the provision of the back-up power is reduced by a capacity factor (P) for the renewable technologies. In the calculation of full costs the ALLGC is summed to the back up cost of a gas-fired CCGT plant for maximum back-up costs.

The methodology proposed above determines for each technology a private cost of electricity production levelised for all Europe. To reach the objective of comparability, country specific cost components are not considered. In particular the estimation is not influenced by the capital market's differences across Europe since overnight investments costs are considered. In addition all costs are considered net of taxes, which change from country to country. This assumption is consistent with the objective to assess full costs from the policy maker point of view, to provide a full production cost scenario. Moreover, for the purpose of comparison, additional plant specific costs – environmental taxes on fuels, carbon emission charges, system integration costs, etc. – are not included in the private cost of generating electricity.

The costs are determined for new plants build respectively in 2007, 2020 and 2030. The values estimated for 2007 are used for the period 2005-2010; this approximation is acceptable by considering the homogeneity of the European electricity scenario in these five years.

2.2 External costs

External cost of electricity generation (in EuroCents/kWh) are calculated by multiplying the average height of release values of unit of emission for classical air pollutants (2000 Eurocent/kg) times the quantity of emission for unit of electricity generated (kg/kWh).

Marginal external costs of emissions

Marginal external costs for classical air pollutants are calculated for CASES project by IER with the updated *EcoSenseWebV1.2* tool.

To estimate external costs by transforming impacts that are expressed in different units into a common monetary unit, the *ExternE* methodology is adopted[5]. The principal stages of the ExternE methodology are[6]:

1) Definition of the activity to be assessed and the background scenario where the activity is embedded. Definition of the important impact categories and externalities.
2) Estimation of the impacts or effects of the activity (in physical units). In general, the impacts allocated to the activity are the difference between the impacts of the scenario with and the scenario without the activity.

[4] Friedrich, R.; Kallenbach, U.; Thöne E.; Voß A.; Rogner, H.; Karl, H.; Externe Kosten der Stromerzeugung. Schlussbetrachtung zum Projekt im Auftrag vom VDEW, VWEW Energieverlag, Frankfurt (Main) 1989.
[5] The ExternE methodology is widely explained in the report "ExternE – Externalities of energy – Methodology 2005 Update" 2005.
[6] "ExternE – Externalities of energy – Methodology 2005 Update" Executive Summary pp 1-6.

3) Monetisation of the impacts, leading to external costs.
4) Assessment of uncertainties, sensitivity analysis.
5) Analysis of the results, drawing of conclusions.

The impact categories which are addressed using the ExternE methodology and that are analyzed in the full costs assessment are the environmental impacts (on human health, crops and loss of biodiversity) the damage to materials and the global warming impact.

The approach used to quantify environmental impacts is the *Impact Pathway Approach* (IPA). The principal steps can be grouped as follows:

- Emission: specification of the relevant technologies and pollutants emitted by a power plant at a specific site, for the whole life cycle, which is from construction to dismantling, including fuel extraction and transportation;
- Dispersion: calculation of increased pollutant concentrations in all affected regions, using models of atmospheric dispersion;
- Impact: calculation of the cumulated exposure from the increased concentration, and calculation of impacts (damage in physical units) from this exposure using an exposure-response function;
- Cost: valuation of these impacts in monetary terms.

The values estimated for CASES for classical air pollutants correspond to an average (stack) height of release for all sectors. However for technologies characterised by a large combustion plant with a high stack, a more sophisticated attribution of emissions would be desirable. As a first step, at least the emissions due to operation (mainly burning fuel) have to be attributed to *high stack* values, instead of average height of release.

The values are based on parameterised results of a complex dispersion model, which is obtained by completely integrating into the EcoSenseWeb system the results of the Industrial Source Complex Model (ISC) and the Source Receptor (SR)-matrices for regional modelling. The *Industrial Source Complex Model (ISC)* is a Gaussian plume model developed by the US-EPA[7]. The ISC is used for transport modelling of primary air pollutants (SO_2, NO_x, particulates) on a local scale (100 km x 100 km around the power plant site, with a resolution of 10 x 10 km^2 grid). The *Source Receptor (SR)-matrices* for regional modelling is based on EMEP/MSC-West Eulerian dispersion model. The chemical transport models developed at Meteorological Synthesizing Centre - West (MSC-W) are concerned with the regional atmospheric dispersion and deposition of acidifying and eutrophying compounds(S, N), ground level ozone(O_3) and particulate matter($PM^{2.5}$, PM^{10}).

The costs of emission are calculated with respect to the impact of pollutants on human health, crops, damage to materials, and loss of biodiversity caused by acidification and eutrophication. For all these categories of impact the following air pollutants are considered:

- Ammonia (NH_3),
- Non-methane volatile organic compounds unspecified (NMVOC),
- Nitrogen oxides (NO_x),
- Particulates (PPM^{co} – between 2.5 and 10 10um, and PPM^{25} – less then 2.5 um),
- Sulfur dioxide (SO_2).

In addition the cost of sulfur dioxide and nitrogen oxides emissions in the atmosphere is calculated with respect to the damage to materials.[8]

Results for damage costs related to impacts on human health, environment, crops and materials are regionally detailed and are available for each EU-27 country and for the EU-27 as an average.

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[7] R.W. Brode, J. Wang: Users's Guide for the Industrial Source Complex (ISC2) Dispersion Models Volumes I-III. EPA-450/4-92-008a. EPA-450/4-92-008b. EPA-450/4-92-008c. U.S. Environmental Protection Agency, 1992, Research Triangle Park, North Carolina 27711.

[8] Values of damage to materials and to crops are based on WTM model run - year 2000.

The values reflect an average of the results for different meteorological years, namely 1996, 1997, 1998, 1999 and 2000. Then estimated values are not affected by the assumption of an arbitrary year, but they reflect more typical and average conditions.

In addition to the values of impact of the air pollutants analysed above, cost of damage on human health per unit of emission is available also for formaldehyde and for the following **heavy metals**:

- Cadmium (Cd),
- Arsenic (As),
- Nickel (Ni),
- Lead (Pb),
- Mercury (Hg),
- Chromium, (Cr)
- Chromium IV (Cr-IV).

This set of marginal external costs is not country specific, hence the same value for each EU-27 country is considered.

An additional set of pollutants for which a generic marginal external cost is estimated for all Europe consists of the following **radionuclides**:

- Aerosols, radioactive, unspecified into air,
- Carbon-14 into air and water,
- Hydrogen-3, Tritium into air and water,
- Iodine-129 into air,
- Iodine-131 into air,
- Krypton-85 into air,
- Noble gases, radioactive, unspecified into air,
- Radon-222 into air,
- Thorium-230 into air and water,
- Uranium-234 into air and water.

The release of these radionuclides and the corresponding radioactivity into the environment causes impacts to human health. The impacts considered are fatal cancers, non-fatal cancers and hereditary defects. The cost in Euro/kBq is obtained by multiplying the collective dose estimation unit (manSv) per kBq, which is specific for each pollutants, times the cases of fatal cancer, non fatal cancer and hereditary defects per manSv and the corresponding Willingness To Pay (WTP) values in Euro per endpoint. The factors relating collective dose to impact, so called risk factors, are determined by a linear dose-effect relationship. The values used in calculation are: 0.05 cases per manSv for fatal cancers, 0.12 cases per manSv for non-fatal cancers and 0.01 cases per manSv for hereditary defects[9]. To calculate the cost in Euro/kBq for radionuclide unit of emission the respective number of cases of endpoint per kBq is multiplied by the following values for WTP per endpoint: 1.120.000 Euro for fatal cancers, 481.000 for non-fatal cancers and 1.500.000 for hereditary defects[10]. These WTP values are derived from estimates for different types of cancer, e.g. leukaemia, lung cancer, etc. Types of cancer differ in latency and estimated YOLL and YLD (year lost due to disability)[11]. For fatal cancers, 15.95 YOLL + 0.26 YLD are assumed. The monetary value for fatal cancer includes also an additional estimation of WTP to avoid the illness based on the costs of illness (COI) (ca. 481,050 E) The YOLL are multiplied with 40,000 Euro/year of life lost. in ExternE 1999. Heredity effects have been valued at the same value as a

[9] The recommendation for ExternE / NEEDS is to use these factors based on the ICRP60 recommendations for core analysis. Further details are presented in the nuclear fuel cycle report (ExternE, 1995, Vol. 5).
[10] These values for WTP for fatal cancers, non-fatal cancers and for hereditary defects seem to be much higher than the values for the other endpoints. However, the units for other endpoints are e.g. per day or per year, while the case of fatal cancer corresponds approximately to 16 years of lifetime lost.
[11] Sections 12.3.2, and 12.4 in ExternE, 1999, Vol. 7.

statistical life[12], since there are no WTP estimates of such impacts available, and given the relevance usually attributed to such effects.

An important component of the total external cost of electricity production is the cost of **green house gases**. In the framework of the CASES project two approaches are followed to assess global warming. The first methodology estimates the quantifiable damage[13] while the second one calculates the marginal abatement costs[14].

The damage costs of greenhouse gases due to climate change impacts are estimated with EcoSenseWeb by using the FUND3.0[15] applied model. The model estimates a selection of the potential impacts of climate change on agriculture, forestry, unmanaged ecosystems, sea level rise, human mortality, energy consumption, and water resources. The impact is calculated as the discounted difference between the flows of real consumption (or welfare) over time calculated by the Integrated Assessment Model for the global economy (FUND3.0) for i) a base scenario for the period 1950-2300, ii) a base scenario perturbed by a small, additional emission of a GHG in a specific time period.

By following the abatement cost methodology, two values are calculated s by the CASES porjct. The first estimate concerns the marginal abatement cost for Europe for emissions reduction required by the Kyoto protocol, the second estimate is based on EU target of 30% reduction in 2020 compared to 1990.

Table 2—2 compares the results of costs in Euro 2000 per Ton of emissions obtained by the alternative approaches.

Marginal costs of GHG emissions in Euro2000 per ton discounted to the year of emission												
	damage costs	abatement costs		damage costs	abatement costs		damage costs	abatement costs		damage costs	abatement costs	
	2000-2009	Kyoto objectives	30%	2010-2019	Kyoto objectives	30%	2020-2029	Kyoto objectives	30%	2030-2039	Kyoto objectives	30%
		2010			2015	2020		2025	2020		2030	
CO2	7	19	19	11	19	74	2020	21	74	15	27	99
CH4	304	399	399	369	399	1554	461	427	1554	641	571	2088
N2O	11816	5890	5890	16777	589	22940	19311	6291	22940	25846	8429	30829

Table 2—2 Comparison of marginal damage costs of GHG and marginal abatement costs of GHG

To calculate the full cost of electricity generation the marginal abatement costs to reach the Kyoto objectives are used. The results are obtained by interpooling 26 models "observations" of MACs for different future years, 61 observations for the years 2000, 2025 and 2050.

The abatement cost for unit of emission is calculated for CO_2, CH_4 and N_2O. Since data are not site specific, the same value for all EU-27 countries is used.

[12] The updated VPF from UNITE_D5_Annex3, 2001 is used.

[13] Marginal damage costs for climate change are estimated by NEEDS project (Deliverable D.5.4). The following assumptions are made: "Average, 1% trimmed" - Discounted to 2005; "1% pure rate of time preference"; "with AvEW, i.e. world average equity weighting" and the exchange from US$ to € corresponds to ca. 1.35$ per €. Factor for recalculate €/tCO2 from €/tC = 44/12.

[14] Marginal avoidance costs of GHG are estimated for CASES project Work Package 3 report "Energy-related External Costs due to Land Use Changes, Acidification and Eutrophication, Visual Intrusion and Climate Change" paragraph 4.3, July 2008. The following assumptions are made: Factor to recalculate from 2005 prices to 2000 prices, based on nominal GDP per capita: Euro2005 --> Euro2000 = 0.898; GWP-ratios, as defined by IPCC 1996, i.e. 21 for CH4 and 310 for N2O.

[15] FUND - *Climate Framework for Uncertainty, Negotiation and Distribution* is a so-called integrated assessment model of climate change. Additional information are available on the website http://www.fnu.zmaw.de/FUND.5679.0.html

EcoSense calculates all types of external costs in Euro2000. Then these values are actualised to 2005 by using the Harmonised Indices of Consumer Prices (HICPs)[16]. Hence the external costs used to calculate full costs are homogeneous with the private costs, which are calculated in Euro 2005.

All results reflect the Willingness To Pay in the year of release, which is respectively 0210, 2020 and 2030.[17]

Life cycle inventory – emissions for electricity generation

To calculate the external cost of each kWh of electricity produced, the marginal value for unit of emission is multiplied by the quantity of pollutants emitted at each production stage per unit of electricity. For the CASES project the emission database for electricity and heat generation in 2007, 2020 and 2030 is provided by IER[18]. The life cycle inventory data for basic processes are taken from the LCA-database Ecoinvent in the version 1.2[19].The methodology adopted to estimate the emissions of pollutants for energy generation subdivides the process of electricity generation into four sub-processes representing the life cycle stages:

- power plant construction,
- fuel supply,
- power plant operation,
- power plant dismantling.

Starting from a detailed process chain analysis, which for most technologies was specified down to the individual power plant components and their performance, the material and energy demand as well as the waste and the release of emissions were identified and quantified. These results for the individual processes refer to the functional unit of one kilowatt hour (1 kWh) of generated net electricity (i.e. electricity, which is supplied to the grid) and summed up along the process chain.

The LCI data analysis performed within CASES covers transport and construction services and the supply of materials. All direct and indirect emissions of the manufacturing and transportation of materials for the power plant construction are relevant. In addition, since during construction phase there is heat demand for several construction processes and before commissioning of fossil power plants, there are test runs of turbines, which go without generation of electricity, the also the heat and the energy demand for construction are taken in to account. Along the life cycle all wastes of the power plant operation as well as the material-specific final end-of-life treatment at the power plant dismantling are balanced. Emissions caused by disposal of operational wastes are included in the process of power plant operation. While disposal of wastes at the end of the technical life time of the power plant are assigned to the process of power plant dismantling.

To ensure homogeneity of cost components the assumption on technology technical life time, installed capacity, power efficiency etc., which are used for estimate the emissions database, are the same used for estimate private costs of electricity and power generation[20].

[16] Data are actualised from 2000 to 2005 by using a coefficient of 1,1095. The coefficient is calculated by using the Harmonised Indices of Consumer Prices (HICPs) from 2001 to 2005, available at the following address:
http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref& language=en&product=STRIND_ECOBAC&root=STRIND_ECOBAC/ecobac/eb040

[17] These external costs are expressed in Euro per tonne in the year of release, 2010-2020-2030, based on aggregation scheme "SIA_E_PPMc" for Human Health Impacts, based on average meteorology - corresponding to emissions from All SNAP-Sectors.

[18] CASES deliverable D.2.1 "Database on life cycle emissions for electricity and heath generation technologies".

[19] Ecoinvent-Datenbank für Lebenszyklusdaten: www.ecoinvent.ch

[20] An exhaustive table with technology description for 2007, 2020 and 2030 is available in the CASES deliverables: D.2.1 "Database on life cycle emissions for electricity and heath generation technologies" and D.4.1 "Private Costs of Electricity and Heat Generation", IER University Stuttgart.

External costs not included in the analysis

The methodology adopted by CASES to calculate the full cost of electricity production includes the damage costs of emissions of pollutants into air, soil and water. This methodology allows to include a wide set of external costs in the analysis and ensure the use of homogeneous and widely approved estimates, however some relevant components of the total external cost are excluded.

These ”other costs” are particularly relevant for nuclear. In the assessment of the nuclear fuel cycle one of the most contentious issues has been the valuation of serious nuclear accidents and the assessment of the risk of nuclear weapons proliferation. The “ExternE Methodology report”[21] indicates that in monetary terms the damage cost of a nuclear accident could amount to billions of Euro. However, even if there is a high level of public concern about the possibility of such an accident, the experts assign very low probability of the kind of failure that would produce a severe accident for the type of reactors used in Western Europe. Then the very low probability that the accident occurs will translate billions of Euro of possible damage costs into thousands of Euro of *expected* damage costs.

Despite their theoretical relevance these types of external costs are not included in the full costs calculation because the statistically small number of accidents made it difficult to elaborate models to calculate a homogeneous set of estimate for Europe until 2030.

Additional external costs not assessed in this full cost report but analysed by CASES project are: the cost of acidification of the aquatic environment and the cost visual intrusion[22].

With respect to the monetary estimates of acidification, the costs of the impact of pollution on freshwater fish populations are not included because there is large uncertainty in the estimated values. The uncertainty is derived from the calculation of impacts and from the economic valuation procedure.

Also the costs of visual intrusion are excluded from the set of external costs analysed in the full costs assessment. These costs are assessed by evaluating the aesthetic effects of wind parks, hydroelectric dams and power transmission lines; however only few studies are available on this topic and a consistent set of estimates is not available for all Europe.

As a separate topic, not included in the social costs assessment, the CASES project provides also energy supply externalities. In particular this analysis focuses on the macro economic costs of energy price fluctuations and on the monetary value of lost load, caused by interruption of electricity supply.[23]

3. Results on European full costs of electricity generation

Table 3—1 and Table 3—2 list the technologies for electricity production which are assessed in this report. The set of technologies includes nuclear, fossil fired technologies, renewables and combined heat and power plants. For fossil fired and for some CHP technologies the same technology is assessed with and without CO_2 capture and storage; this distinction is available only for values referred to 2020 and 2030. For the period 2005-2010 the same levelised values are reported for technologies with and without CO_2 storage.

In Table 3—1 technologies are ordered from the cheapest to the most expensive with respect to the private cost of electricity generation in Euro cents per units of electricity production (kWh). If only private costs are considered the cheapest technologies are combined heat and power technologies, for which the electricity

[21] “ExternE Methodology report”, EC, 1995.
[22] These types of external costs are assessed in the CASES deliverable D.3.2 “Report on the monetary valuation of energy related impacts on land use changes, acidification, eutrophication, visual intrusion and climate change”.
[23] Supply externalities are assessed by CASES – WP5 “Report on National EU level estimates for energy supply externalities”, D.5.1 December 2007.

production cost is net of heat credits. The most expensive technologies are renewables, in particular solar photo voltaic[24] and fuel cells technologies.

Moving the time horizon from present to 2030 yields no differences in the ranking of traditional technologies; however the table shows that the price of production will decrease for renewables technologies and a strong price reduction is observable for fuel cells technologies. The trends of full costs components are more extensively assessed in the paragraph 4.2.

PRIVATE COSTS OF ELECTRICITY GENERATION IN EU (Ec/kWh)						
rank	2005-10		2020		2030	
1	hard coal CHP with backpressure turbine	0,89	hard coal CHP with backpressure turbine	0,91	biomass (woodchips) CHP with an extraction condensing turbine	0,98
2	biomass (woodchips) CHP with an extraction condensing turbine	1,13	biomass (woodchips) CHP with an extraction condensing turbine	0,98	hard coal CHP with backpressure turbine	1,04
3	hard coal CHP with extraction condensing turbine without CO2 capture	1,31	hard coal CHP with extraction condensing turbine without CO2 capture	1,34	hard coal CHP with extraction condensing turbine without CO2 capture	1,39
4	hard coal CHP with extraction condensing turbine with CO2 capture	1,31	biomass (straw) CHP with an extraction condensing turbine	2,18	lignite condensing power plant	2,14
5	biomass (straw) CHP with an extraction condensing turbine	2,59	lignite condensing power plant	2,18	biomass (straw) CHP with an extraction condensing turbine	2,18
6	lignite condensing power plant	2,68	nuclear power plant	2,62	nuclear power plant	2,28
7	lignite IGCC without CO2 capture	3,00	lignite IGCC without CO2 capture	2,83	lignite IGCC without CO2 capture	2,77
8	lignite IGCC with CO2 capture	3,00	hard coal CHP with extraction condensing turbine with CO2 capture	3,12	hard coal CHP with extraction condensing turbine with CO2 capture	3,09
9	nuclear power plant	3,10	hard coal condensing power plant	3,23	hard coal condensing power plant	3,16
10	hard coal condensing power plant	3,33	lignite IGCC with CO2 capture	3,39	lignite IGCC with CO2 capture	3,34
11	hard coal IGCC without CO2 capture	3,91	hard coal IGCC without CO2 capture	3,54	hard coal IGCC without CO2 capture	3,50
12	hard coal IGCC with CO2 capture	3,91	hard coal IGCC with CO2 capture	4,20	hard coal IGCC with CO2 capture	4,16
13	natural gas CHP with extraction condensing turbine without CO2 capture	4,12	natural gas combined cycle CHP with backpressure turbine	4,27	natural gas combined cycle CHP with backpressure turbine	4,24
14	natural gas CHP with extraction condensing turbine with CO2 capture	4,12	natural gas CHP with extraction condensing turbine without CO2 capture	4,37	natural gas CHP with extraction condensing turbine without CO2 capture	4,40
15	natural gas combined cycle CHP with backpressure turbine	4,31	natural gas combined cycle without CO2 capture	4,58	natural gas combined cycle without CO2 capture	4,54
16	natural gas combined cycle without CO2 capture	4,81	natural gas combined cycle with CO2 capture	5,98	wind, off-shore	5,81
17	natural gas combined cycle with CO2 capture	4,81	wind, on-shore	6,02	natural gas combined cycle with CO2 capture	5,91
18	wind, on-shore	6,11	wind, off-shore	6,14	wind, on-shore	5,96
19	wind, off-shore	6,36	natural gas CHP with extraction condensing turbine with CO2 capture	6,37	natural gas CHP with extraction condensing turbine with CO2 capture	6,32
20	heavy oil condensing power plant	6,57	natural gas, gas turbine	6,60	MCFC (biogas)	6,36
21	natural gas, gas turbine	6,58	hydropower, run of river >100MW	6,80	natural gas, gas turbine	6,53
22	hydropower, run of river >100MW	6,81	heavy oil condensing power plant	7,19	hydropower, run of river >100MW	6,80
23	hydropower, run of river 10MW	7,83	hydropower, run of river 10MW	7,83	SOFC (natural gas)	7,02
24	hydropower, run of river <100MW	7,93	hydropower, run of river <100MW	7,93	MCFC (natural gas)	7,26
25	light oil gas turbine	9,87	light oil gas turbine	10,08	heavy oil condensing power plant	7,46
26	hydropower, dam (reservoir)	11,04	solar thermal, parabolic trough	10,30	hydropower, run of river 10MW	7,83
27	hydropower, pump storage	11,04	hydropower, dam (reservoir)	11,04	hydropower, run of river <100MW	7,93
28	solar thermal, parabolic trough	12,76	hydropower, pump storage	11,04	solar thermal, parabolic trough	9,50
29	MCFC (biogas)	31,88	SOFC (natural gas)	11,55	light oil gas turbine	10,34
30	MCFC (natural gas)	33,55	MCFC (biogas)	13,23	hydropower, dam (reservoir)	11,04
31	solar PV, open space	35,91	MCFC (natural gas)	13,34	hydropower, pump storage	11,04
32	solar PV, roof	44,76	solar PV, open space	20,83	solar PV, open space	16,58
33	SOFC (natural gas)	46,80	solar PV, roof	25,14	solar PV, roof	23,48

Table 3—1 List of technologies of electricity generation ordered by average European private cost of generation (EuroCents/kWh) in 2005-2010, in 2020 and in 2030

In Table 2—1 the technologies are ordered by full generation cost, which is calculated by adding all external costs to the private cost of production. At present the cheapest technology, after the internalization of external costs, is biomass (woodchips) CHP with an extraction condensing turbine. The other "cheap" technologies in the present scenario are nuclear (European pressurized reactor) and hard coal CHP with

[24] Private costs calculated with the average lifetime levelised generating technology seem to underestimate the real industrial production cost, in particular for nuclear, as declared by stakeholders of the electricity sector invited to the "First CASES Stakeholders Workshop – Social costs of electricity production" February 2008, Brussels.

backpressure turbine. But with respect to the low value of nuclear full cost should be stressed that some nuclear specific external costs (eg the cost of a nuclear accident or the risk of nuclear proliferation) are not considered in this analysis. In addition it should be remarked that private costs calculated with the average lifetime levelised generating technology seem to underestimate the real industrial production cost, in particular for nuclear, as declared by stakeholders of the electricity sector invited to the "First CASES Stakeholders Workshop – Social costs of electricity production" February 2008, Brussels.

Photovoltaic technologies are the most expensive technologies even if the share of external cost is very small, however a strong decreasing in private cost is foreseen for the next 20 years. For the next 20 years a good performance of full cost reduction is foreseen also for fuel cells technologies and for hydroelectric (run of river hydropower less than 100MW).

The high value of full costs for solar technologies is in part explained by the assumption of European average values for the Life Cycle Analysis. However the country specific cost per kWh should be very lower than the average in the Mediterranean area, because it is higher the quantity of electricity which is produced.

In addition Table 2—2 shows that, if full costs instead of private costs are considered, then the renewables technologies hydropower and wind will be cheaper than almost all classical fossil fired technologies. These sets of technologies are fully comparable since back up costs, calculated for a fired CCGT plant as back up technology, are added to generation costs for wind and solar, which are intermittent renewables energies.

FULL COSTS OF ELECTRICITY GENERATION IN EU (Ec/kWh)						
rank	2005-10		2020		2030	
1	biomass (woodchips) CHP with an extraction condensing turbine	1,79	biomass (woodchips) CHP with an extraction condensing turbine	1,80	biomass (woodchips) CHP with an extraction condensing turbine	1,97
2	nuclear power plant	3,32	nuclear power plant	2,76	nuclear power plant	2,40
3	hard coal CHP with backpressure turbine	3,88	lignite IGCC with CO2 capture	4,15	lignite IGCC with CO2 capture	4,28
4	hard coal CHP with extraction condensing turbine without CO2 capture	4,07	hard coal CHP with backpressure turbine	4,19	hard coal CHP with extraction condensing turbine with CO2 capture	4,48
5	hard coal CHP with extraction condensing turbine with CO2 capture	4,07	hard coal CHP with extraction condensing turbine with CO2 capture	4,26	biomass (straw) CHP with an extraction condensing turbine	4,80
6	biomass (straw) CHP with an extraction condensing turbine	4,61	hard coal CHP with extraction condensing turbine without CO2 capture	4,31	hard coal CHP with extraction condensing turbine without CO2 capture	5,21
7	lignite IGCC without CO2 capture	5,38	biomass (straw) CHP with an extraction condensing turbine	4,37	hard coal CHP with backpressure turbine	5,25
8	lignite IGCC with CO2 capture	5,38	lignite IGCC without CO2 capture	4,96	lignite IGCC without CO2 capture	5,68
9	natural gas CHP with extraction condensing turbine without CO2 capture	5,39	lignite condensing power plant	5,15	wind, off-shore	5,88
10	natural gas CHP with extraction condensing turbine with CO2 capture	5,39	hard coal IGCC with CO2 capture	5,66	hard coal IGCC with CO2 capture	5,95
11	lignite condensing power plant	5,65	natural gas CHP with extraction condensing turbine without CO2 capture	5,72	wind, on-shore	6,03
12	natural gas combined cycle CHP with backpressure turbine	5,71	natural gas combined cycle CHP with backpressure turbine	5,83	lignite condensing power plant	6,07
13	natural gas combined cycle without CO2 capture	6,20	hard coal IGCC without CO2 capture	6,03	natural gas CHP with extraction condensing turbine without CO2 capture	6,17
14	natural gas combined cycle with CO2 capture	6,20	natural gas combined cycle without CO2 capture	6,04	natural gas combined cycle CHP with backpressure turbine	6,31
15	wind, on-shore	6,21	wind, on-shore	6,09	natural gas combined cycle without CO2 capture	6,43
16	wind, off-shore	6,46	wind, off-shore	6,21	hard coal IGCC without CO2 capture	6,77
17	hard coal condensing power plant	6,47	hard coal condensing power plant	6,52	hydropower, run of river >100MW	6,86
18	hard coal IGCC without CO2 capture	6,61	hydropower, run of river >100MW	6,85	natural gas combined cycle with CO2 capture	7,03
19	hard coal IGCC with CO2 capture	6,61	natural gas combined cycle with CO2 capture	6,90	hard coal condensing power plant	7,30
20	hydropower, run of river >100MW	6,85	natural gas CHP with extraction condensing turbine with CO2 capture	7,22	natural gas CHP with extraction condensing turbine with CO2 capture	7,36
21	hydropower, run of river 10MW	7,90	hydropower, run of river 10MW	7,91	hydropower, run of river 10MW	7,92
22	hydropower, run of river <100MW	7,98	hydropower, run of river <100MW	7,99	hydropower, run of river <100MW	8,00
23	natural gas, gas turbine	8,66	natural gas, gas turbine	8,89	SOFC (natural gas)	8,25
24	heavy oil condensing power plant	8,96	heavy oil condensing power plant	10,19	natural gas, gas turbine	9,48
25	hydropower, pump storage	11,10	solar thermal, parabolic trough	10,41	solar thermal, parabolic trough	9,61
26	hydropower, dam (reservoir)	11,12	hydropower, pump storage	11,11	MCFC (natural gas)	9,91
27	light oil gas turbine	12,34	hydropower, dam (reservoir)	11,13	MCFC (biogas)	10,75
28	solar thermal, parabolic trough	12,88	SOFC (natural gas)	12,54	heavy oil condensing power plant	11,10
29	MCFC (biogas)	35,21	light oil gas turbine	13,01	hydropower, pump storage	11,13
30	MCFC (natural gas)	35,55	MCFC (natural gas)	15,77	hydropower, dam (reservoir)	11,15
31	solar PV, open space	36,80	MCFC (biogas)	17,26	light oil gas turbine	14,03
32	solar PV, roof	45,63	solar PV, open space	21,65	solar PV, open space	17,51
33	SOFC (natural gas)	47,73	solar PV, roof	25,94	solar PV, roof	24,39

Table 3—2 List of technologies of electricity generation ordered by average European full cost of generation (EuroCents/kWh) in 2005-2010, in 2020 and in 2030. [Full cost = private cost + external costs]

All results on full costs are reported in detail in the tables from Table 7—1 to Table 7—33 at the end of this report. Average European values are reported for the period 2005-2010, for 2020 and for 2030. External costs, private cost and full costs are reported for each technology. External costs are divided into human health related external costs (excluding those caused by radionuclides), environmental (not related to human health) external costs, radionuclides damage costs and marginal abatement cost of greenhouse gas emissions. The tables show the incidence, in percentage terms, of each cost component on the total value, and the increasing or decreasing of each value from present to 2030.

Figure 3.1 shows the results obtained for 2005-2010, 2020 and 2030 as are summarized in Table 2—2.

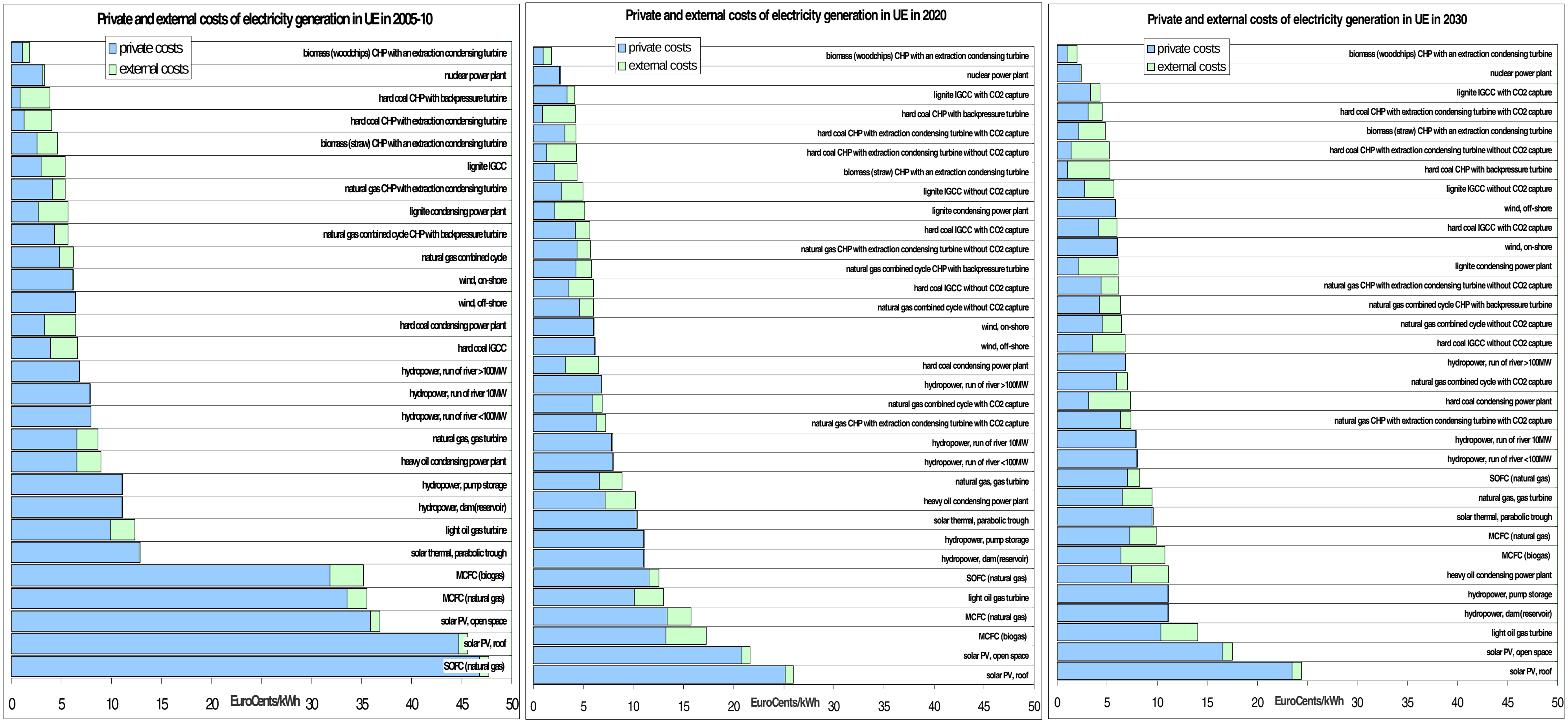

Figure 3.1 Private and External costs of electricity generation for 2005-2010, 2020 and 2030 (EuroCents 2005 / kWh)

4. Assessment and comparison of full costs and full cost composition

4.1 Technological comparison in 2005-2010

The following graphs, from Figure 4.1 to Figure 4.3, show the incidence of external costs on the total costs. Figures confirm the general opinion that external costs have a strong impact on full costs for fossil fuel thermal power plants. At present the share of external costs for hard coal and lignite is around the 50 percent, this is caused principally by an important negative impact on climate change, since abatement costs of green house gases are between the 60 and the 80 percent of total external cost. This means that if external cost was internalized, then the market price of electricity generated by classical fossil technologies should be doubled.

The share of external costs on total is between 20 and 25 percent for oil and gas thermal plants and for gas combined heath and power plants. For these technologies the high price of fuel has an high incidence on private costs. The principal components of external cost are related to human health for oil power plants, while they are related to climate change for gas power plants and CHPs.

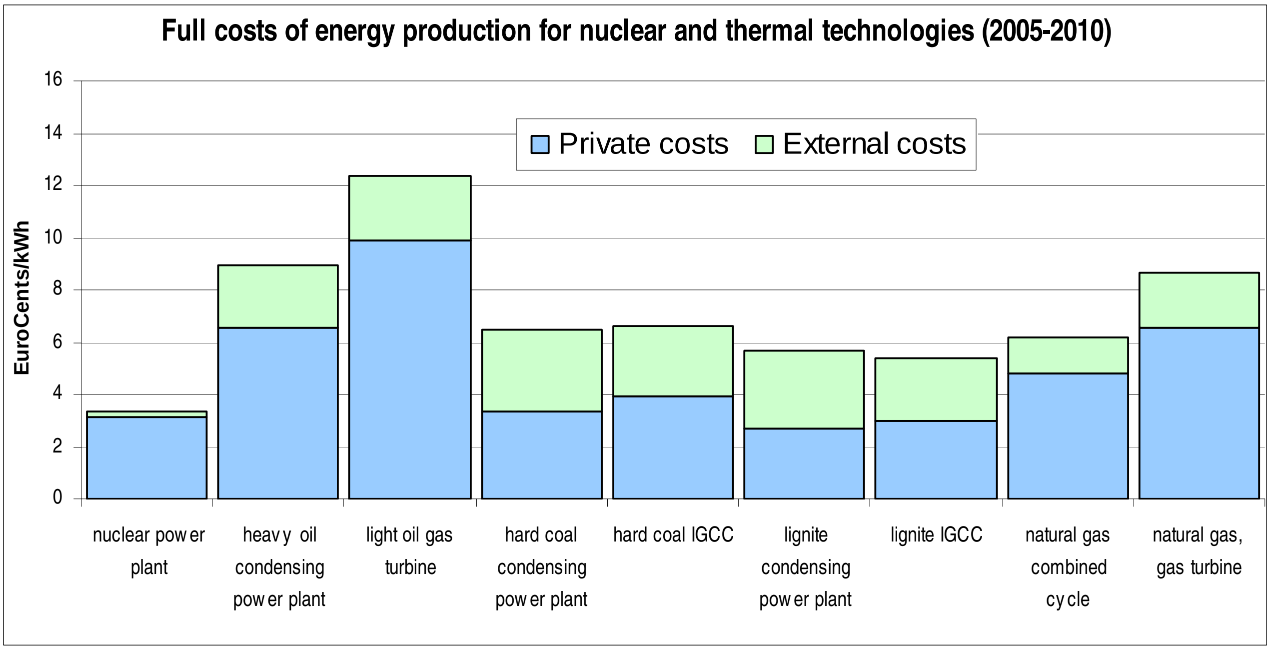

Figure 4.1 Full cost composition for nuclear and fossil fired technologies in 2005-2010

Figure 4.2 confirms that renewables are "clean" technologies, since the share of external costs is around 1 or 2 percent of full cost. For renewables external costs are referred for 2/3 to human health and for 1/3 to climate change. External costs are referred to emission caused principally during dismantling of the plants, for hydro and wind, while are produced principally during the construction of the plant for solar technologies.

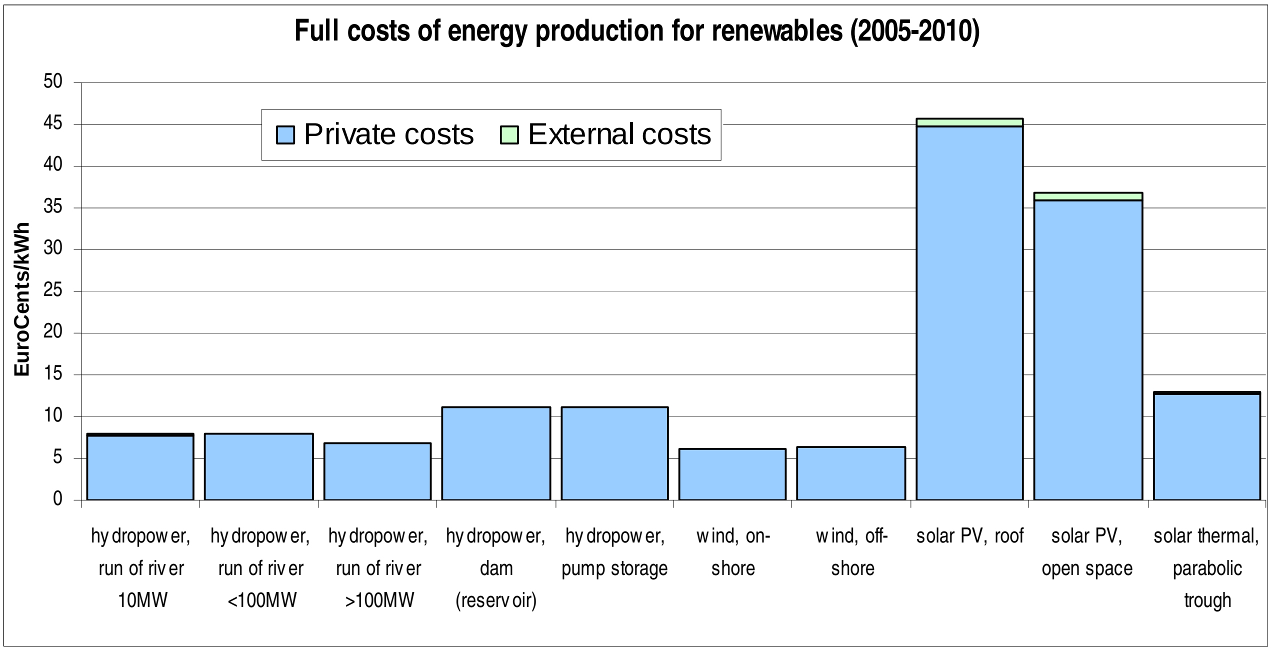

Figure 4.2 Full cost composition for renewables technologies in 2005-2010

Figure 4.3 shows the impact of external costs on full cost for combined heat and power technologies. The share of external costs is very high for coal combined heat and power technologie; it reachs the 70 percent of full cost. If only private costs were considered the cheapest technologies will be hard coal combined heat and power technologies with backpressure turbine, for which the electricity production cost is net of heat credits.i

In the set of CHP technologies the smallest share of external cost, lower than 10 percent of full cost, is reported for fuel cell. The levels of external costs for fuel cells are low not only as percentage, compared to the high values of private costs for these technologies, but also in absolute terms. The amount of external costs for Solid Oxide Fuel Cell at natural gas is lower than the external costs of other CHP technologies.

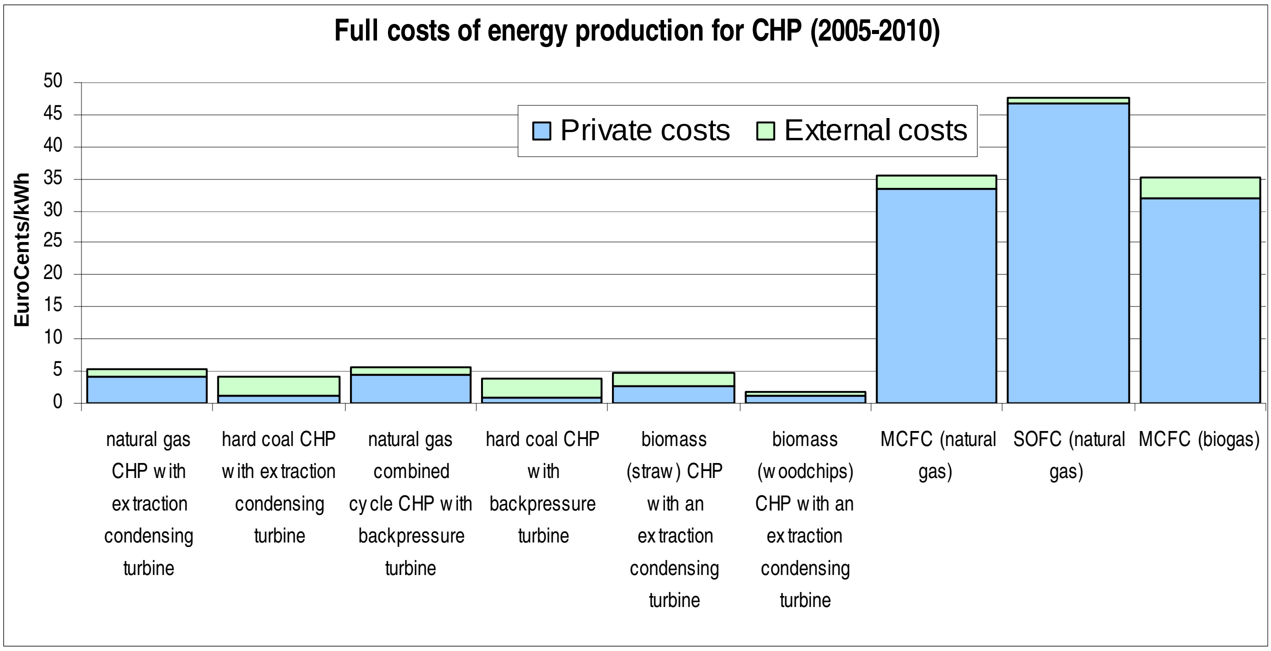

Figure 4.3 Full cost composition for combined heat and power plants in 2005-2010

4.2 Technological comparison and trends in 2020 and 2030

The graphs below from Figure 4.4 to Figure 4.9 show that for the majority of the technologies the share of external cost on full generation cost is foreseen to increase in the next 20 years.

The trend of full costs is given by an increasing of the willingness to pay from present to 2030, which increase the damage cost of each unit of emission, and by the emissions per kWh, which are foreseen to reduce thanks to the technological improvements.

The low level of external cost reported for renewables for present will remain almost constant for the next 20 years. A different trend is reported for solar thermal technology, for which a constant high reduction of costs is registered for the whole period for all private and external costs components.

A different evolution is foreseen for private costs, which are strongly conditioned by the trend of the international fuel prices, and by the introduction of new cheaper technologies. Fuel costs increases for gas and oil and causes increasing private costs for the thermal technologies using these fuels, partially compensated by a decrease in investment costs. The investment costs are generally constant or deceasing from present to 2030. Solar technologies display the most substantial decrease in private costs. Since it is foreseen for these technologies that higher R&D activities will reduce significantly the production costs, generating 1 kWh of electricity with solar PV will cost in 2030 only 30 percent of the present cost.

Data show a strong increasing of private price for thermal technologies with CO2 sequestration because for 2005 no distinction is made between plants without and with CO2 capture, while distinction is made for 2020 and 2030. Analogously results show a consistent decreasing of external costs, in particular for the marginal abatement cost of GHGs. On average the investments costs observed in 2005 are lower than the real cost which should be observed if carbon sequestration would be assessed. However for these technologies, the increase of investment cost is widely compensated by a reduction in external costs. Data show that from 2005 (without considering CO2 sequestration) to 2020 (with CO2 sequestration assessment), the full cost of electricity generation will decrease for almost all types of power plants.

Moving the time horizon from present to 2030 yields no differences in the ranking of traditional technologies; however the table shows that the price of production will decrease for renewables technologies and a strong price reduction is observable for fuel cells technologies.

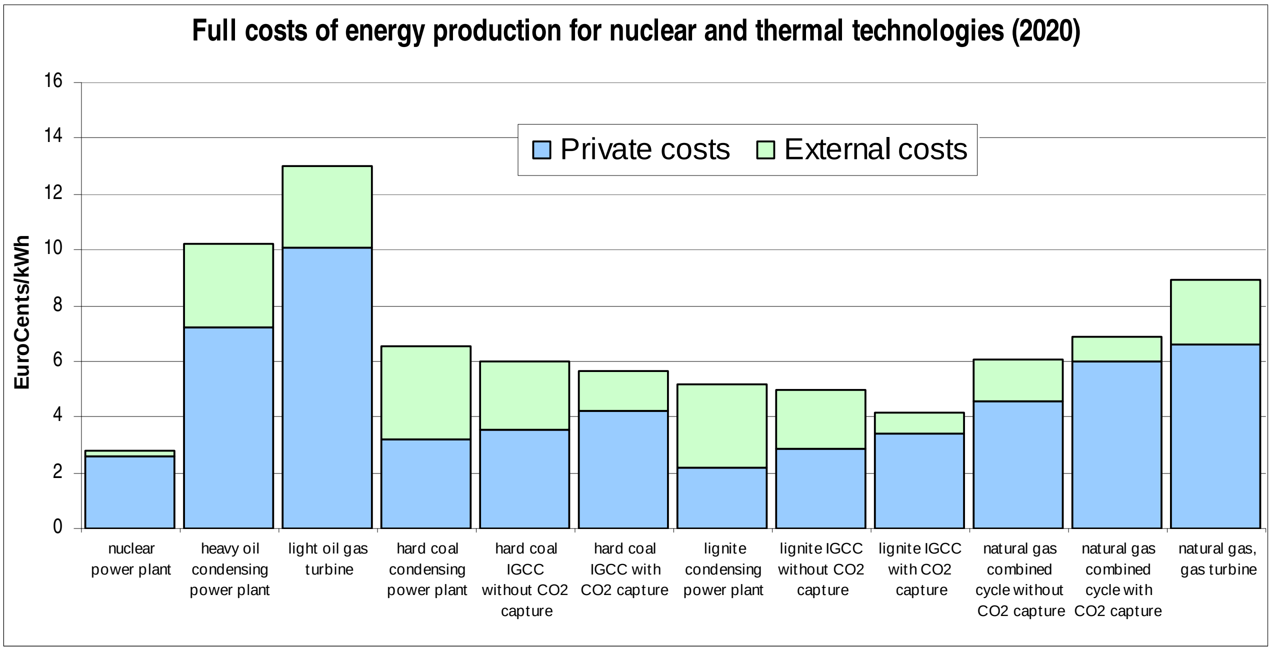

Figure 4.4 Full cost composition for nuclear and fossil fired technologies in 2020

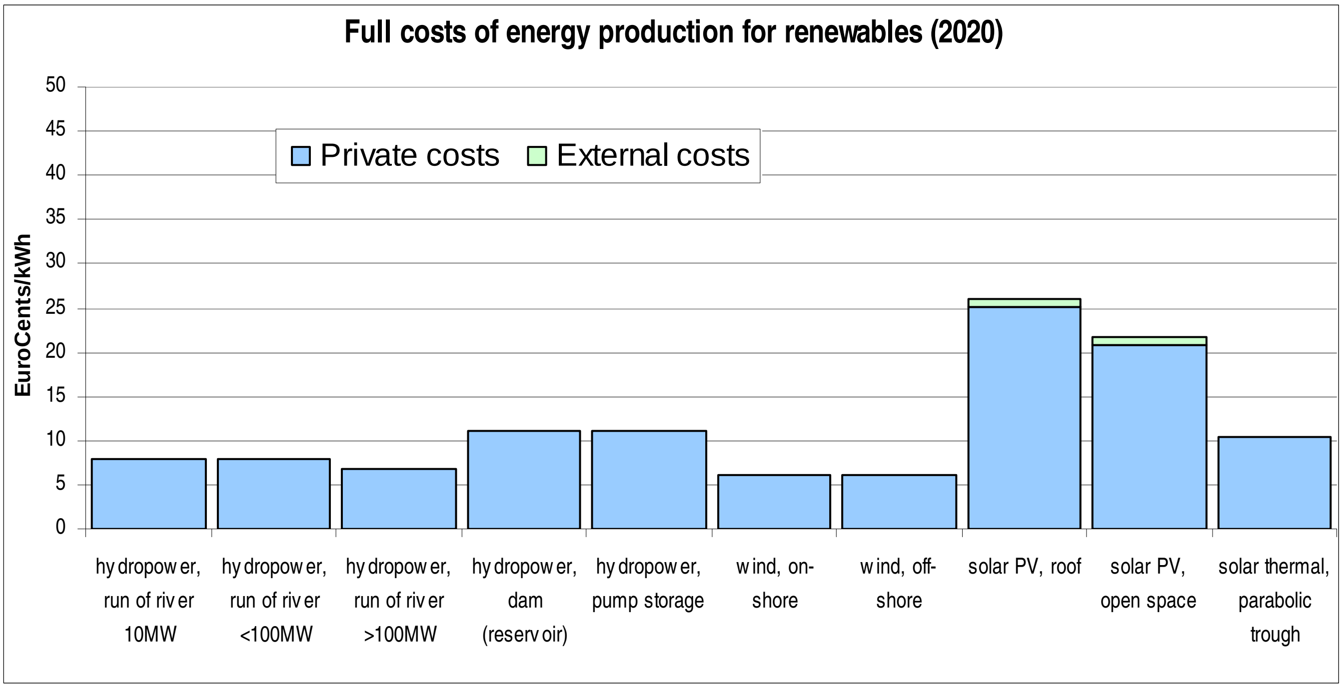

Figure 4.5 Full cost composition for renewables technologies in 2020

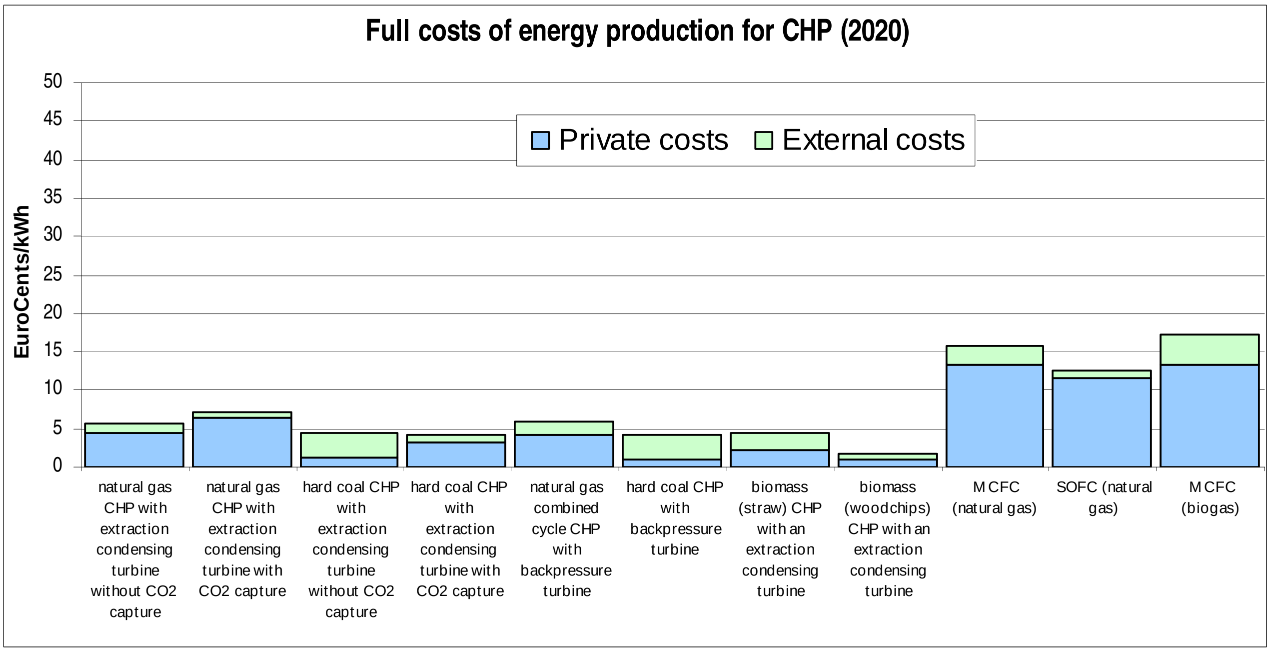

Figure 4.6 Full cost composition for combined heat and power plants in 2020

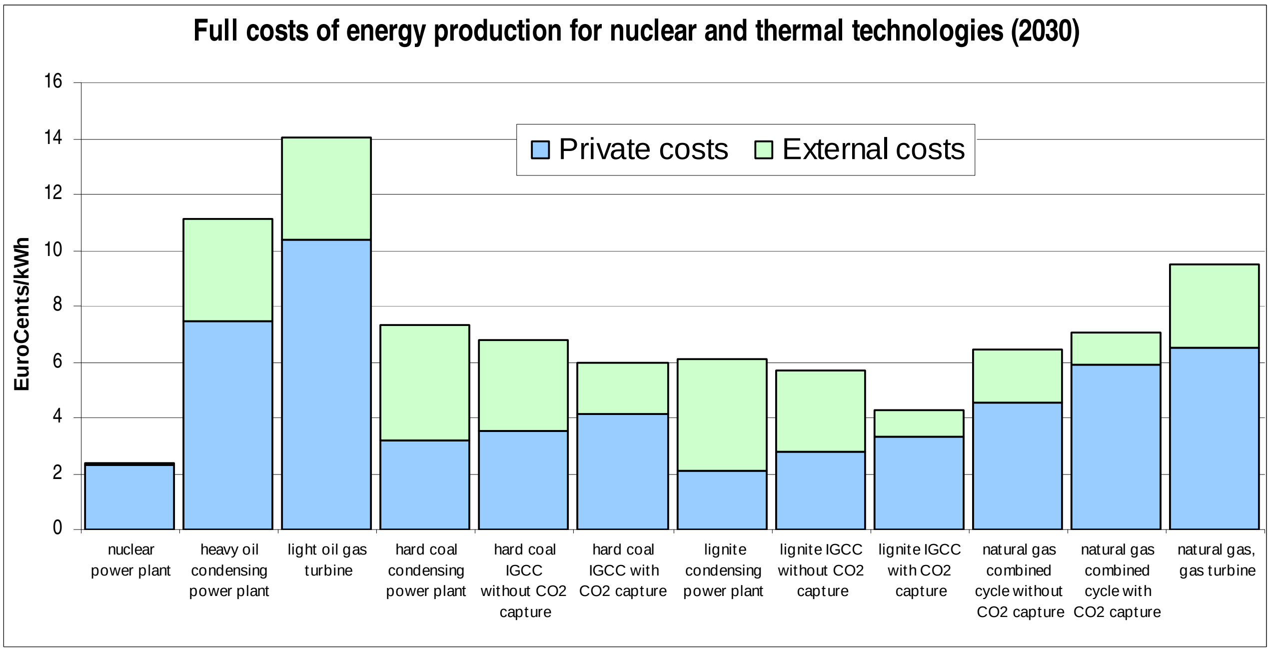

Figure 4.7 Full cost composition for nuclear and fossil fired technologies in 2030

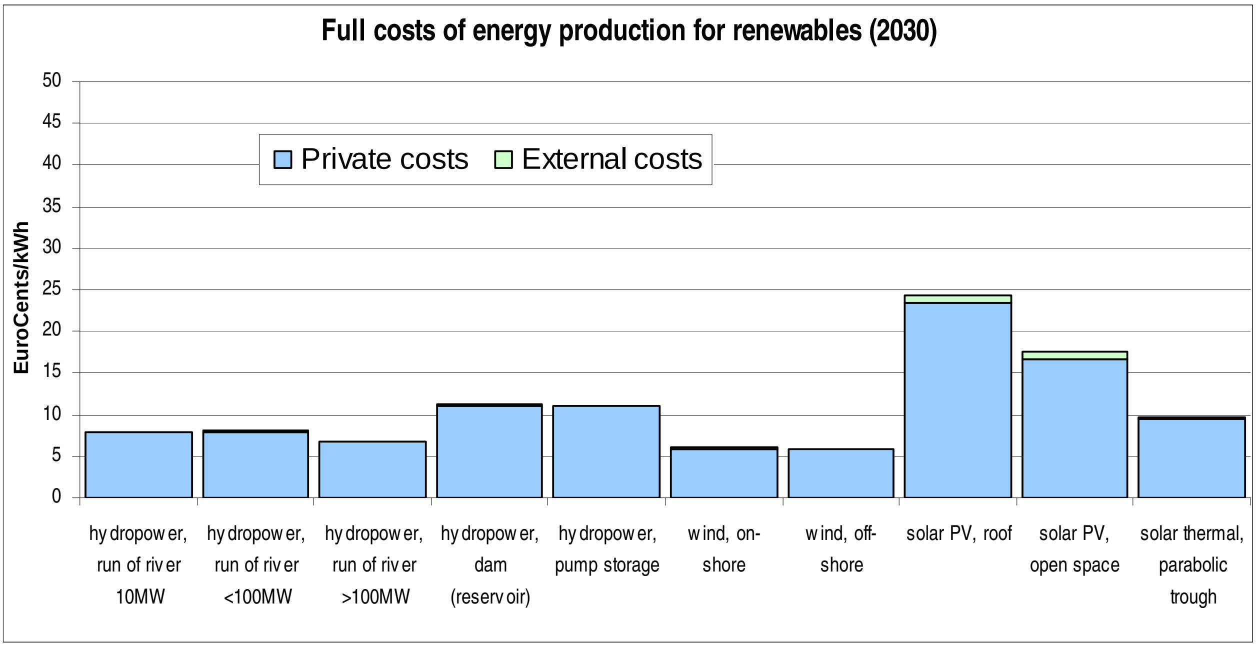

Figure 4.8 Full cost composition for renewables technologies in 2030

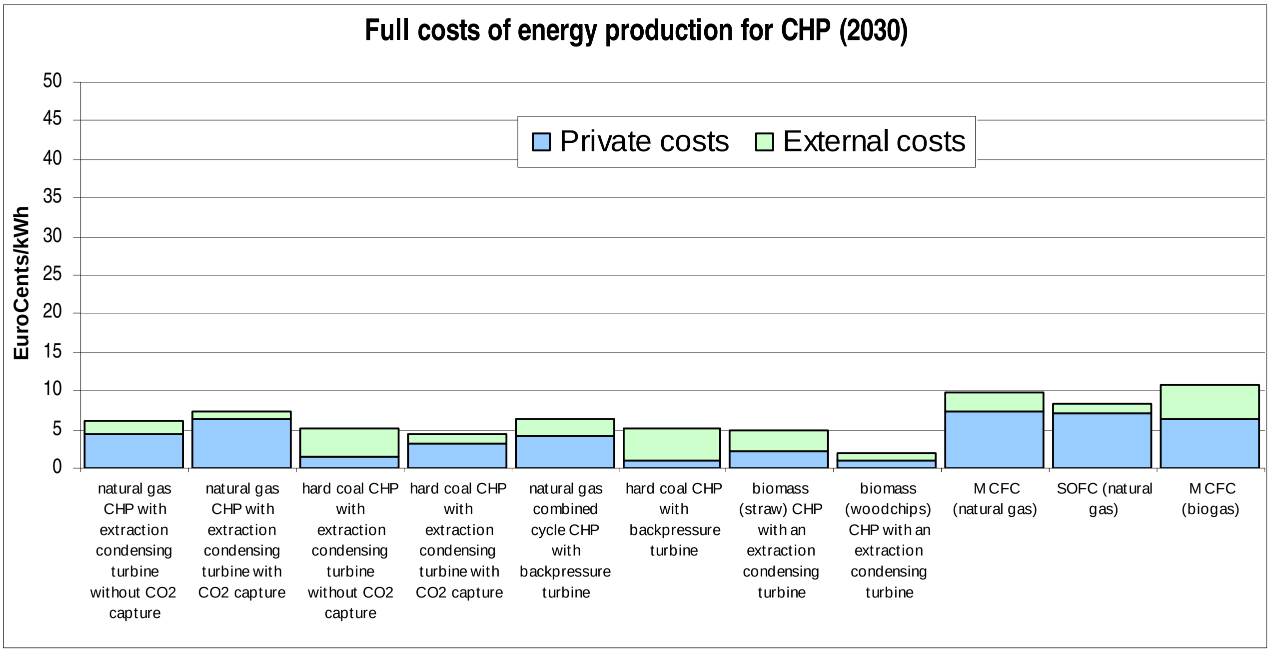

Figure 4.9 Full cost composition for combined heat and power plants in 2030

4.3 Assessment of external costs variability across countries

Since the private cost is set at a levelised value for Europe, the variations across countries are assessed only for external costs. Differences of values across countries depend on the marginal external value for unit of air pollutants, which changes from region to region, according to meteorological and atmospheric conditions, to the biological equilibrium of the region and to the economic situation of the country.

The principal factors influencing the damage of pollutants in each region are the meteorological conditions, the biological characteristics of the area and the economical situation of the country.

A complete country detailed analysis of external costs should also take into account that also WTP varies across countries. However, European levelised values of WTP are used to determine country specific external costs. Nonetheless in ExternE always values for the whole of Europe have been used for several reasons. One of the reasons is that for European policy it is useful to use harmonised values, because the WTP in different countries will be more homogeneous in the future. In addition the country specific values are based on emissions in the corresponding country but the impacts are mostly outside the corresponding country. Hence external costs presented in this paragraph vary only depending on dispersion model.

Country specific external costs, even if are calculated by using an average WTP, are actualised from 2000 to 2010, 2020 and 2030 by using a country specific price index.

Figure 4.10 shows how external costs of electricity production change from country to country. The same results are detailed in Figure 4.11, Figure 4.12 and Figure 4.13. Monetary value of emissions is shown for the period from 2005 to 2010 for traditional technologies, renewables and combined cycle technologies.

Figure 4.10 shows that Romania has the highest external costs for all technologies. Other countries with external costs very higher than the EU average for almost all technologies are Slovakia, Slovenia, Netherland and Hungary.

Conversely, Portugal and Finland have the lowest external costs, followed by Sweden, Finland, Denmark, Latvia and Lithuanian.

Values very similar to the European average are shown for Poland, Bulgaria and United Kingdom. Cyprus has external costs very near to the EU average for thermal and renewables technologies and very lower for CHP.

The dispersion model predicts a strong impact on environment of pollutants emitted by traditional fossil fired technologies in Austria, Germany and East-Europe countries; while values are lower in Portugal, Finland and Sweden. With respect to renewables the highest values are observed in Germany, Netherlands and Belgium. The differences across countries of the impact of CHP technology is similar to the impact of nuclear and fossil fired power plants since the higher values are registered in central Europe.

The data show strong differences across countries for oil and CHP technologies. This is caused by the different value of the impact of air pollutants on human health in the various countries. In particular biogas fuel cells (MSFC) has the highest variance, followed by heavy oil condensing power plant and biomass CHP. Conversely, renewables technologies and nuclear have a variance which is almost zero. For renewables some differences in external costs are shown only for solar PV.

Country specific analysis for renewables, in particular solar PV, have the limit that pollutants are principally emitted during the production of the plant (or solar cells), and partly during dismantling. However cells are often constructed in another country, for this reason it may be not correct to use the damage factor of the country where the plant is operating; the use of average values may be more appropriate. In addition, it is not taken into account the difference in quantity of electricity which is produced in different part of Europe by each technology. This should be taken into account in particular for wind and solar, because the quantity produced in windy and sunny countries is higher than the average EU, for this reason in this countries external costs should be lower than those reported in these graphs while values should be higher for most disadvantaged countries.

All the limits of the country specific external costs estimation, which are listed above, make the analysis incomplete. However this paragraph is useful to show the magnitude of the variations in external costs if, ceteris paribus, a detailed dispersion model for air pollutants is considered instead of an average value for the whole Europe.

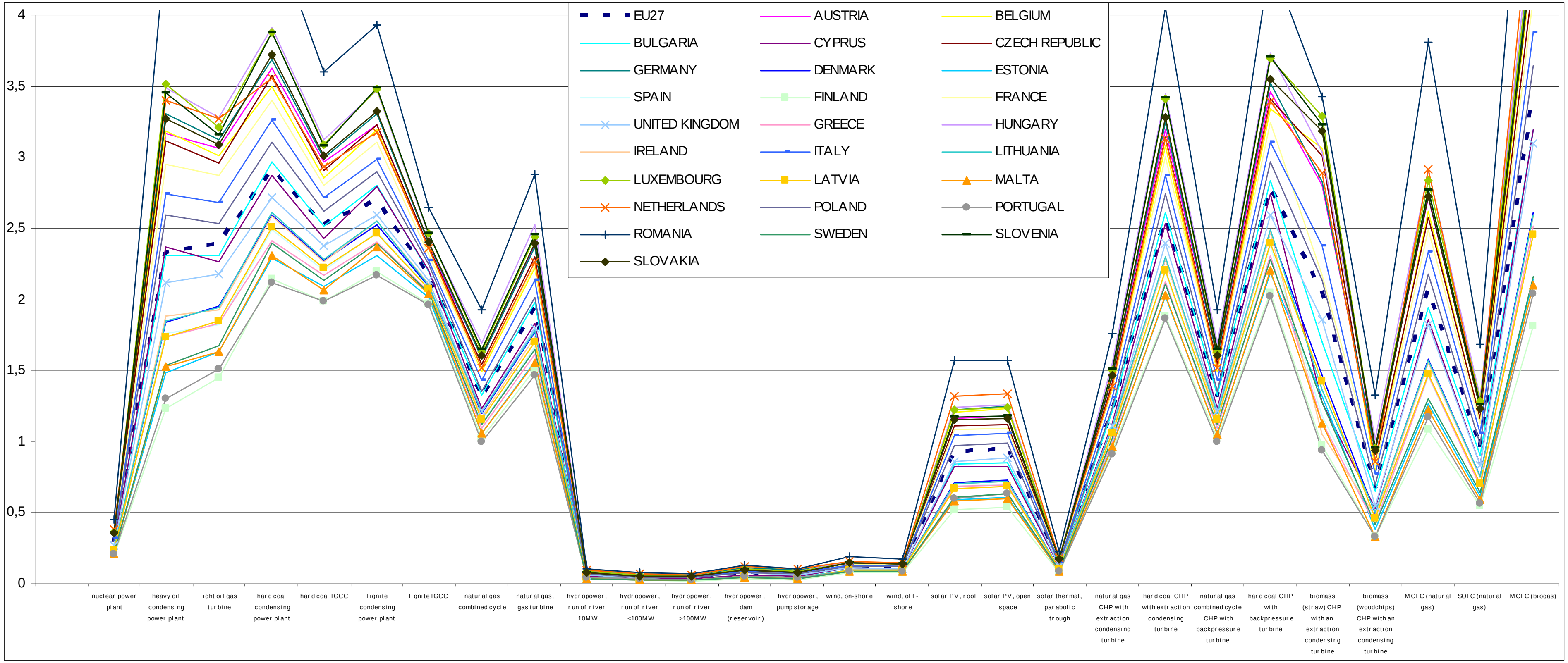

Figure 4.10 External costs in EuroCents / kWh 2005-2010 in each EU-27 Country for all technologies assessed

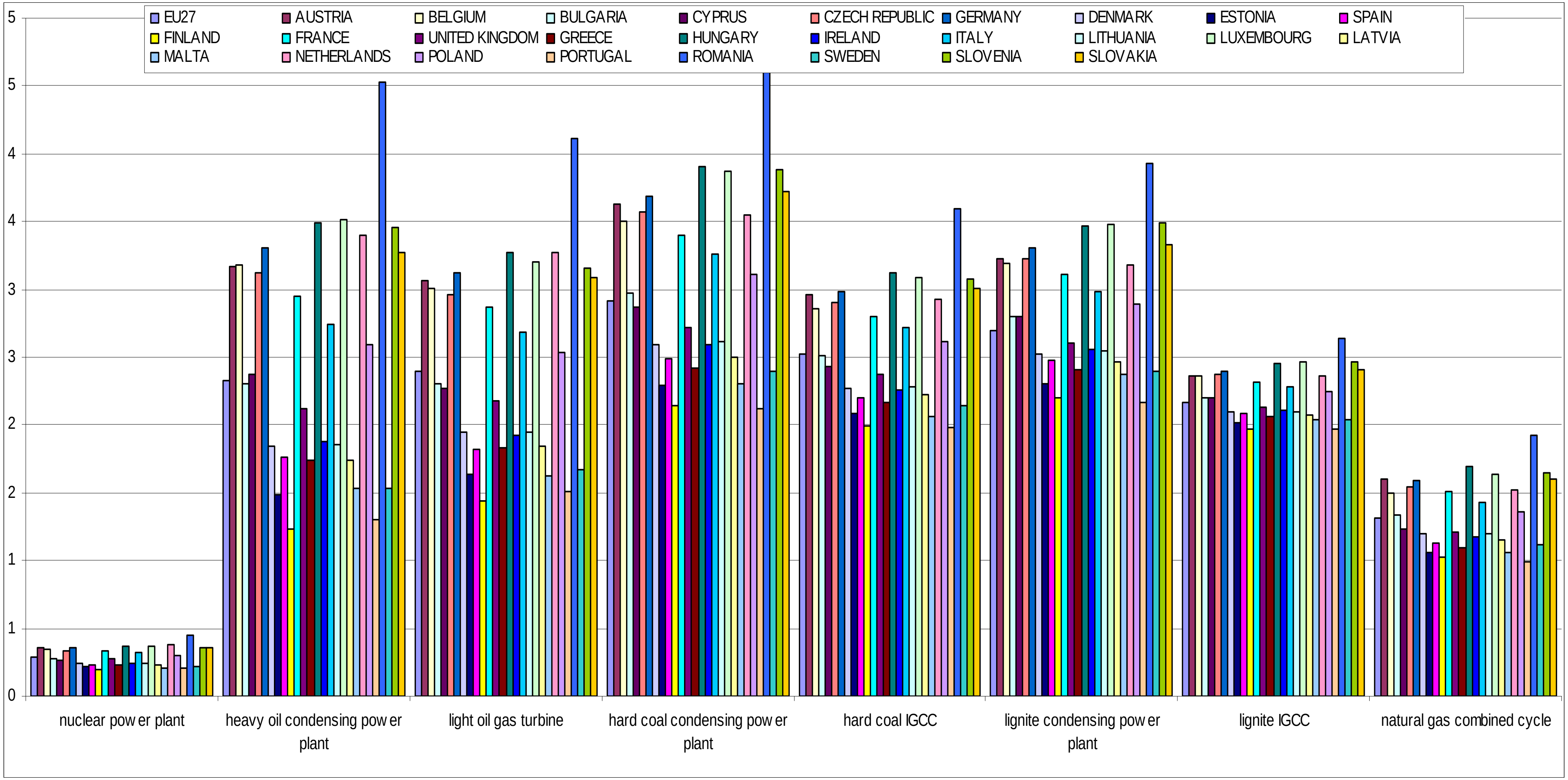

Figure 4.11 External costs in EuroCents / kWh 2005-2010 – Nuclear and Fossil fired technologies

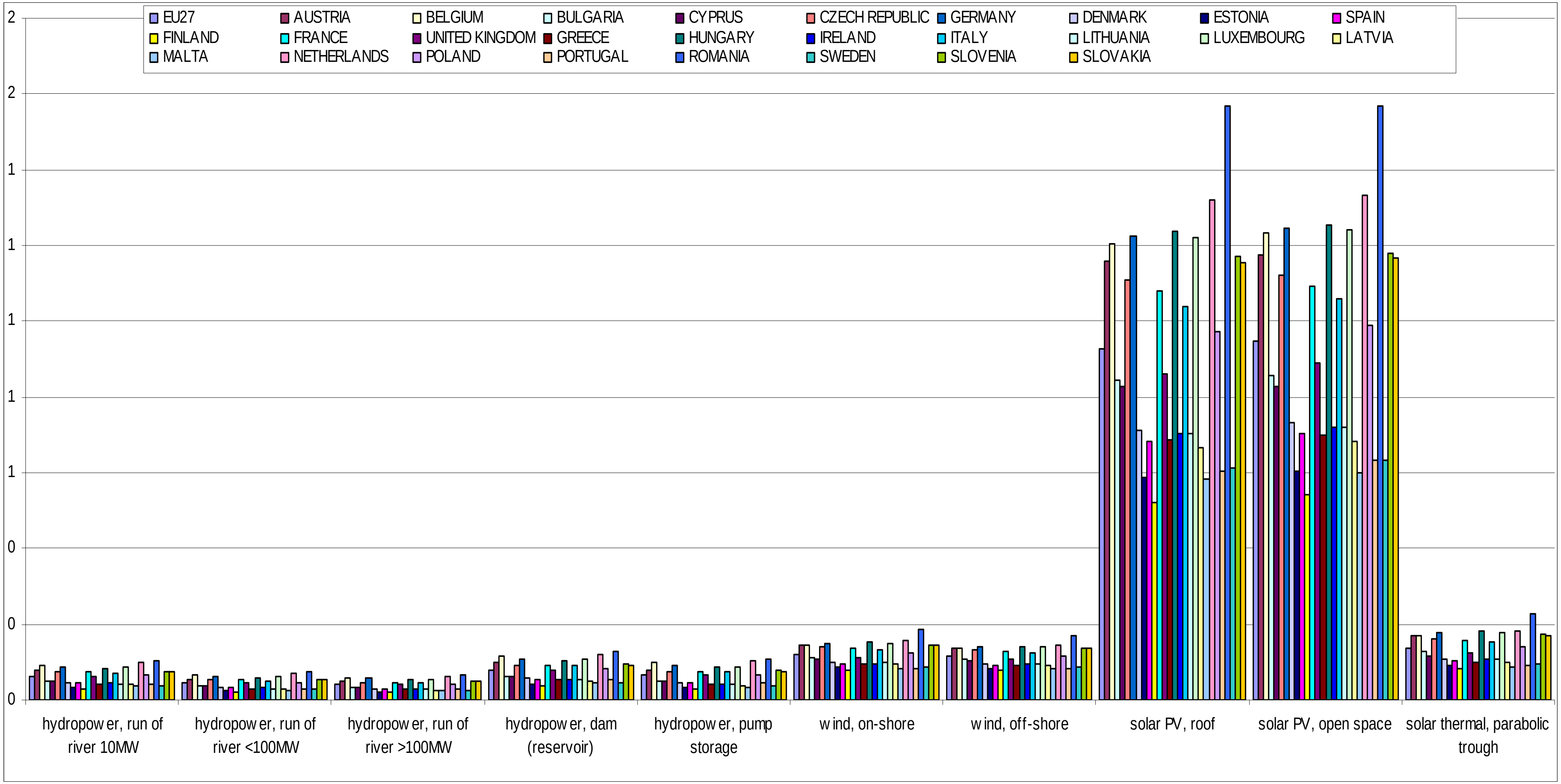

Figure 4.12 External costs in EuroCents / kWh 2005-2010 – Renewables technologies

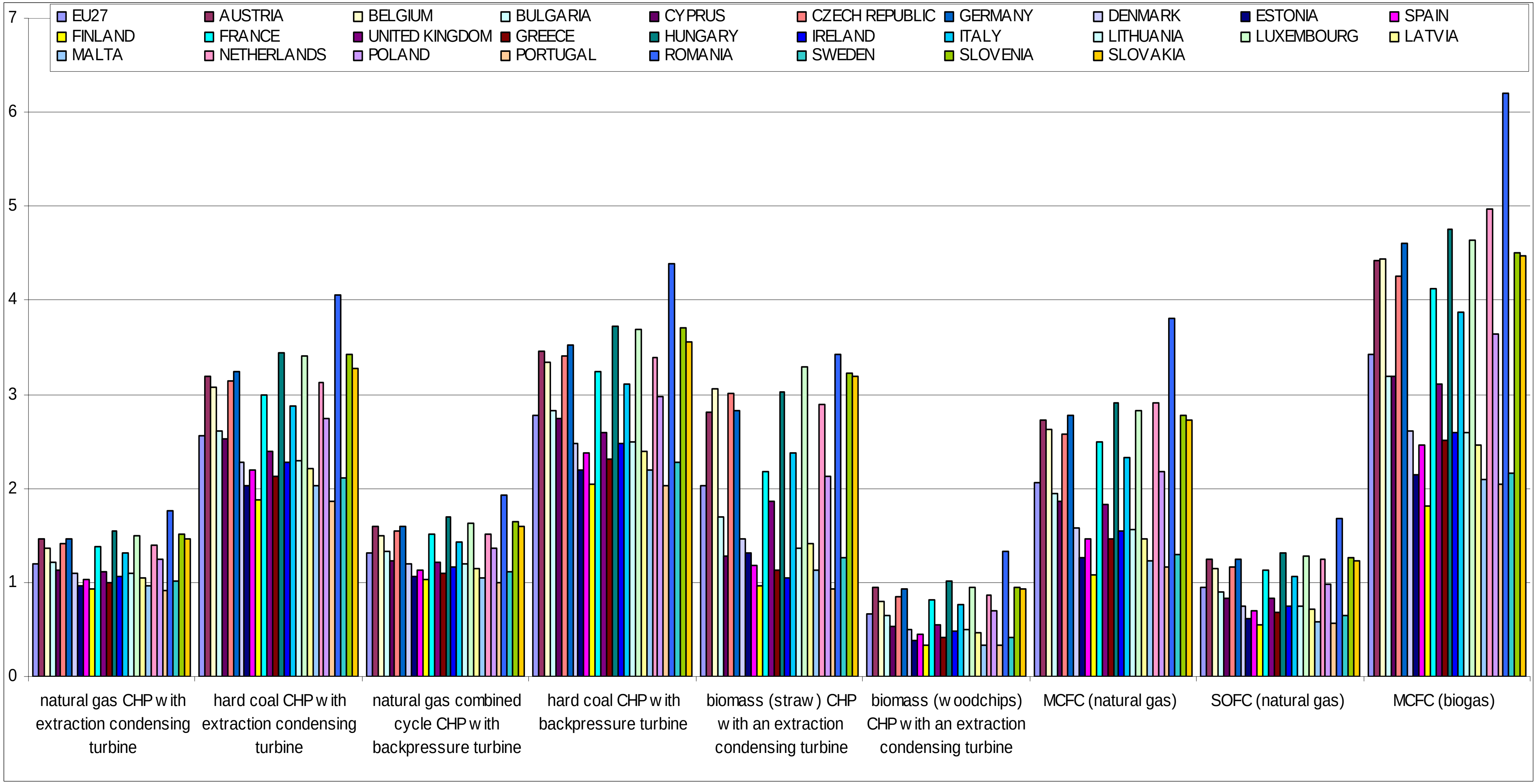

Figure 4.13 External costs in EuroCents / kWh 2005-2010 – Combined heath and power technologies

5. Conclusions

This report provided estimates, updated to 2007, on full costs of electricity generation in Europe. The results are obtained for present, for 2020 and for 2030 by summing external costs on human health, environment, materials and climate change to private generation costs. Full costs were calculated and assessed for a wide set of technologies, which includes nuclear and fossil fired power plants, renewables and combined heat and power plants. Full costs are assessed as average values of all EU-27 countries; in addition a country specific analysis is presented for external costs.

Results indicate that, in 2005-2010, the least expensive technology is biomass (woodchips) CHP with an extraction condensing turbine with a European average full cost of 1.79 Eurocents per kWh. This technology is followed by nuclear (European pressurized reactor) and hard coal CHP with a full cost of 3.32 and 4.07 Eurocents per kWh. This rank will not change significantly in the next years. Also for 2020 and 2030 it is foreseen that the least expensive technology will be woodchips) CHP with a price of 1.80 and 1.97 Eurocents per kWh.

The most expensive technology are natural gas fuel cells and solar photo voltaic, which have a full generation costs from 35 up to 48 Ec/kWh in 2005-2010. However a strong reduction of generation costs is foreseen in the next 20 years for these technologies thanks to investments in technological improvement.

Results show that hard coal combined heath and power generation has the highest share of external costs on full costs, presenting for 2005-2010 85 percent of full cost. High incidence of external costs on full costs, around 50 percent, is obtained also for coal and lignite thermal power plants.

Solar photo voltaic and solar thermal technologies display the lowest incidence of external costs on total costs (in the order of 1 percent only).

In the analysis performed, private and external costs are assessed for the whole life cycle of the power plant, from construction to dismantling, including cost of extraction and transportation of fuel and waste disposal. Private costs and quantity of pollutants emitted, which are plant specific, are calculated for new power plants build in 2005-2010, in 2020 and 2030, hence old power plants, still existing are excluded from the analysis. All costs are expressed in Euro 2005.

Some limits to the analysis are due to the exclusion from the assessment of probabilistic external costs, e.g. external cost of nuclear accident. These external costs may have a very high cost but are usually associated to a very low probability of occurrence. Moreover, for combined heat and power (CHP) heath credits have been subtracted to the private costs, to analyse the share of cost relative to power generation, excluding the share relative to heat generation, while all external cost are attributed into power generation costs; thus external costs for CHP are overestimated.

6. References

- "Private Costs of Electricity and Heat Generation", IER University of Stuttgart, 2007, CASES report D.4.1, http://www.feem-project.net/cases/downloads_deliverables.php .
- "Database on life cycle emissions for electricity and heath generation technologies", IER University of Stuttgart, 2007, CASES report D.2.1, http://www.feem-project.net/cases/downloads_deliverables.php
- "Report on the monetary valuation of energy related impacts on land use changes, acidification, eutrophication, visual intrusion and climate change", IVM - Vrije Universiteit Amsterdam, CASES report D.3.2, http://www.feem-project.net/cases/downloads_deliverables.php .
- "Report on methodology for estimating external costs to human health, crops and materials" IER University of Stuttgart, 2007, CASES report D.2.2, http://www.feem-project.net/cases/downloads_deliverables.php
- "Report on National EU level estimates for energy suplly externalities", University of Bath, CASES report D.5.1, December 2007 http://www.feem-project.net/cases/downloads_deliverables.php
- "ExternE – Externalities of energy – Methodology report", EC, 1995.
- "ExternE – Externalities of energy", 1995, Vol. 5.
- "ExternE– Externalities of energy", 1999, Vol. 7.
- "ExternE – Externalities of energy – Methodology 2005 Update" 2005.
- "Projected Costs of Generating Electricity", IEA, OECD, NEA, Paris, 2005.
- "Comprehensive Analysis of Future European Demand and Generation of European Electricity and its Security of Supply", EU, European Sustainable Electricity, Leuven 2006.
- Friedrich, R.; Kallenbach, U.; Thöne E.; Voß A.; Rogner, H.; Karl, H.; „Externe Kosten der Stromerzeugung" Schlussbetrachtung zum Projekt im Auftrag vom VDEW, VWEW Energieverlag, Frankfurt (Main) 1989.
- Ecoinvent-Datenbank für Lebenszyklusdaten. www.ecoinvent.ch

7. ANNEX 1 - European private and external costs from 2005 to 2030 per technology

7.1 Nuclear and Fossil fired

	nuclear power plant							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,1552	73%	0,1099	78%	-29%	0,0897	79%	-18%
Environmental cost	0,0136	6%	0,0085	6%	-37%	0,0065	6%	-24%
Radionuclides damage cost	0,0024	1%	0,0020	1%	-14%	0,0022	2%	6%
Marginal abatement cost of GHG	0,0428	20%	0,0202	14%	-53%	0,0156	14%	-23%
Total External costs	*0,2141*	*6%*	*0,1407*	*5%*	*-34%*	*0,1140*	*5%*	*-19%*
Total Private costs	*3,1028*	*94%*	*2,6169*	*95%*	*-16%*	*2,2825*	*95%*	*-13%*
Full cost	**3,3169**	**100%**	**2,7576**	**100%**	**-17%**	**2,3964**	**100%**	**-13%**

Table 7—1 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for nuclear technology

	heavy oil condensing power plant							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,7879	75%	2,3393	78%	31%	2,7688	76%	18%
Environmental cost	0,1707	7%	0,2194	7%	29%	0,2463	7%	12%
Radionuclides damage cost	0,0002	0%	0,0002	0%	18%	0,0002	0%	18%
Marginal abatement cost of GHG	0,4381	18%	0,4381	15%	0%	0,6272	17%	43%
Total External costs	*2,3968*	*27%*	*2,9970*	*29%*	*25%*	*3,6425*	*33%*	*22%*
Total Private costs	*6,5658*	*73%*	*7,1939*	*71%*	*10%*	*7,4593*	*67%*	*4%*
Full cost	**8,9627**	**100%**	**10,1909**	**100%**	**14%**	**11,1018**	**100%**	**9%**

Table 7—2 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for heavy oil condensing power plant

	light oil gas turbine							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,3941	57%	1,8311	63%	31%	2,1673	59%	18%
Environmental cost	0,1540	6%	0,1791	6%	16%	0,2011	5%	12%
Radionuclides damage cost	0,0002	0%	0,0002	0%	18%	0,0003	0%	18%
Marginal abatement cost of GHG	0,9170	37%	0,9170	31%	0%	1,3158	36%	43%
Total External costs	*2,4654*	*20%*	*2,9274*	*23%*	*19%*	*3,6845*	*26%*	*26%*
Total Private costs	*9,8703*	*80%*	*10,0792*	*77%*	*2%*	*10,3436*	*74%*	*3%*
Full cost	**12,3356**	**100%**	**13,0066**	**100%**	**5%**	**14,0281**	**100%**	**8%**

Table 7—3 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for light oil gas turbine

	hard coal condensing power plant							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,2553	40%	1,5230	46%	21%	1,7498	42%	15%
Environmental cost	0,1599	5%	0,1913	6%	20%	0,2081	5%	9%
Radionuclides damage cost	0,0001	0%	0,0001	0%	9%	0,0002	0%	14%
Marginal abatement cost of GHG	1,7198	55%	1,5822	48%	-8%	2,1820	53%	38%
Total External costs	*3,1352*	*48%*	*3,2967*	*51%*	*5%*	*4,1402*	*57%*	*26%*
Total Private costs	*3,3341*	*52%*	*3,2264*	*49%*	*-3%*	*3,1644*	*43%*	*-2%*
Full cost	**6,4693**	**100%**	**6,5231**	**100%**	**1%**	**7,3046**	**100%**	**12%**

Table 7—4 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hard coal condensing power plant

	hard coal IGCC without CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,8353	31%	0,9098	37%	9%	1,0668	33%	17%
Environmental cost	0,1048	4%	0,1086	4%	4%	0,1218	4%	12%
Radionuclides damage cost	0,0001	0%	0,0001	0%	-1%	0,0002	0%	17%
Marginal abatement cost of GHG	1,7562	65%	1,4639	59%	-17%	2,0802	64%	42%
Total External costs	*2,6964*	*41%*	*2,4825*	*41%*	*-8%*	*3,2689*	*48%*	*32%*
Total Private costs	*3,9146*	*59%*	*3,5428*	*59%*	*-9%*	*3,5027*	*52%*	*-1%*
Full cost	**6,6111**	**100%**	**6,0253**	**100%**	**-9%**	**6,7717**	**100%**	**12%**

Table 7—5 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hard coal IGCC without CO2 capture

	hard coal IGCC with CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,8353	31%	1,0208	70%	22%	1,1956	67%	17%
Environmental cost	0,1048	4%	0,1221	8%	17%	0,1368	8%	12%
Radionuclides damage cost	0,0001	0%	0,0001	0%	11%	0,0002	0%	17%
Marginal abatement cost of GHG	1,7562	65%	0,3242	22%	-82%	0,4582	26%	41%
Total External costs	*2,6964*	*41%*	*1,4673*	*26%*	*-46%*	*1,7908*	*30%*	*22%*
Total Private costs	*3,9146*	*59%*	*4,1970*	*74%*	*7%*	*4,1560*	*70%*	*-1%*
Full cost	**6,6111**	**100%**	**5,6643**	**100%**	**-14%**	**5,9468**	**100%**	**5%**

Table 7—6 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hard coal IGCC with CO2 capture

	lignite condensing power plant							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,9270	31%	1,1106	37%	20%	1,3151	33%	18%
Environmental cost	0,1066	4%	0,1335	5%	25%	0,1510	4%	13%
Radionuclides damage cost	0,0001	0%	0,0001	0%	6%	0,0001	0%	19%
Marginal abatement cost of GHG	1,9356	65%	1,7229	58%	-11%	2,4722	63%	43%
Total External costs	*2,9693*	*53%*	*2,9671*	*58%*	*0%*	*3,9383*	*65%*	*33%*
Total Private costs	*2,6830*	*47%*	*2,1844*	*42%*	*-19%*	*2,1350*	*35%*	*-2%*
Full cost	**5,6523**	**100%**	**5,1514**	**100%**	**-9%**	**6,0733**	**100%**	**18%**

Table 7—7 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for lignite condensing power plant

	lignite IGCC without CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,3838	16%	0,4302	20%	12%	0,5043	17%	17%
Environmental cost	0,0387	2%	0,0463	2%	20%	0,0517	2%	12%
Radionuclides damage cost	0,0001	0%	0,0001	0%	1%	0,0001	0%	17%
Marginal abatement cost of GHG	1,9569	82%	1,6562	78%	-15%	2,3538	81%	42%
Total External costs	*2,3795*	*44%*	*2,1327*	*43%*	*-10%*	*2,9099*	*51%*	*36%*
Total Private costs	*2,9991*	*56%*	*2,8270*	*57%*	*-6%*	*2,7712*	*49%*	*-2%*
Full cost	**5,3786**	**100%**	**4,9597**	**100%**	**-8%**	**5,6811**	**100%**	**15%**

Table 7—8 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for lignite IGCC without CO2 capture

	lignite IGCC with CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,3838	16%	0,4839	64%	26%	0,5666	60%	17%
Environmental cost	0,0387	2%	0,0522	7%	35%	0,0583	6%	12%
Radionuclides damage cost	0,0001	0%	0,0001	0%	13%	0,0001	0%	17%
Marginal abatement cost of GHG	1,9569	82%	0,2243	29%	-89%	0,3170	34%	41%
Total External costs	*2,3795*	*44%*	*0,7604*	*18%*	*-68%*	*0,9420*	*22%*	*24%*
Total Private costs	*2,9991*	*56%*	*3,3905*	*82%*	*13%*	*3,3428*	*78%*	*-1%*
Full cost	**5,3786**	**100%**	**4,1510**	**100%**	**-23%**	**4,2849**	**100%**	**3%**

Table 7—9 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for lignite IGCC with CO2 capture

	natural gas combined cycle without CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,4240	30%	0,5423	37%	28%	0,6316	33%	16%
Environmental cost	0,0717	5%	0,0798	5%	11%	0,0888	5%	11%
Radionuclides damage cost	0,0000	0%	0,0000	0%	9%	0,0000	0%	17%
Marginal abatement cost of GHG	0,8974	64%	0,8322	57%	-7%	1,1749	62%	41%
Total External costs	*1,3931*	*22%*	*1,4543*	*24%*	*4%*	*1,8953*	*29%*	*30%*
Total Private costs	*4,8087*	*78%*	*4,5827*	*76%*	*-5%*	*4,5372*	*71%*	*-1%*
Full cost	**6,2018**	**100%**	**6,0370**	**100%**	**-3%**	**6,4325**	**100%**	**7%**

Table 7—10 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas combined cycle without CO2 capture

	natural gas combined cycle with CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,4240	30%	0,5983	65%	41%	0,6957	62%	16%
Environmental cost	0,0717	5%	0,0883	10%	23%	0,0981	9%	11%
Radionuclides damage cost	0,0000	0%	0,0000	0%	19%	0,0000	0%	16%
Marginal abatement cost of GHG	0,8974	64%	0,2321	25%	-74%	0,3265	29%	41%
Total External costs	*1,3931*	*22%*	*0,9187*	*13%*	*-34%*	*1,1203*	*16%*	*22%*
Total Private costs	*4,8087*	*78%*	*5,9771*	*87%*	*24%*	*5,9066*	*84%*	*-1%*
Full cost	**6,2018**	**100%**	**6,8958**	**100%**	**11%**	**7,0269**	**100%**	**2%**

Table 7—11 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas combined cycle with CO2 capture

	natural gas, gas turbine							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,6339	30%	0,8545	37%	35%	0,9851	33%	15%
Environmental cost	0,1083	5%	0,1274	6%	18%	0,1405	5%	10%
Radionuclides damage cost	0,0000	0%	0,0000	0%	15%	0,0000	0%	15%
Marginal abatement cost of GHG	1,3423	64%	1,3079	57%	-3%	1,8293	62%	40%
Total External costs	*2,0845*	*24%*	*2,2898*	*26%*	*10%*	*2,9549*	*31%*	*29%*
Total Private costs	*6,5785*	*76%*	*6,6022*	*74%*	*0%*	*6,5266*	*69%*	*-1%*
Full cost	**8,6629**	**100%**	**8,8920**	**100%**	**3%**	**9,4816**	**100%**	**7%**

Table 7—12 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas, gas turbine

7.2 Renewables

	hydropower, run of river 10MW							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0459	75%	0,0564	78%	23%	0,0668	75%	18%
Environmental cost	0,0028	5%	0,0031	4%	10%	0,0035	4%	12%
Radionuclides damage cost	0,0000	0%	0,0000	0%	18%	0,0000	0%	18%
Marginal abatement cost of GHG	0,0127	21%	0,0127	18%	0%	0,0183	21%	44%
Total External costs	*0,0615*	*1%*	*0,0723*	*1%*	*17%*	*0,0885*	*1%*	*23%*
Total Private costs	*7,8340*	*99%*	*7,8340*	*99%*	*0%*	*7,8340*	*99%*	*0%*
Full cost	**7,8955**	**100%**	**7,9063**	**100%**	**0%**	**7,9225**	**100%**	**0%**

Table 7—13 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hydropower, run of river 10MW

	hydropower, run of river <100MW							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0328	75%	0,0403	78%	23%	0,0477	75%	18%
Environmental cost	0,0020	5%	0,0022	4%	10%	0,0025	4%	12%
Radionuclides damage cost	0,0000	0%	0,0000	0%	18%	0,0000	0%	18%
Marginal abatement cost of GHG	0,0091	21%	0,0091	18%	0%	0,0130	21%	44%
Total External costs	*0,0439*	*1%*	*0,0516*	*1%*	*17%*	*0,0632*	*1%*	*23%*
Total Private costs	*7,9340*	*99%*	*6,8010*	*99%*	*-14%*	*6,8010*	*99%*	*0%*
Full cost	**7,9779**	**100%**	**6,8526**	**100%**	**-14%**	**6,8642**	**100%**	**0%**

Table 7—14 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hydropower, run of river <100MW

	hydropower, run of river >100MW							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0295	75%	0,0363	78%	23%	0,0429	75%	18%
Environmental cost	0,0018	5%	0,0020	4%	10%	0,0022	4%	12%
Radionuclides damage cost	0,0000	0%	0,0000	0%	18%	0,0000	0%	18%
Marginal abatement cost of GHG	0,0082	21%	0,0082	18%	0%	0,0117	21%	44%
Total External costs	*0,0395*	*1%*	*0,0465*	*1%*	*17%*	*0,0569*	*1%*	*23%*
Total Private costs	*6,8100*	*99%*	*6,8010*	*99%*	*0%*	*6,8010*	*99%*	*0%*
Full cost	**6,8495**	**100%**	**6,8475**	**100%**	**0%**	**6,8579**	**100%**	**0%**

Table 7—15 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hydropower, run of river >100MW

	hydropower, dam (reservoir)							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0572	75%	0,0706	78%	23%	0,0836	76%	18%
Environmental cost	0,0036	5%	0,0040	4%	13%	0,0045	4%	12%
Radionuclides damage cost	0,0000	0%	0,0000	0%	18%	0,0000	0%	18%
Marginal abatement cost of GHG	0,0155	20%	0,0155	17%	0%	0,0222	20%	44%
Total External costs	*0,0763*	*1%*	*0,0901*	*1%*	*18%*	*0,1103*	*1%*	*22%*
Total Private costs	*11,0390*	*99%*	*11,0390*	*99%*	*0%*	*11,0390*	*99%*	*0%*
Full cost	**11,1153**	**100%**	**11,1291**	**100%**	**0%**	**11,1493**	**100%**	**0%**

Table 7—16 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hydropower, dam (reservoir)

	hydropower, pump storage							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0496	79%	0,0611	82%	23%	0,0723	80%	18%
Environmental cost	0,0027	4%	0,0031	4%	15%	0,0035	4%	13%
Radionuclides damage cost	0,0000	0%	0,0000	0%	18%	0,0000	0%	18%
Marginal abatement cost of GHG	0,0105	17%	0,0105	14%	0%	0,0150	17%	44%
Total External costs	*0,0628*	*1%*	*0,0747*	*1%*	*19%*	*0,0908*	*1%*	*22%*
Total Private costs	*11,0390*	*99%*	*11,0390*	*99%*	*0%*	*11,0390*	*99%*	*0%*
Full cost	**11,1018**	**100%**	**11,1137**	**100%**	**0%**	**11,1298**	**100%**	**0%**

Table 7—17 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hydropower, pump storage

	wind, on-shore							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0755	74%	0,0542	76%	-28%	0,0542	73%	0%
Environmental cost	0,0057	6%	0,0039	6%	-31%	0,0039	5%	-2%
Radionuclides damage cost	0,0001	0%	0,0000	0%	-37%	0,0000	0%	0%
Marginal abatement cost of GHG	0,0212	21%	0,0132	18%	-38%	0,0166	22%	26%
Total External costs	*0,1025*	*2%*	*0,0714*	*1%*	*-30%*	*0,0747*	*1%*	*5%*
Total Private costs	*6,1100*	*98%*	*6,0190*	*99%*	*-1%*	*5,9580*	*99%*	*-1%*
Full cost	**6,2125**	**100%**	**6,0904**	**100%**	**-2%**	**6,0327**	**100%**	**-1%**

Table 7—18 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for wind, on-shore

	wind, off-shore							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0718	77%	0,0554	80%	-23%	0,0574	77%	4%
Environmental cost	0,0047	5%	0,0035	5%	-27%	0,0034	5%	0%
Radionuclides damage cost	0,0001	0%	0,0000	0%	-32%	0,0000	0%	2%
Marginal abatement cost of GHG	0,0172	18%	0,0105	15%	-39%	0,0133	18%	27%
Total External costs	*0,0938*	*1%*	*0,0694*	*1%*	*-26%*	*0,0743*	*1%*	*7%*
Total Private costs	*6,3620*	*99%*	*6,1430*	*99%*	*-3%*	*5,8060*	*99%*	*-5%*
Full cost	**6,4558**	**100%**	**6,2124**	**100%**	**-4%**	**5,8803**	**100%**	**-5%**

Table 7—19 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for wind, off-shore

	solar PV, roof							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,6420	73%	0,6231	77%	-3%	0,6833	75%	10%
Environmental cost	0,0502	6%	0,0435	5%	-13%	0,0452	5%	4%
Radionuclides damage cost	0,0004	0%	0,0003	0%	-12%	0,0004	0%	9%
Marginal abatement cost of GHG	0,1819	21%	0,1373	17%	-25%	0,1815	20%	32%
Total External costs	*0,8745*	*2%*	*0,8043*	*3%*	*-8%*	*0,9103*	*4%*	*13%*
Total Private costs	*44,7570*	*98%*	*25,1400*	*97%*	*-44%*	*23,4840*	*96%*	*-7%*
Full cost	**45,6315**	**100%**	**25,9443**	**100%**	**-43%**	**24,3943**	**100%**	**-6%**

Table 7—20 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for solar PV, roof

	solar PV, open space							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,6576	74%	0,6394	78%	-3%	0,6991	75%	9%
Environmental cost	0,0495	6%	0,0435	5%	-12%	0,0451	5%	4%
Radionuclides damage cost	0,0003	0%	0,0003	0%	-8%	0,0003	0%	10%
Marginal abatement cost of GHG	0,1805	20%	0,1376	17%	-24%	0,1816	20%	32%
Total External costs	*0,8880*	*2%*	*0,8207*	*4%*	*-8%*	*0,9260*	*5%*	*13%*
Total Private costs	*35,9130*	*98%*	*20,8300*	*96%*	*-42%*	*16,5830*	*95%*	*-20%*
Full cost	**36,8010**	**100%**	**21,6507**	**100%**	**-41%**	**17,5090**	**100%**	**-19%**

Table 7—21 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for solar PV, open space

	solar thermal, parabolic trough							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,0918	76%	0,0907	80%	-1%	0,0854	77%	-6%
Environmental cost	0,0080	7%	0,0073	6%	-9%	0,0067	6%	-9%
Radionuclides damage cost	0,0000	0%	0,0000	0%	-9%	0,0000	0%	-7%
Marginal abatement cost of GHG	0,0204	17%	0,0159	14%	-22%	0,0182	16%	14%
Total External costs	*0,1202*	*1%*	*0,1139*	*1%*	*-5%*	*0,1103*	*1%*	*-3%*
Total Private costs	*12,7640*	*99%*	*10,2950*	*99%*	*-19%*	*9,4980*	*99%*	*-8%*
Full cost	**12,8842**	**100%**	**10,4089**	**100%**	**-19%**	**9,6083**	**100%**	**-8%**

Table 7—22 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for solar thermal, parabolic trough

7.3 Combined Heat and Power

	natural gas CHP with extraction condensing turbine without CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,3902	31%	0,5072	37%	30%	0,5932	33%	17%
Environmental cost	0,0656	5%	0,0742	5%	13%	0,0829	5%	12%
Radionuclides damage cost	0,0000	0%	0,0000	0%	12%	0,0000	0%	17%
Marginal abatement cost of GHG	0,8193	64%	0,7724	57%	-6%	1,0951	62%	42%
Total External costs	*1,2751*	*24%*	*1,3537*	*24%*	*6%*	*1,7713*	*29%*	*31%*
Total Private costs	*4,1168*	*76%*	*4,3710*	*76%*	*6%*	*4,3981*	*71%*	*1%*
Full cost	**5,3918**	**100%**	**5,7248**	**100%**	**6%**	**6,1694**	**100%**	**8%**

Table 7—23 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas CHP with extraction condensing turbine without CO2 capture

	natural gas CHP with extraction condensing turbine with CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,3902	31%	0,5535	65%	42%	0,6472	62%	17%
Environmental cost	0,0656	5%	0,0812	10%	24%	0,0907	9%	12%
Radionuclides damage cost	0,0000	0%	0,0000	0%	20%	0,0000	0%	17%
Marginal abatement cost of GHG	0,8193	64%	0,2136	25%	-74%	0,3021	29%	41%
Total External costs	*1,2751*	*24%*	*0,8484*	*12%*	*-33%*	*1,0400*	*14%*	*23%*
Total Private costs	*4,1168*	*76%*	*6,3737*	*88%*	*55%*	*6,3245*	*86%*	*-1%*
Full cost	**5,3918**	**100%**	**7,2221**	**100%**	**34%**	**7,3645**	**100%**	**2%**

Table 7—24 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas CHP with extraction condensing turbine with CO2 capture

	hard coal CHP with extraction condensing turbine without CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,1068	40%	1,3832	46%	25%	1,6148	42%	17%
Environmental cost	0,1408	5%	0,1718	6%	22%	0,1917	5%	12%
Radionuclides damage cost	0,0001	0%	0,0001	0%	11%	0,0002	0%	17%
Marginal abatement cost of GHG	1,5142	55%	1,4207	48%	-6%	2,0102	53%	41%
Total External costs	*2,7619*	*68%*	*2,9758*	*69%*	*8%*	*3,8169*	*73%*	*28%*
Total Private costs	*1,3072*	*32%*	*1,3365*	*31%*	*2%*	*1,3927*	*27%*	*4%*
Full cost	**4,0690**	**100%**	**4,3123**	**100%**	**6%**	**5,2097**	**100%**	**21%**

Table 7—25 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hard coal CHP with extraction condensing turbine without CO2 capture

	hard coal CHP with extraction condensing turbine with CO2 capture							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,1068	40%	0,7886	70%	-29%	0,9314	67%	18%
Environmental cost	0,1408	5%	0,0944	8%	-33%	0,1066	8%	13%
Radionuclides damage cost	0,0001	0%	0,0001	0%	0%	0,0001	0%	18%
Marginal abatement cost of GHG	1,5142	55%	0,2507	22%	-83%	0,3573	26%	43%
Total External costs	*2,7619*	*68%*	*1,1338*	*27%*	*-59%*	*1,3954*	*31%*	*23%*
Total Private costs	*1,3072*	*32%*	*3,1239*	*73%*	*139%*	*3,0868*	*69%*	*-1%*
Full cost	**4,0690**	**100%**	**4,2578**	**100%**	**5%**	**4,4822**	**100%**	**5%**

Table 7—26 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hard coal CHP with extraction condensing turbine with CO2 capture

	natural gas combined cycle CHP with backpressure turbine							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,4265	31%	0,5882	38%	38%	0,6917	34%	18%
Environmental cost	0,0715	5%	0,0858	5%	20%	0,0965	5%	12%
Radionuclides damage cost	0,0000	0%	0,0000	0%	18%	0,0000	0%	18%
Marginal abatement cost of GHG	0,8939	64%	0,8939	57%	0%	1,2743	62%	43%
Total External costs	*1,3920*	*24%*	*1,5680*	*27%*	*13%*	*2,0625*	*33%*	*32%*
Total Private costs	*4,3148*	*76%*	*4,2655*	*73%*	*-1%*	*4,2440*	*67%*	*-1%*
Full cost	**5,7068**	**100%**	**5,8335**	**100%**	**2%**	**6,3065**	**100%**	**8%**

Table 7—27 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas combined cycle CHP with backpressure turbine

	hard coal CHP with backpressure turbine							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,2038	40%	1,5298	47%	27%	1,7848	42%	17%
Environmental cost	0,1522	5%	0,1890	6%	24%	0,2109	5%	12%
Radionuclides damage cost	0,0001	0%	0,0001	0%	13%	0,0002	0%	17%
Marginal abatement cost of GHG	1,6364	55%	1,5627	48%	-5%	2,2102	53%	41%
Total External costs	*2,9925*	*77%*	*3,2817*	*78%*	*10%*	*4,2060*	*80%*	*28%*
Total Private costs	*0,8908*	*23%*	*0,9057*	*22%*	*2%*	*1,0411*	*20%*	*15%*
Full cost	**3,8834**	**100%**	**4,1874**	**100%**	**8%**	**5,2471**	**100%**	**25%**

Table 7—28 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for hard coal CHP with backpressure turbine

	biomass (straw) CHP with an extraction condensing turbine							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,5553	77%	1,6663	76%	7%	1,9723	75%	18%
Environmental cost	0,3156	16%	0,3751	17%	19%	0,4390	17%	17%
Radionuclides damage cost	0,0003	0%	0,0003	0%	18%	0,0004	0%	18%
Marginal abatement cost of GHG	0,1462	7%	0,1462	7%	0%	0,2062	8%	41%
Total External costs	*2,0174*	*44%*	*2,1879*	*50%*	*8%*	*2,6178*	*55%*	*20%*
Total Private costs	*2,5910*	*56%*	*2,1779*	*50%*	*-16%*	*2,1779*	*45%*	*0%*
Full cost	**4,6084**	**100%**	**4,3659**	**100%**	**-5%**	**4,7958**	**100%**	**10%**

Table 7—29 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for biomass (straw) CHP with an extraction condensing turbine

	biomass (woodchips) CHP with an extraction condensing turbine							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,4642	71%	0,6178	75%	33%	0,7312	74%	18%
Environmental cost	0,0689	11%	0,0801	10%	16%	0,0904	9%	13%
Radionuclides damage cost	0,0003	0%	0,0003	0%	18%	0,0004	0%	18%
Marginal abatement cost of GHG	0,1203	18%	0,1203	15%	0%	0,1718	17%	43%
Total External costs	*0,6537*	*37%*	*0,8185*	*46%*	*25%*	*0,9938*	*50%*	*21%*
Total Private costs	*1,1325*	*63%*	*0,9776*	*54%*	*-14%*	*0,9776*	*50%*	*0%*
Full cost	**1,7862**	**100%**	**1,7960**	**100%**	**1%**	**1,9714**	**100%**	**10%**

Table 7—30 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for biomass (woodchips) CHP with an extraction condensing turbine

	MCFC (natural gas)							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	1,4486	73%	1,8724	77%	29%	1,9848	75%	6%
Environmental cost	0,1520	8%	0,1716	7%	13%	0,1724	6%	0%
Radionuclides damage cost	0,0002	0%	0,0002	0%	18%	0,0002	0%	6%
Marginal abatement cost of GHG	0,3943	20%	0,3874	16%	-2%	0,4972	19%	28%
Total External costs	*1,9951*	*6%*	*2,4317*	*15%*	*22%*	*2,6547*	*27%*	*9%*
Total Private costs	*33,5544*	*94%*	*13,3398*	*85%*	*-60%*	*7,2581*	*73%*	*-46%*
Full cost	**35,5495**	**100%**	**15,7715**	**100%**	**-56%**	**9,9127**	**100%**	**-37%**

Table 7—31 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas fuel cell - MCFC

	SOFC (natural gas)							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	0,5591	60%	0,6478	66%	16%	0,7664	62%	18%
Environmental cost	0,0709	8%	0,0705	7%	-1%	0,0790	6%	12%
Radionuclides damage cost	0,0001	0%	0,0001	0%	15%	0,0001	0%	18%
Marginal abatement cost of GHG	0,3063	33%	0,2688	27%	-12%	0,3850	31%	43%
Total External costs	*0,9363*	*2%*	*0,9872*	*8%*	*5%*	*1,2305*	*15%*	*25%*
Total Private costs	*46,7953*	*98%*	*11,5502*	*92%*	*-75%*	*7,0210*	*85%*	*-39%*
Full cost	**47,7316**	**100%**	**12,5374**	**100%**	**-74%**	**8,2515**	**100%**	**-34%**

Table 7—32 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for natural gas fuel cell - SOFC

	MCFC (biogas)							
	2005-10		2020			2030		
	Ec/kWh	%	Ec/kWh	%	Δ 2005	Ec/kWh	%	Δ 2020
Human health related ext cost	2,4190	73%	3,0913	77%	28%	3,2722	75%	6%
Environmental cost	0,2196	7%	0,2483	6%	13%	0,2494	6%	0%
Radionuclides damage cost	0,0027	0%	0,0032	0%	19%	0,0033	0%	3%
Marginal abatement cost of GHG	0,6876	21%	0,6866	17%	0%	0,8639	20%	26%
Total External costs	*3,3290*	*9%*	*4,0294*	*23%*	*21%*	*4,3889*	*41%*	*9%*
Total Private costs	*31,8777*	*91%*	*13,2258*	*77%*	*-59%*	*6,3645*	*59%*	*-52%*
Full cost	**35,2066**	**100%**	**17,2552**	**100%**	**-51%**	**10,7533**	**100%**	**-38%**

Table 7—33 External costs, private costs and full costs in 2005-2010, 2020 and 2030 for biogas fuel cell – MCFC

[i] Private costs calculated with the average lifetime levelised generating technology seem to underestimate the real industrial production cost, in particular for nuclear, as declared by stakeholders of the electricity sector invited to the “First CASES Stakeholders Workshop – Social costs of electricity production” February 2008, Brussels.