SIXTH FRAMEWORK PROGRAMME

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NEEDS
New Energy Externalities Developments for Sustainability

INTEGRATED PROJECT
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Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy.

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“Report on the application of the tools for innovative energy technologies”

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Author: USTUTT.TFU, Philipp PREISS and Rainer FRIEDRICH, Germany
with contribution from
Ari Rabl, ARMINES/Ecole des Mines de Paris, and Joe V. Spadaro
Alistair Hunt, University of Bath,
Douros, Ioannis, AUTH,
Torfs, Rudi, VITO

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1. Introduction

The quantification of damage costs is based on the ‘impact pathway approach” (IPA) which has been developed in the series of ExternE projects, and was further improved within NEEDS. The IPA aims at modelling the causal chain of interactions from a pressure (e.g. the emission of a pollutant) through transport and chemical transformation in the atmosphere to the impacts on receptors, such as humans, crops, building materials and ecosystems. Damages resulting from these impacts are weighted and aggregated into monetary values.

Externalities exist in the form of external costs and external benefits. External costs occur when an economic subject causes a loss of welfare to another one and does not compensate this change of welfare. A compensation for this change of welfare due to external costs would eliminate the market imperfection caused by externalities. This procedure is called internalisation of externalities because external costs are considered in market mechanisms. In a situation where all externalities are internalised there is no relevant externality anymore although there are of course still emissions and damages.

The damages calculated with the aid EcoSense are to major part external costs. Although, for certain processes some parts of the external cost may already by internalised in one or the other way the “damage costs” are referred to as “external costs” in the following text.

The improved framework of EcoSenseWeb is applied to a number of innovative energy technologies assumed at different locations within some member countries of the current EU. The purpose of this is to demonstrate the application of the detailed methodology developed to estimate new external cost values.
Moreover, using the final LCI data of NEEDS from (Frischknecht, 2008), the external cost of all investigated technologies in 2025 and 2050 and the configurations according to the corresponding scenarios have been calculated and results are displayed in this report.

Which External Costs have been considered?
Considered are quantifiable releases of substances or energy (noise, radiation) into environmental media (air, indoor air, soil, water), that cause - after transport and transformation - considerable (not negligible) harm to ecosystems, humans, crops or materials. Regarding climate change impacts damage costs and avoidance cost approach is taken into account
Regarding accidents: public and partly occupational risks caused by accidents have been considered by use of expectation value (i.e. potential outcome * probability).
Regarding insecurity of energy supply unexpected changes in availability and prices of energy carriers leads according to CASES to small externalities.

Which Effects Are Not Included ?

As they are not considered as externalities:

- Effects on Employment

- Depletion of non-renewable resources (oil, gas, silicon, copper, …)
- Research and development (sunk costs)
- Income and damage distribution
- Local ecosystem damage (however, they are addressed and at least partly compensated within the Environmental Impact Assessment).

As agreed methods or reliable information are not available, though impacts on the result may be large:

- Assessment of risk aversion (so called Damocles risks, i.e. low probability-high damage risks) – agreed method not available
- Risk of terrorism or proliferation – information not publicly available
- Visual Intrusion or annoyance (large variability, thus benefit transfer difficult)
- Risk analysis of carbon storage – no quantitative information yet available
- Security of supply for natural gas - methodology not available.

In general: unknown or unquantifiable impacts are can not be included. However, as far as possible, critical issues are as far as possible, at least mentioned and will be included in future research.

Short summary of main improvements of the ExternE Methodology within NEEDS

- Geographical Extension
- Eulerian regional & North Hemispheric model
- Local model and "urban increment"
- Site dependent multi-media modelling including trade for heavy metals
- New methodology for assessing biodiversity losses due to eutrophication, acidification and land use change
- Survey for valuing changes in life expectancy
- Updates for concentration-response-relationships and monetary values
- New unit costs for greenhouse gases, etc

The calculation of external costs is done in two ways:

Assessment with EcoSenseWeb

Firstly, emissions from operation of typical present fossil fuelled technologies (data taken from the CASES project, (Blesl and Mayer-Spohn, 2007) have been used to run EcoSenseWeb model based on distinct locations (defined by longitude and latitude). The results do not show total external costs per kWh but only costs due to operation at different locations in the corresponding countries. The locations have been chosen because at these sites there are in reality fossil fuelled plants operating. The emissions caused by up- and downstream processes (construction, fuel supply and dismantling) are not included because these emissions are caused by many different processes including for example, production of steel, production of concrete, transport processes and energy consumption, etc. The external costs are only displayed for the main air pollutants emitted due to operation but not for greenhouse gases due to operation.

The purpose is to emphasis on the site dependents of impacts caused by these pollutants. The external costs of greenhouse gases are not site depended of the emission and will be added in the second part, where also up- and downstream processes will be included. If the country consist of only one regional sub-region the results show the difference of local dispersion model (the effects of primary pollutants PPM2.5 and PPMco in the vicinity of the plants) within the corresponding example countries. If the country consist of several sub-region the results do also show the differences regarding the regional chemical transport model (primary and secondary pollutants). The purpose of this is to show variability within countries.

Assessment with generalised country specific factors (derived with EcoSenseWeb)

Secondly, LCI data (emission and resource consumption) from NEEDS Rs1a for the full set of technologies, different years and different scenarios are used to calculate the total external costs. This is done by applying generalised values (i.e. country average) Euro per LCI unit (e.g. Euro per tonne SO_2) values. These values have been derived with EcoSenseWeb and they are documented in the NEEDS Rs3a, WP1 report (Preiss et al., 2008) on generalisation.

The purpose of this is to produce technology specific external cost expressed as Euro-Cent per kWh. The results can be used and combined with private costs per technology in order to report the "real cost", i.e., the full social costs of each technology expressed as Euro-Cent per kWh. This enables to provide rankings of technologies.

Kommentar [p1]: Alternative rankings are also provided by applying sensitivity analysis (e.g., different approaches on how to value emissions of greenhouse gases. Finally, the social costs are used to draw some conclusions regarding the recommendations for a possible, optimal and reasonable future energy mix.

In the following the external costs caused by the normal operation of different technologies for electricity generation are presented. In addition to the impacts that can be quantified and monetised based on the state-of-the-art methods developed in NEEDS RS1b it is possible that there exist still other, not quantified (and partly not quantifiable) externalities. Some are known but due to a lack of a reliable method it is today not possible to quantify these external costs, i.e. to express the physical impacts in monetary terms. Moreover, it is possible that there are externalities, especially effects in the future which are not know at all. For example, it can be speculated that due to the extinction of certain species a severe imbalance in the ecosystem could causes serious, irreversible consequences. However, if it is not possible to quantify neither extend of the consequences nor the probability of occurrence of this it can not be taken into account quantitatively.

The report presents currently quantifiable external costs. It is assumed that these are the major part of the total external costs related with electricity generation.

N.B.: "Main air pollutants" are the once emitted in relatively high amounts, i.e. primary particulate matter, SO_2, NOx, NMVOC and NH3. Greenhouse gases (CO_2, CH_4, NO_x) are not named "air pollutants" because of the indirect effect due to climate change. Other pollutants which are included in the impact assessment like heavy metals, formaldehyde and dioxin emitted into the air are emitted in relatively small amounts and therefore, not included in the category "main air pollutants" but named separately as heavy metals and organic substances.

2. Application of EcoSenseWeb tool for Point Sources

The application of EcoSenseWeb tool is demonstrated for the operation phase of typical fossil fuelled power plants – CASES Technologies (Present)

2.1. Technologies

Each considered technology is assumed as to operate 7500 full load hours and has a technical life time of 35 years (Nuclear = 40 a)

Table 1: List of technologies and important technical parameters

Energy carrier	**Technology**	**net el. Cap.**	**el. effici**		**Flue gas**		**Stack**	
		[MW]	**[%]**	**[GWh/a]**	**Vol. [Nm3]**	**T [K]**	**Height [m]**	**Diameter [m]**
heavy fuel oil	Condens.	350	43.0	2,625	1.67E+05	470	146	4.94
light oil	Gas Turbine	50	36.0	375	7.85E+04	468	96	2.60
hard coal	Condens.	600	46.0	4,500	1.38E+06	381	167	4.62
	IGCC	450	45.0	3,375	1.38E+06	381	167	4.62
lignite	Condens.	965	44.5	7,238	4.74E+05	432	147	6.19
	IGCC	450	44.0	3,375	4.74E+05	432	147	6.19
natural gas	Combined Cycle (CC)	1,000	57.5	7,500	2.92E+05	385	186	6.05
	Gas Turbine	50	38.0	375	9.30E+04	405	59	2.18

2.2. Locations

For the assessment of the external cost of the technologies listed in Table 1 locations have been chosen where actually energy generation facilities are located. The number of locations depends on the number of available sub-regions of the regional dispersion modelling. For Belgium, although consisting of only one sub-regions 4 locations have been chosen to investigate the influence of local population differences.

The locations are defined by their longitude and latitude coordinates.

2.2.1. Belgium

Facility-ID	**Latitude**	**Longitude**
BE_E	50.583	5.416
BE_N	51.325	4.258
BE_NE	50.941	5.489
BE_SE	50.783	3.475

2.2.2. France

Facility-ID	Latitude	Longitude
Fr_01	47.28	-1.88
Fr_03	49.15	6.70
Fr_04	45.13	1.23
Fr_05	43.47	5.49
Fr_06	48.86	2.35
Fr_07	49.48	0.15

2.2.3. Greece

Facility-ID	Latitude	Longitude
GR_N	40.39	21.92
GR_S	37.75	24.07

2.2.4. UK

Facility-ID	Latitude	Longitude
UK_S_01	51.39	-3.41
UK_N_02	56.05	-3.68
UK Mid_03	53.71	-1.13

2.2.5. Germany

Facility-ID	Latitude	Longitude
Ger_01	52.39	12.42
Ger_02	52.19	8.93
Ger_03	50.84	6.31
Ger_04	50.03	10.22

2.3. Emissions

LCI data for the operation of the power plant are displayed in the following table. The data corresponds to the CASES data set.

Table 2: LCI data for the operation taken from CASES for present innovative (newly build) technologies

[- / kWhel]		**heavy oil condensing power plant**	**light oil gas turbine**	**hard coal condensing power plant**	**hard coal IGCC**	**lignite condensing power plant**	**lignite IGCC**	**natural gas combined cycle**	**natural gas, gas turbine**
Sulfur dioxide, air, total	mg/Nm3	1.45E+03	2.65E+01	2.41E+02	7.40E+01	1.32E+03	2.41E+02	2.47E+01	2.24E+01
Particulates, < 10 um, air, total	mg/Nm3	3.52E+00	0.00E+00	1.19E+01	1.02E-01	6.58E+01	3.04E-01	1.16E+01	0.00E+00
Ammonia, air, total	mg/Nm3	1.01E+00	8.50E-01	2.51E-02	1.94E-02	1.22E-01	5.77E-02	1.61E-01	0.00E+00
Nitrogen oxides, air, total	mg/Nm3	9.57E+02	1.62E+02	2.40E+02	5.99E+01	1.32E+03	2.00E+02	9.39E+02	2.21E+02
Particulates, < 2,5 um, air, total	mg/Nm4	2.46E+00	0.00E+00	8.32E+00	7.16E-02	4.60E+01	2.13E-01	8.12E+00	0.00E+00
NMVOC, unspecified origin, air, total	mg/Nm3	2.45E+00	2.97E+00	5.90E+00	2.25E+00	1.42E+01	6.71E+00	1.89E+01	8.61E-01
Cadmium, air, total	µg/Nm3	1.62E+01	0.00E+00	1.70E-01	1.34E-01	8.02E-01	1.31E-01	1.21E-01	0.00E+00
Arsenic, air, total	µg/Nm3	3.38E+01	0.00E+00	3.47E+00	2.69E+01	1.61E+01	4.42E+00	3.15E-01	0.00E+00
Chromium, air, total	µg/Nm3	6.05E+01	0.00E+00	2.24E+00	1.77E+00	1.04E+01	2.33E+00	3.35E+00	0.00E+00
Nickel, air, total	µg/Nm3	1.40E+03	0.00E+00	6.84E+00	5.36E+00	3.17E+01	3.07E+00	1.57E+00	0.00E+00
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin, air, total	ng/Nm3	8.78E-02	2.55E-03	2.23E-02	1.75E-02	1.04E-01	4.95E-02	2.45E-02	1.18E-03
Mercury, air, total	µg/Nm3	1.77E+00	2.83E+00	1.10E+01	8.63E+00	5.09E+01	1.38E+01	1.51E+00	1.22E+00
Lead, air, total	µg/Nm3	1.75E+02	0.00E+00	1.49E+01	1.17E+01	6.89E+01	3.59E+00	1.50E+00	0.00E+00
Chromium IV, air, total	µg/Nm3	2.19E+00	0.00E+00	2.28E-01	1.79E-01	1.05E+00	1.70E-01	8.43E-02	4.30E+03
Formaldehyde, air, total	µg/Nm3	5.41E+03	5.10E+03	1.55E+02	1.21E+02	7.15E+02	3.41E+02	3.24E+04	0.00E+00
Carbon dioxide, fossil, air, total	t/a	2.98E+05	1.24E+05	3.28E+06	2.51E+06	6.51E+06	3.07E+06	2.66E+06	1.99E+05
Methane, air, total	t/a	3.81E+01	1.75E+00	6.37E+01	4.86E+01	9.72E+01	4.59E+01	4.45E+01	3.00E+00
Dinitrogen monoxide, air, total	t/a	7.80E+01	3.28E+00	1.41E+02	1.04E+02	2.08E+02	9.80E+01	7.08E+01	5.25E+00

2.4. Results

The results of the EcoSenseWeb calculations are summarised for each country in the Figure 1 to Figure 5. The results correspond to the local and regional and hemispheric scale, i.e. the regional model results are corrected by the local model results. In addition, the damages occurring outside of Europe in the northern hemisphere are calculated by the northern hemispheric model, and they are also added to the total damage.

2.4.1. Belgium

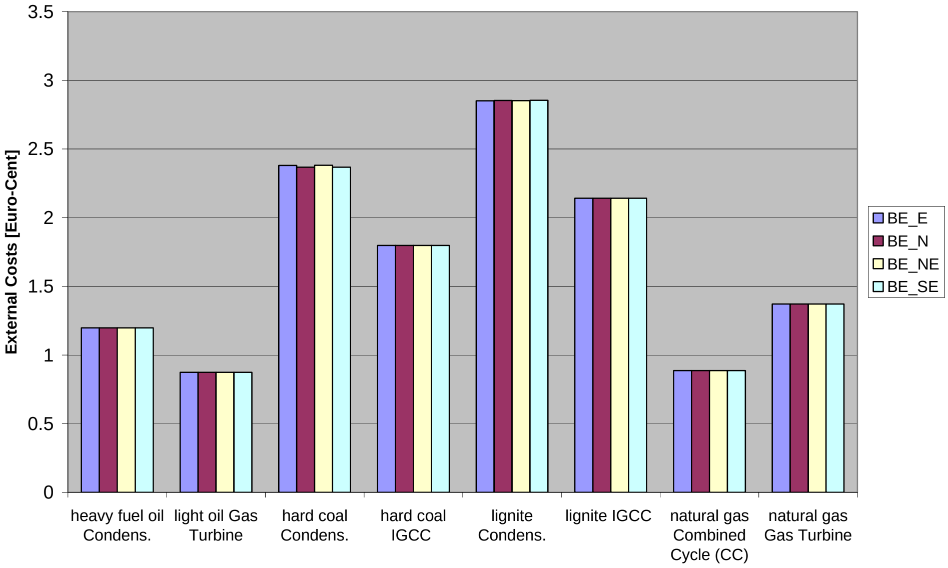


Figure 1: External cost of operation of fossil fuelled power plants in Belgium - without greenhouse gases

Since the whole of Belgium is covered by one sub-region of the regional dispersion model the results for different locations within Belgium differ only very slightly. The differences between the locations are only caused due to the differences of the additional local model results for primary particulate matter. However, since the stack height is above 100 meter (except of “light oil gas turbine” (ca. 96m) and “natural gas CC” (ca. 56 meter)) the impacts due to primary particulates in the vicinity are below 5 % of the total impacts due to primary particulate matters.

2.4.2. France

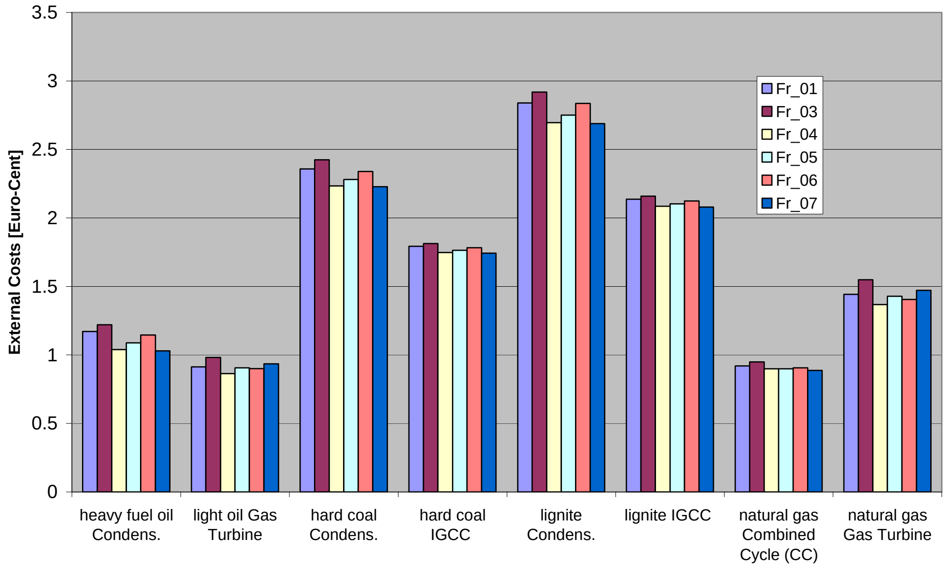


Figure 2: External cost of operation of fossil fuelled power plants in France - without greenhouse gases

France consists of 6 sub-regions and therefore, the results of the regional dispersion model of MET.NO leads to different results within France. The largest damages are caused by emissions taking place in the sub-region FR_03. The emissions taking place in sub-region Fr_06 which is a small sub-region covering Paris do not cause the highest damages.

2.4.3. Germany

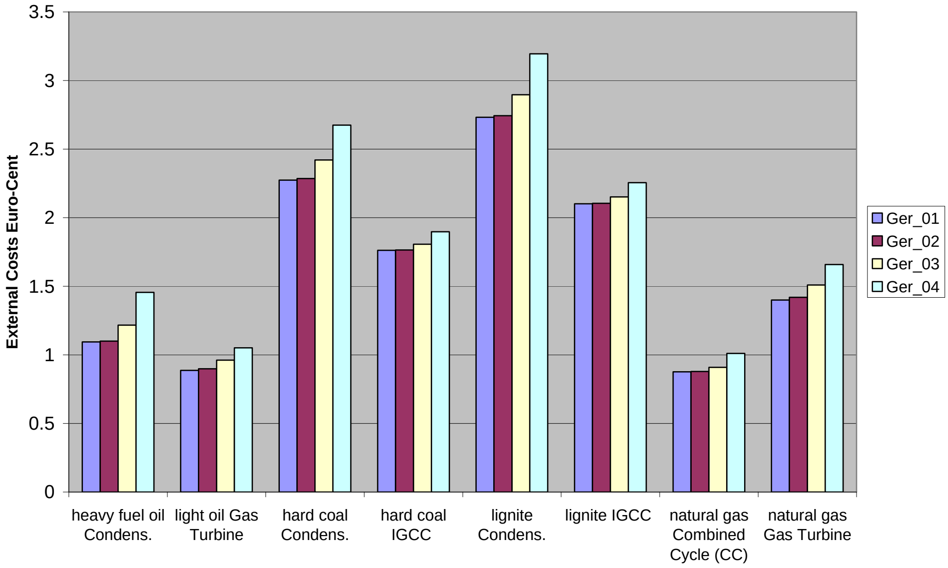


Figure 3: External cost of operation of fossil fuelled power plants in Germany - without greenhouse gases

Germany consists of 4 sub-regions and therefore, the results of the regional dispersion model of MET.NO leads to 4 different results within Germany whereas the highest results in sub-region 4 are up to 25% higher than in sub-region 1.

2.4.4. Greece

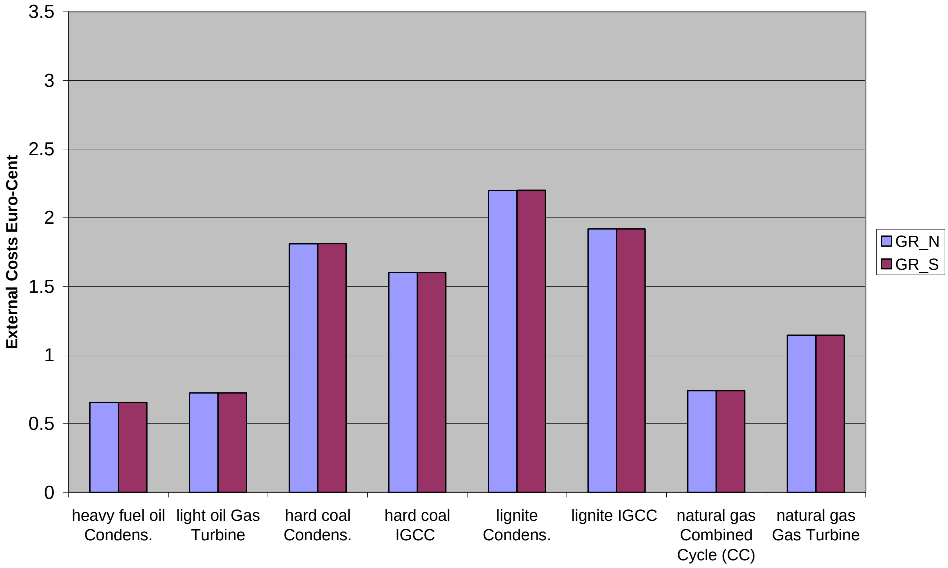


Figure 4: External cost of operation of fossil fuelled power plants in Greece - without greenhouse gases

Greece is also covered by one sub-region of the regional dispersion model of MET.NO. Therefore, the results for different locations within Greece also differ only very slightly (not visible in the Figure).

2.4.5. UK

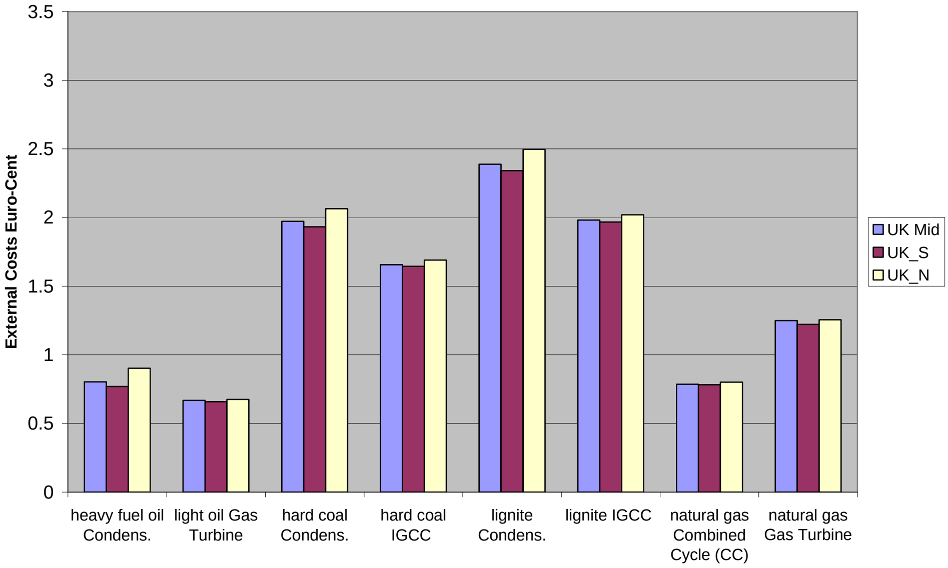


Figure 5: External cost of operation of fossil fuelled power plants in UK - without greenhouse gases

UK consists of 3 sub-regions and therefore, the results of the regional dispersion model of MET.NO leads to different results within UK. The highest results are up to 15 % higher than the lowest.

2.5. The Modelling of the Local Effect (50 km radius)

The external costs displayed in the Figures above are dominated by the dispersion of SO_2 and NOx and the chemical transformation and creation of secondary pollutants (secondary particulate matter nitrates and sulfates) over several 1000 km. This leads to the main exposure of population and the corresponding damages to human health due to (secondary) particulate matter. Primary pollutants can affect the receptors in the local scale area immediately. However, if the stack has a sufficient height the emissions do not cause considerable concentration increments in the local scale area. Moreover, the reason for the dominance of SO_2 and NOx is the high efficiency of the flue gas cleaning and the effective reduction of primary particulate matter (PPM) emission.

The effect of PPM emissions on the local scale concentration increment is modelled within EcoSenseWeb with the Industrial Source Complex Model (ISC).

The ISC is a Gaussian plume model developed by the US-EPA. It is used for transport modelling of primary air pollutants on a local scale, on a grid 100 km x 100 km around the power plant site (i.e. ca. 50 km radius). EcoSenseWeb uses the short-term version of the model which uses hourly site specific meteorological data. These data are generated within EcoSenseWeb. The user has only to provide longitude and latitude coordinates (in decimal degree). The tool used to derive local meteorological data was developed within NEEDS, RS1b, WP1 (Douros et al., 2009).

Since the effect of PPM can hardly be recognised in the Figure 1 to Figure 5 in the following Figure results for separate model runs on PPM emissions are shown.

In Figure 6 the variability of the local impact within Germany is shown. For 186 actual power plant sites calculations with the local dispersion model ISC have been performed with regard to PPM. Typical technical conditions of a power plant such as, stack diameter, flue gas temperature, flue gas volume stream, etc have been used. The stack height has been fixed to 100m.

The results of the model runs are shown in Figure 6 from left to right in ascending order. The results are normalised by division by the highest value. It can be seen that the local impact even at a height of release of 100 meter can vary by a factor of up to 20 depending on the location within Germany.

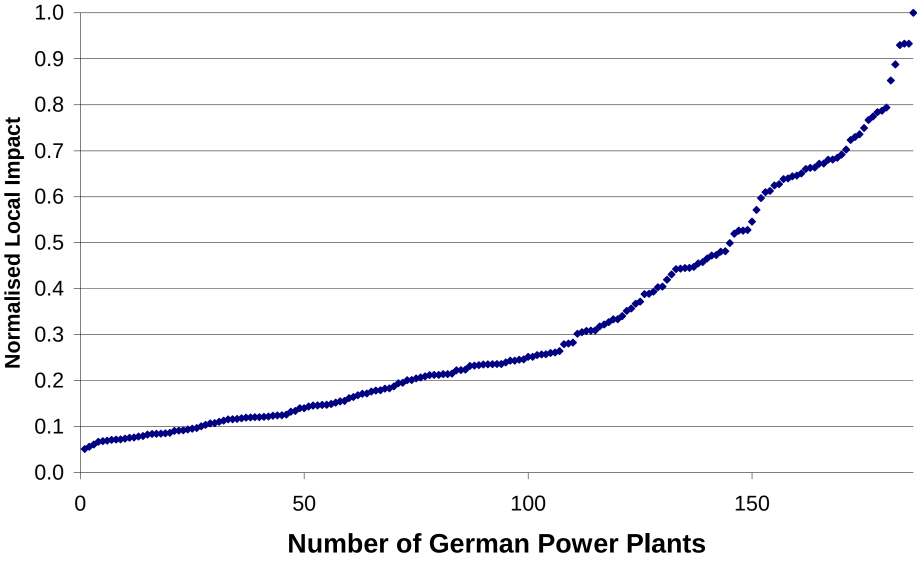


Figure 6: Variability of local effect from PPM emission at 186 German sites (actual power plant locations but one generic source with 100 meter stack height)

In Figure 7 the share of impacts due to PPM in the local area of the impact in the regional area, i.e. Europea scale is shown as a function of height of release. It has to benoted that the local scale mode uses dispersion coefficients which are defined till 60 meter and avove. Secondly, the 16% value at 110 meter can be explained by the fact that the regional model distinguishes into height of release till 100 meter and above. The results for the regional scale for height of release above 100 meter are of course lower as for below 100 meter. Therefore, the share of the local model, increases again although the absolute vlaue is lower. The calculations have been performed with coordinates in the city Bochum, a city in the relatively high popluated area, the German Ruhr Area, a accumulation of 5.3 million people and an average population density of ca. 1,200 cap / km². The share of impacts due to PPM in the local area is significant. However, the share of PPM on the total impacts due to the main air pollutants is still relatively small.

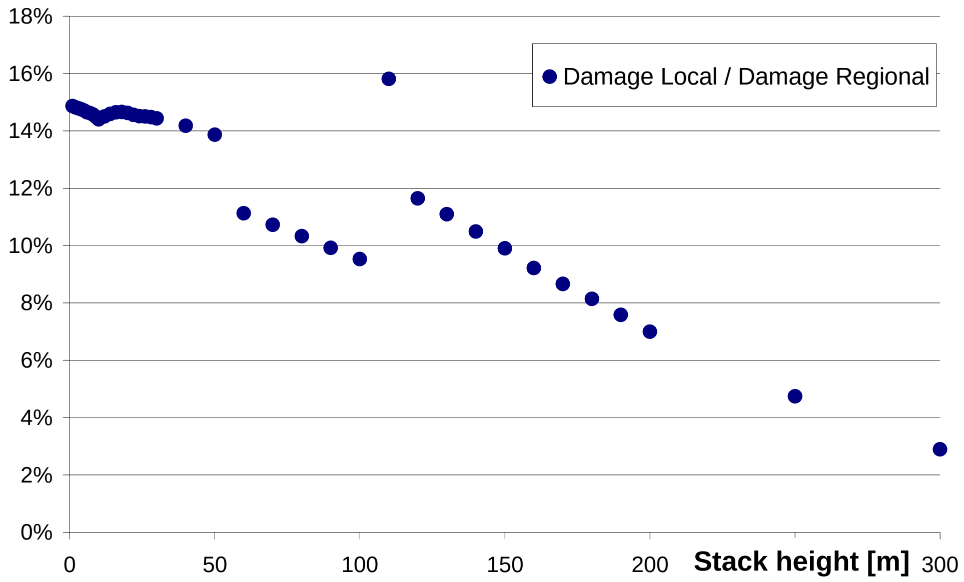


Figure 7: Examples of the share of impact due to PPM in the local area on the impact of PPM in the regional Europea scale as a function of height of release

2.6. Conclusion on EcoSenseWeb Results for the Operation Phase of the Fossil Fuelled Power Plants

The results show that for the same technologies there are different results if the technologies operate in different countries. The highest external costs occur in Germany, the lowest in Greece and UK. For example, the same technology (heavy fuel oil) operating in Greece would cause ca. 50% of the external costs than if the plant operates in Germany. The emissions taking place in Greece are dispersed to areas with low population density or even to the sea where no people live.

The differences within the countries are mainly caused by the sub-regionalisation of the regional dispersion model (the concept of the regional dispersion model is explained in more detail in (Wind, 2006), (MET.NO, 2008) and (Preiss et al., 2008). Due to the application of a highly sophisticated Eulerian dispersion model the reliability of the results has been increased. To use smaller sub-regions, i.e. more sub-regions would surely increase the accuracy of the site specific calculations. It is to be expected that the variability of results within a country will increase because the higher the number of sub-regions the smaller is the “dilution effect” by averaging results for a relatively large area. However, this will increase the computational effort necessary for the parameterisation of the Eulerian dispersion model by an increased number of model runs.

External costs of primary pollutants are especially high if the population density is high and the release height is low, as it can be the cases for transport processes or domestic heating. For the fossil fuelled power plants with high stacks the external costs in the vicinity of the power plant contribute only to a very small amount to the total external costs.

3. Total External Costs of NEEDS Technologies

The external costs are calculated based on LCI data from Rs1a (Frischknecht, 2008). For the present "typical" new technologies corresponding to average emission values have been investigated. For two different future years, i.e. in 2025 and 2050, results have been calculated for each 3 different scenarios. These technology development scenarios are called Pessimistic (PE), Realistic/Optimistic (RO), and Very Optimistic (VO).

The general assumptions valid for all datasets are the following:

Pessimistic (PE)

> *"Socio-economic framing conditions do not stimulate market uptake and technical innovations."*

- it is assumed that there is no technological development (i.e. the datasets are left unchanged) except for transports (due to legal requirements) and electricity mixes
- the development of technologies covered in separate NEEDS work packages are, of course, implemented accordingly
- the business as usual (BAU) electricity mix scenario is applied on European electricity supply.

Realistic/Optimistic (RO)

> *"Strong socio-economic drivers support dynamic market uptake and continuous technology development. It is very likely that the respective technology gains relevance on the global electricity market."*

- the pathway of technology development is as far as possible according to predictions and goals of the industry that seem reasonable to be achieved
- the 440 ppm electricity mix scenario is applied on European electricity supply

Very Optimistic (VO)

> *"A technological breakthrough makes the respective technology on the long term a leading global electricity supply technology."*

- improvements according to the optimistic-realistic scenario are introduced earlier
- a switch to cleaner energy generating technologies (e.g. oil to gas) is more common or more pronounced
- the enhanced renewables electricity mix scenario (Renew.) is applied on European electricity supply.

The different technology development scenarios result in different LCI data because of e.g., different underlying energy mix and different assumptions regarding the possible development of technologies.

The LCI data are based on the '440 ppm stabilisation scenario', as it basically represents current European policy targets.

Results are expressed as [Euro-Cent per kWh_{el}].

Total external costs are disaggregated into 4 life cycle stages, i.e. Construction, Operation, Fuel and Dismantling.

3.1. Technologies

The technologies investigated are partly different for the different scenarios, e.g. in

2025 RO the wind park has a size of 1,068 MW but in the 2025 VO 1,332 MW. Therefore, results for all technology configurations for the RO scenarios and years are listed in the result tables in the Appendix (Table 9 to Table 11). More detailed technical descriptions on the technologies can be found in the corresponding deliverables listed in Table 3 below.

Table 3: List of deliverables from RS1a on technical data, costs and LCI for each technology

D7.2 Final report on technical data, costs and life cycle inventories of advanced fossil fuels
D9.2 Final report on technical data, costs and life cycle inventories of fuel cell power plants
D10.2 Final report on technical data, costs and life cycle inventories of offshore wind farms
D11.2 Final report on technical data, costs and life cycle inventories of PV applications
D12.2 Final report on technical data, costs and life cycle inventories of solar thermal power plants
D13.2 Final report on technical data, costs and life cycle inventories of biomass power plants
D14.2 Final report on technical data, costs and life cycle inventories of nuclear power plants
D15.2 LCA of background processes
D16.1 Report on technical specification of reference technologies (wave and tidal power plant)

3.2. Locations

The location (expressed as coordinates latitude and longitude) and the effective height of release (stack height) of an emission has an influence on the corresponding impact. On the other hand results for a typical technology configuration and not for a certain single source such as a certain power plant are often needed. To conceal this trade-off technology specific average LCI data have to be combined with average, or generalised unit damage factors. For a first order approximation EU27 average unit damage factors, distinguished into factors to be applied to releases below 100 meter and above 100 meter, are applied to the LCI data for the life cycle process "operation" of the technology. Moreover, for the LCI data corresponding to the up- and downstream processes (construction, fuel supply, dismantling) EU27 average unit damage factors for all heights of release are applied.

For a country specific refinement of this approach the location of the power plants, i.e. the emission due to operation are assumed to take place in Belgium, France, Germany, Greece, Norway, Spain and UK.

These countries have been selected in order to cover central Europe but also Southern and Northern Europe. In principle, calculations can also be performed for all other countries.

3.3. Life Cycle Inventory (LCI)

For the present LCI data from (Krewitt, 2009) have been used. These cover smaller number of different typical or average technologies.

For the future scenarios the final version of NEEDS LCI has been used. The LCI data are downloaded at ESU services (Frischknecht, 2008). The LCI data corresponding to final Version 1.1 have been used (based on 440ppm-mix). A summary of the emission data can also be found in the corresponding deliverables listed in Table 3. It has to be noted that the LCI data correspond to average European conditions. Moreover, life cycle data of PV are subdivided to values for central Europe and values corresponding to technologies to be located in Southern Europe. Moreover, the concentrated solar power (CSP) technologies are also assumed to be located in Southern Europe.

Actually, the efficiency and therefore, the emissions per kWh and the internal generation costs of conventional and other renewable power plants will also differ from country to country. Also up- and downstream processes, e.g. fuel supply chains and corresponding emissions are different in real conditions. However, that is not reflected by the LCI data because they are not country dependent.

Figure 8 shows a comparison of the LCI data. The emissions and the land use are normalised by dividing values per kWh of the "Hard Coal Internal Gasification Combined Cycle 450 MW" power plant (HC_IGCC_450MW). It is shown that HC_IGCC_450MW performs better or worse than the "bio fuelled (poplar) steam turbine" on different pressures.

It becomes obvious that from this level of information a judgment regarding the overall environmental performance can not be made. Moreover, in order to make a reasonable comparison of the total costs to the society (i.e. private costs and external costs) the LCI data and the corresponding impacts have to be weighted and aggregated to external cost. Finally, this external cost can be added to the private costs to compare the total costs (social costs), and the advantages and disadvantages in a more comprehensible way.

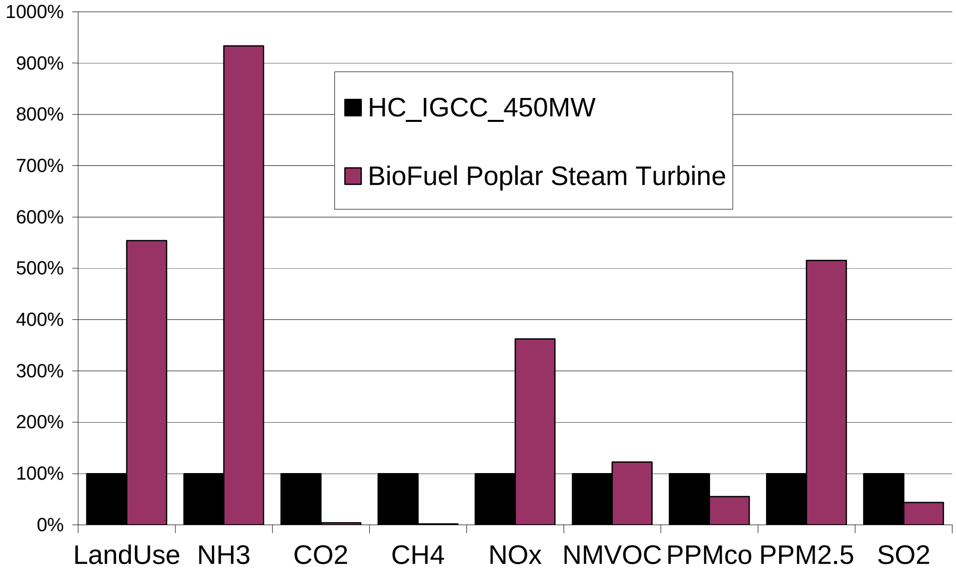


Figure 8: Example LCI data for two technologies

3.4. *External Costs of Transport of Oil and Gas and Transmission of Electricity*

The external costs of transport of oil and gas have been separately investigated in

NEEDS Rs1c and results have been reported in (FEEM and NTUA, 2007).

According to the report the resulting values are quite low, ranging from 2.32 Euro per tonne of fuel in 2030 in the “Low demand” scenarios to 2.60 Euro in 2010 in the high-demand-scenario.

Average direct cost of bringing oil to Europe is about 10 $/b (or about 70 $/t of oil). Present oil prices are in the order of 130 $/b or 950 $/t.

Thus externalities represent about 4-5% of direct cost and about 0.3 % of today’s prices (2% if the oil price was at 20 $/b).

The impact on local populations affected (e.g. fishery and oil spills) can be very substantial.

Within the Tasks 2.3-2.6. “Burdens, Impacts and Externalities from Natural Gas Chain” the following conclusions have been drawn:

“… operational externalities related to the extraction of natural gas for European consumption and to its transportation to Europe… has generated overall externality values which range between 0.32 Euro per tonne of natural gas… to 1.71 Euro per tonne of natural gas…”

ithin the calculations of total external costs of the NEEDS technologies the life cycle stage “fuel” is explicitly included in the calculation. This takes into account also emissions caused by fuel supply and incorporate also the emission of transport of oil and gas. The exact location of the emissions can not be explicitly reported.

In (Vito, 2007) the external costs of electricity transmission have been assessed. The following text has been extracted from this report. The study focuses on the quantification of priority impacts based on the available information from literature. It aims to get an idea of the orders of magnitude of the impacts and external costs and important factors. It focuses on

- the assessment of public health impacts from EMF for overhead lines,
- analysis of visual intrusion,
- life cycle impacts of construction phase and materials used.

Overall, the study indicates that the externalities of transmission are likely to be small compared to those of power generation if they are expressed per kWh consumed for a whole country or grid. Some impacts like visual intrusion and health impacts of EMF – both for EHV overhead lines - may be locally important. For a total grid, these impacts will be diluted as planning of overhead tries to avoid urban area’s and scenery landscapes.

The single most important contributor is likely to be losses of electricity due to transmission, which depends on technology, distance and external costs of generation. This impact may be important when considering individual technologies or trajectories, but cannot be used directly in other contexts without taking care for double counting.

The central estimate for external costs of visual intrusion per km line in urbanised area is of similar magnitude as the construction costs of overhead lines per km.

There is some evidence of impacts from electro magnetic fields of overhead lines on leukaemia in children that live very close (a few 100 metres) to these lines. There is some evidence of impacts from electro magnetic fields of overhead lines on leukaemia in children that live very close (a few 100 metres) to these lines.

Based on life cycle emissions associated with material use and construction of transmission overhead lines and cables. the external costs results show that these costs are around 8 k€/ km overhead line, which corresponds also to a few % of internal construction costs.

3.5. Generalised Approach – Country Specific Operation

External costs are calculated by multiplying the relevant life cycle inventory data expressed as "kg per kWh", "kBq per kWh" or "m^2 per kWh" with the country and time dependent unit external costs derived in Research Stream 3a (Preiss et al., 2008) for the corresponding lifecycle stage. Since LCI data are disaggregated into up- and downstream processes (construction, fuel supply and dismantling) on the one hand, and operation phase on the other hand, it is possible to apply for the operation of large fossil fuelled power plants the unit external costs corresponding to emission from SNAP (Selected Nomenclature for Air Pollution) sector 1 (i.e., sector "Combustion in energy and transformation industry"). This does reflect the dispersion from relatively high stacks and takes into account the actual spatial distribution of plants for combustion in energy and transformation industry. For all other technologies for the operation phase the unit external cost factors corresponding to emissions below 100 meter are applied.

The emissions due to operation phase are assumed to take place in specific countries. Country specific results are provided for Germany, France, UK, Greece, Spain, Belgium and Norway. Moreover, a EU27 average has been calculated, too.

The exact locations of most processes included in the LCI calculation are very difficult, and partly impossible to identify and hence, not explicitly reported in (Frischknecht, 2008). For example, emissions caused by processes summarised in the life cycle stage "construction" incorporated e.g., emissions due to steel and copper production. These emissions partly occur even outside of Europe. Moreover, there is no detailed information on the stack height of releases available. Therefore, because of lack of more detailed information the emissions due to up- and downstream process are valued by the Eu27 average unit external cost factors. These external cost factors for the main air pollutants are displayed in Table 4 (all sectors). For comparison also the damage factors derived for emissions only from SNAP sector 1 are included. It can be seen that especially the damage factors for primary particulate matter are sensitive towards the sector specification. For NH3 and NMVOC no S1 values have been calculated – therefore, the damage factors for "all sectors" are used to.

It has to be noted that for 2010 on the one hand, and for 2025 and 2050 on the other hand the external costs are based on different background emission scenarios and hence, on results of different dispersion and chemical transformation. This is the reason why the costs per tonne of NH_3 or NMVOC in 2010 are higher than in 2025 although the costs per tonne of NOx or SO_2 are smaller in 2010 than in 2025.

Table 4: Unit external costs for main air pollutants – Eu27 average [€$_{2000}$ per tonne] – discounted to the year of release (source: NEEDS Research Stream 3a)

€/t	**2010**		**2025**		**2050**	
Emiss. to air	**All Sectors**	***SNAP S1***	**Av. height**	***SNAP S1***	**Av. height**	***SNAP S1***
NH_3	15,078	15,078	13,961	13,961	18,043	18,043
NMVOC	1,220	1,220	934	934	1,174	1,174
NOx	8,286	6,302	12,176	10,072	15,544	12,867
PPM_{CO} (2.5-10 µm)	1,570	582	2,108	737	2,717	950
$PPM_{2.5}$ (< 2.5	29,081	14,693	36,977	18,421	47,649	23,738

€/t	2010		2025		2050	
µm)						
SO2	7,951	7,295	11,106	9,697	14,252	12,440

The variability of external costs per tonne of pollutant between the European countries is exemplified in the Figure 9 till Figure 13 for the year 2025 and emissions from all sectors. The values span the following ranges in Euro per tonne.

External costs [€ / tonne]	Min	Max
PPM2.5	3,546 (Norway)	29,073 (Belgium)
NOx	405 (Bosnia/Hercegovina)	2,020 (Belgium)
NH3	2,175 (Portugal)	26,348 (Switzerland)
SO2	293 (Estonia)	4,281 (Netherland)
NMVOC	8,867 (Norway)	72,138 (Belgium)

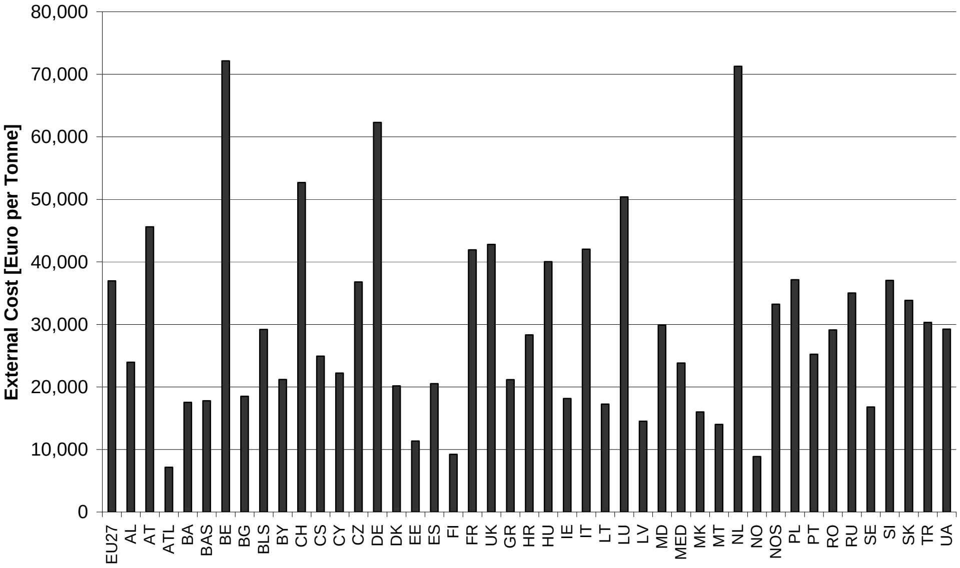


Figure 9: Euro per tonne for PPM2.5 Eu27 average and country specific values in 2025

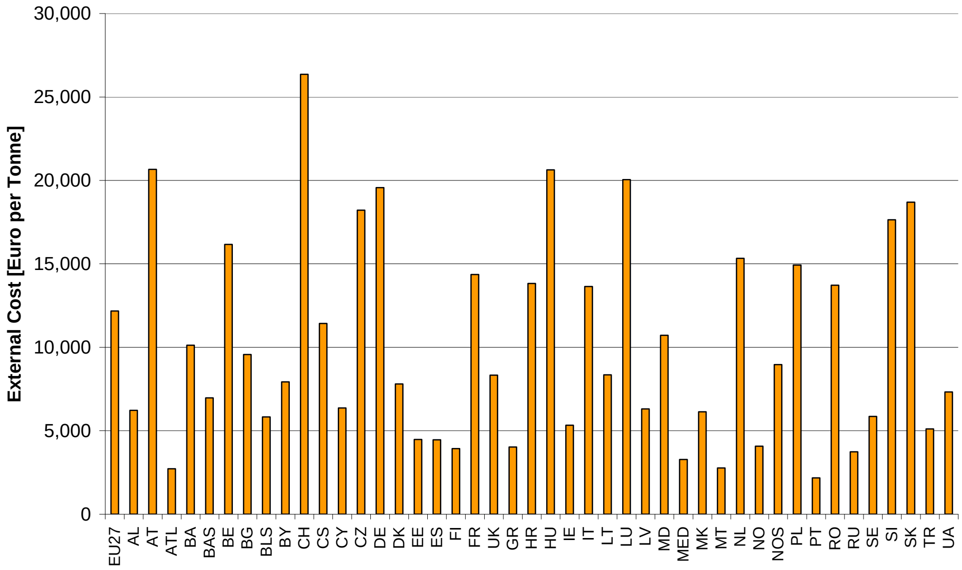


Figure 10: Euro per tonne for NOx Eu27 average and country specific values in 2025

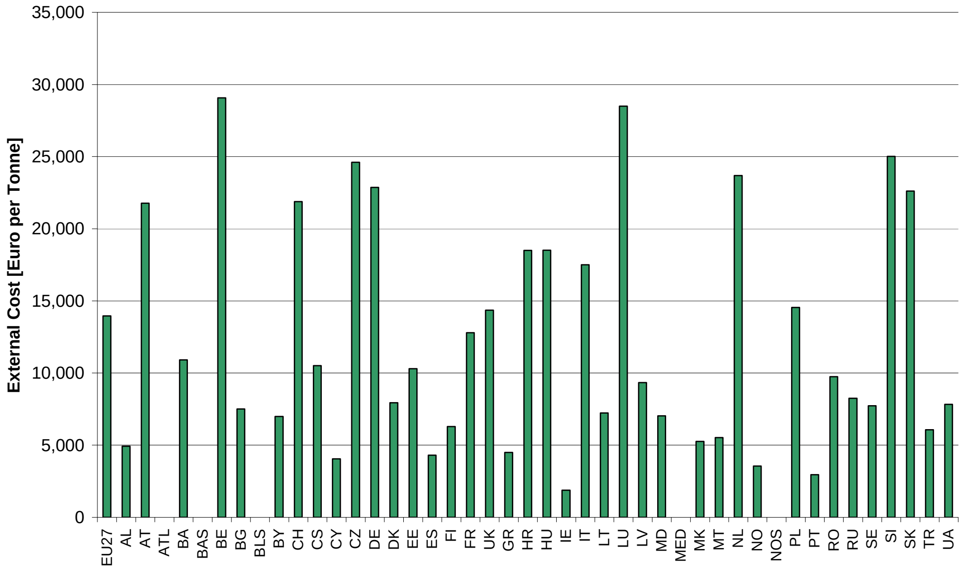


Figure 11 Euro per tonne for NH_3 Eu27 average and country specific values in 2025

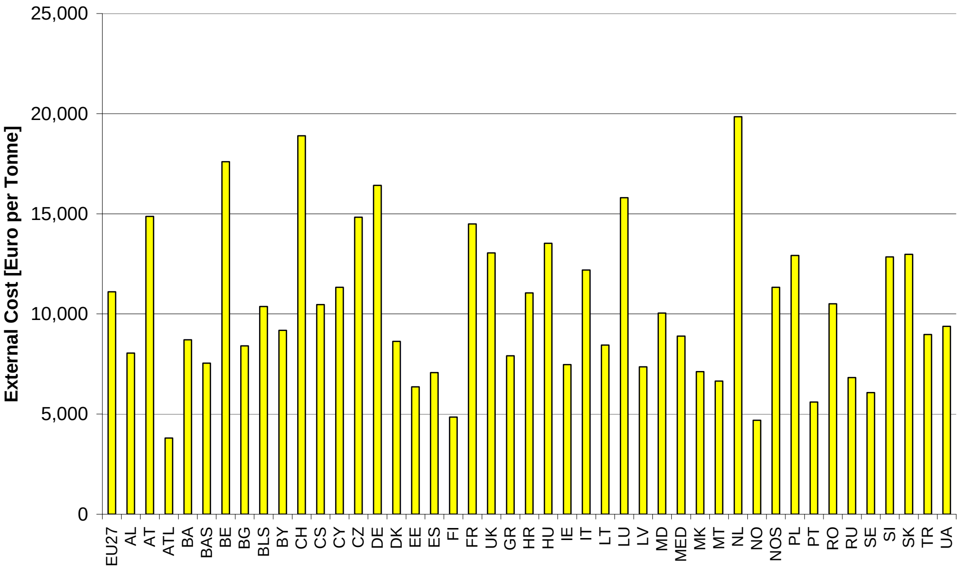


Figure 12: Euro per tonne for SO_2 Eu27 average and country specific values in 2025

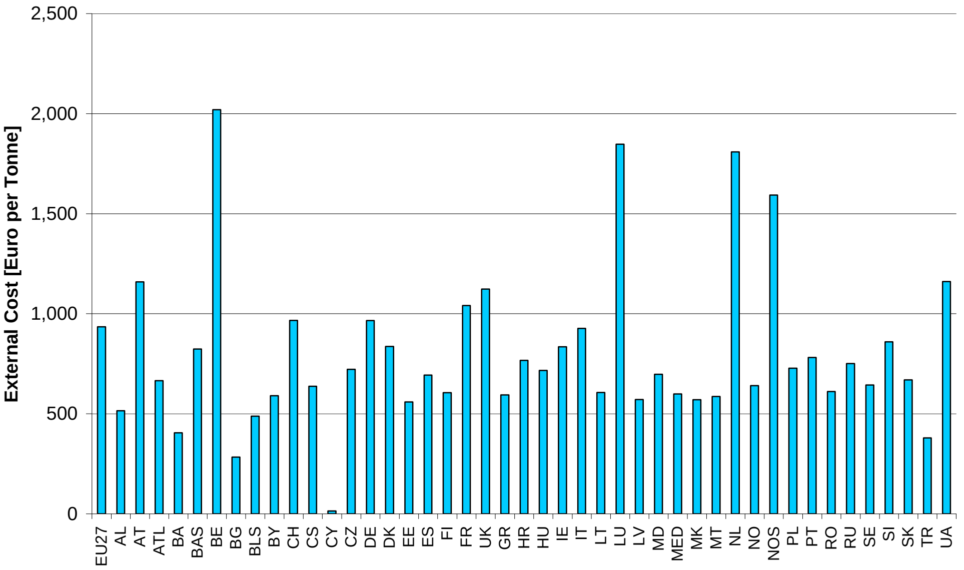


Figure 13: Euro per tonne for NMVOC Eu27 average and country specific values in 2025

The influence of different background emission scenarios is illustrated in Figure 14 for each country. The relation between damage costs per tonne (with regard to emissions from all sectors and the impacts to human health) based on the present and the future background emission scenario is shown for the three main pollutants NH_3, SO_2 and NO_x. The relation is calculated by dividing the damage per tonne for the present by the damage per tonne in the future. A value above 1 indicates that in the present the physical impact per tonne emission is higher than in the future (i.e. total exposure due to concentration of secondary pollutants is higher).

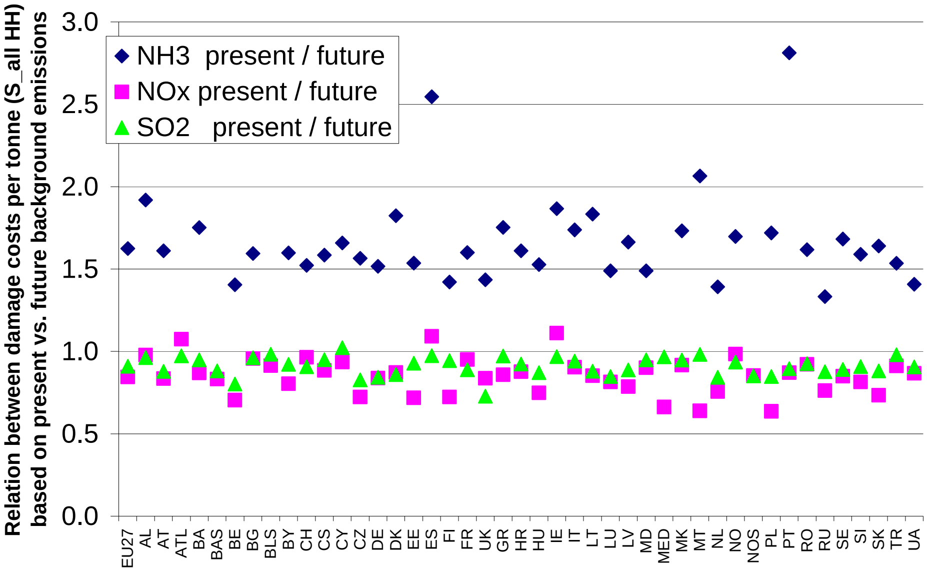


Figure 14: Relation between damage costs per tonne (S_all HH) based on present vs. future background emissions – main pollutants NH3, SO2, and NOx

The relation with regard to NMVOC emissions, which is one precursor for ozone creation, is shown in Figure 15. It can be seen that the difference between damage costs based on the two background emission scenarios are much higher.

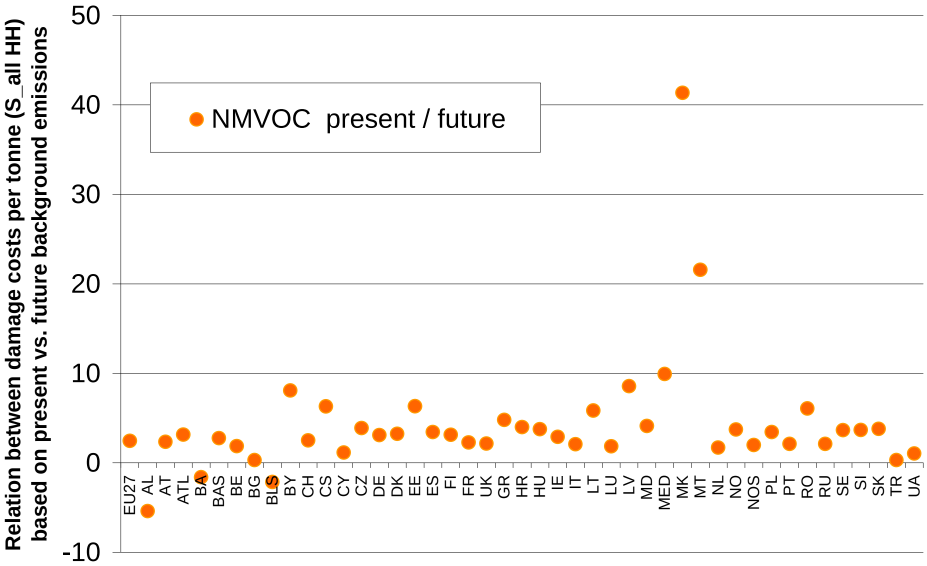


Figure 15: Relation between damage costs per tonne (S_all HH) based on present vs. future background emissions – main pollutant NMVOC

Technology specific external costs per kWh are calculated by multiplying the relevant life cycle inventory data expressed as “kg per kWh”, “kBq per kWh” or “m² per kWh” with appropriate country and time dependent unit external costs factors.

3.6. Evaluation of Greenhouse Gas Emissions and Climate Change

Within NEEDS Rs1b WP5 new model runs with the updated FUND3.0 regarding the evaluation of greenhouse gas emissions and the corresponding climate change have been conducted. The results were presented for different assumptions regarding the main influencing parameters, i.e. the question of equity weighting and discounting. Based on these results and taking into account all relevant studies on this topic by taking results of different meta-analyses into account there have been lively discussions among NEEDS partners on how to quantifying a reasonable range of monetary values to be used within NEEDS. Finally, the NEEDS coordinator summarised the input from all research streams and proposed the use of two different scenarios, i.e. two sets of unit external cost factors regarding greenhouse gases.
These two sets are called Scenario I and Scenario II.

Table 5: Recommended values for GHG

[Euro2005 per tonne CO2eq]	2010	2015	2025	2035	2045	2050
Scen I	23.5	31	51	87	146	198
Scen II	23.5	27	32	37	66	77

A description on how recommended values should be derived has been provided by (Friedrich, 2008). Moreover, reasoning for using these values has been provided by the NEEDS coordinator in the following way:
Scenario 1 (ambitious, reflecting policy targets) is in fact a direct and smooth combination of the more ambitious scenario proposed by RS1b and of the preferred scenario proposed by RS1a, which are almost identical in the first place. Moreover, the 2050 value (198 €/t) is fully consistent with the values proposed by (Kuik et al., 2008) and the value recommended by the recent CAS study (France), while the values proposed for 2020 and 2030 are not very far from those proposed by the recent JRC study.
Scenario 2 (more realistic) is directly inspired by the post-Kyoto scenario proposed by (Friedrich, 2008). It also turns out to be almost half way between the values proposed by (Anthoff, 2007) in his “WorldAverage EW” scenario and the averages proposed by Watkiss.
All calculations/modelling in NEEDS should be made with both these sets and results should be reported.

3.7. Evaluation of Land Use due to Transformation

The impact due to transformation of land is mainly relevant for the technologies using poplar or wood gas. Short rotation forestry (SRF) is applied for rapidly growing woods, which are felled at intervals of several years and shoot again. The poplar is a tree with a particularly high yield.
The land used for poplar growing is defined as: “..to forest intensive short cycle”. For the following valuation it is assumed that the biodiversity of poplar forestry can be compared with the biotope group listed in (Ott et al., 2006) called “Conventional / intensive arable”.
Therefore, for the different categories of transformation the monetary values listed in

Table 6 are applied.

Table 6: Categories of "transformed" area and corresponding monetary value for estimation of external costs (European average)

Resource	**Euro$_{2004}$ per m2**
Transformation, from arable, unspecified	0.17
Transformation, from arable, intensive	0.17
Transformation, from forest, unspecified	2.66
Transformation, from pasture and meadow, unspecified	1.9
Transformation, from pasture and meadow, extensive	1.9
Transformation, from pasture and meadow, intensive	1.9
Transformation, from shrub land, sclerophyllous	1.9
Transformation, from unknown	0.17

The external costs of the technologies "electricity, at steam turbine (poplar), emission ctrl., Centr. EU, alloc. Exergy" and "electricity, at MCFC CHP 250kW, from wood gas" are quite sensitive to the valuation of the "Transformation, from unknown" because the area per kWh is relatively large (ca. 0.03 m² per kWh). The available values in (Ott et al., 2006) range up to 8.39 Euro$_{2004}$ per m² for restoration to the biotope category "Forest edge". Since the starting biotope is defined as "unknown" a part of the transformed area can be a biotope with a higher biodiversity than poplar forestry (which has a lower biodiversity). Another part can also called to be a restoration activity changing for example, an industrial area into poplar forestry which has surely a slightly higher biodiversity. The later would even be an external benefit, i.e. cause negative external costs. However, the largest share of transformed area will be arable areas which have a biodiversity which is not very different from the biodiversity of growing polar. Therefore, the relatively low value of 0.17 Euro per m² damage costs is used to evaluate the area categorised as "transformation from unknown". In this case the external costs caused by land use are still dominated by the category "transformation from unknown".

The monetary values listed in Table 6 correspond to the European average of restoration costs, which are used as a best guess for the willingness to pay to avoid the impact of lost biodiversity. In a sensitivity analysis for country specific costs one could use country specific values which are PPS (Purchasing Power Standard) adjusted.

For the calculation of external costs within NEEDS it is assumed that the willingness to pay for avoiding impacts to human health and biodiversity will increase in the future because of economic growth. For the adjustment of the monetary values in Table 6 a factor of ca. 1.5 for the external cost in 2025 and a factor of ca. 2 for 2050 is applied.

3.8. Results for NEEDS Technologies

The results are expressed in Euro$_{2000}$ prices and correspond to external costs in the defined years i.e. for the present in 2010, for the future scenarios in 2025 and 2050, respectively (but still expressed in Euro$_{2000}$ prices).

3.8.1. Present (2010)

In Figure 16 the external costs of newly build technologies are displayed. For the large hard coal (HC) and lignite (Lig) power plants, as well as for the 400 MW natural gas (NG) power plants a stack height above 100 meter is assumed.

The external costs are sub-divided into the contributions of greenhouse gase (GHG), impacts to human heath due to the main (classical) air pollutants SO_2, NOx, $PPM_{2.5}$ and PPMco, NH_3 and NMVOC (Human Health class), impacts to crops, materials and biodiversity (Crop_Mat_BioDiv), impacts on the biodiversity due to land use, i.e. transformation (Land Use), and impacts to human health due to heavy metals, organic substances and radionuclides (HH_others). The evaluation of greenhouse gases according to the Scenario 1 and Scenario 2 is identical because in 2010 the suggested value is 23.5 $Euro_{2005}$ per tonne CO_{2eq} in both cases.

Moreover, in Figure 17 the contribution of different life cycle stages is divided into external costs due processes during construction, operation, fuel supply and dismantling are illustrated.

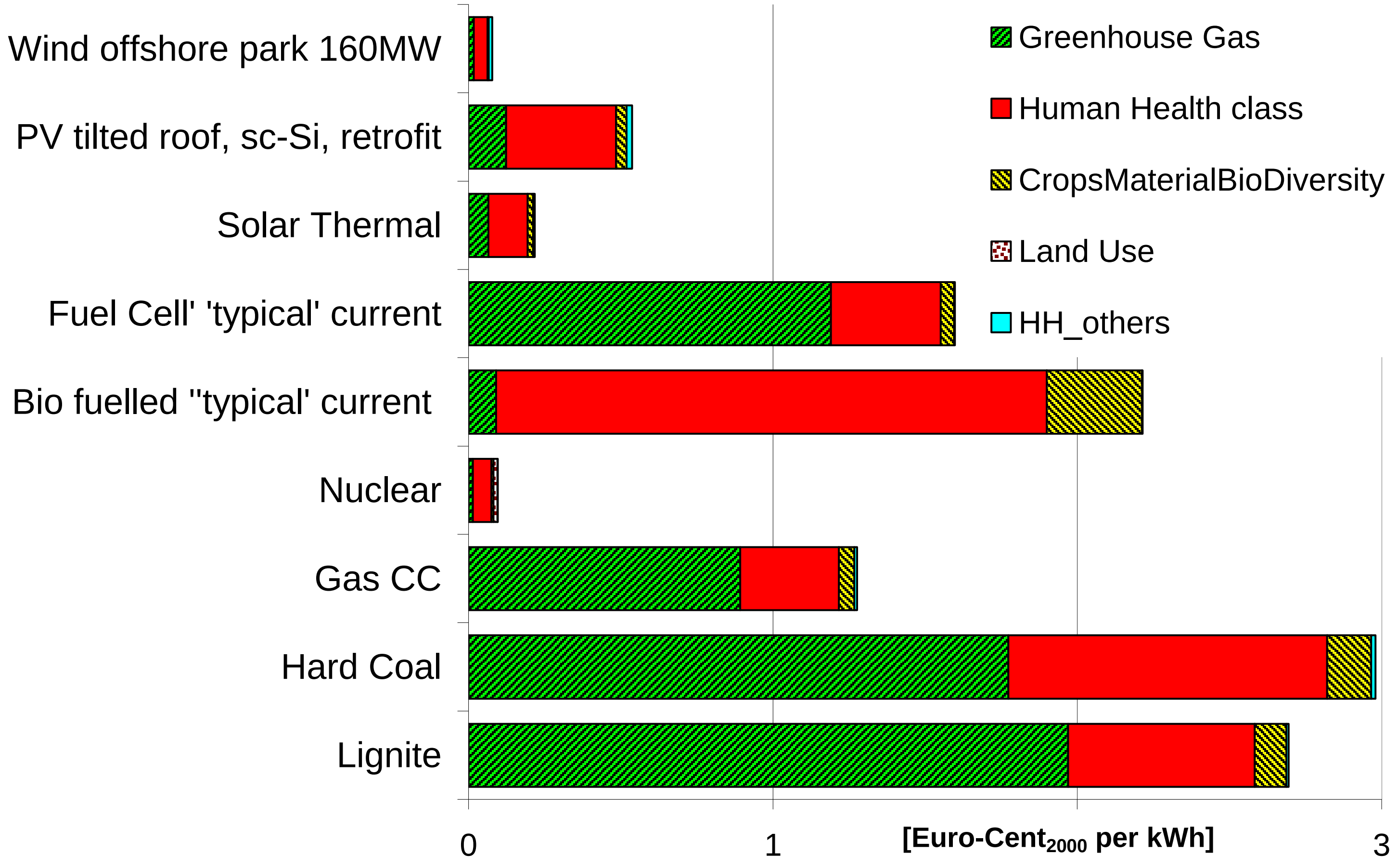


Figure 16: External costs for typical present technologies – operation in Eu27

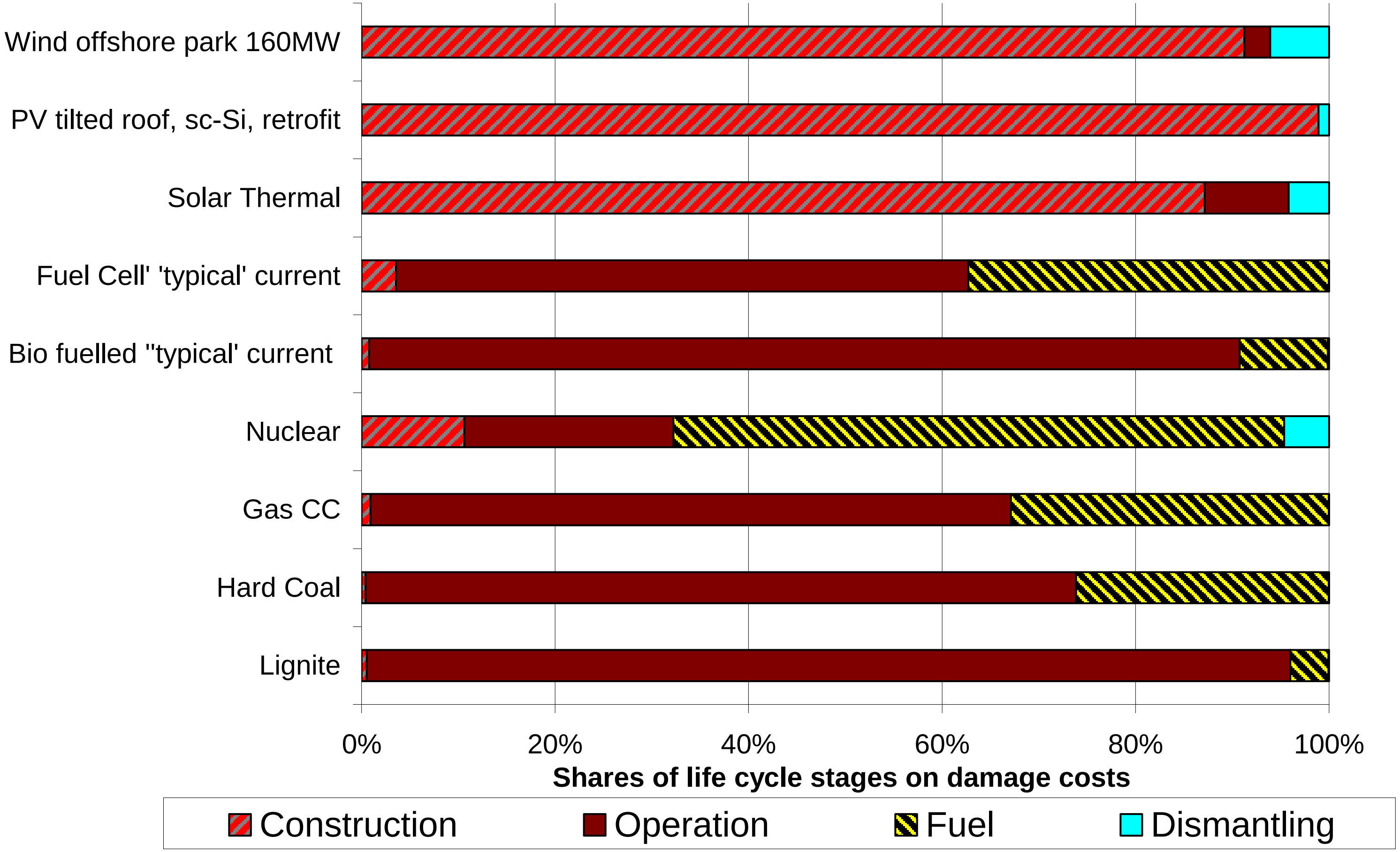


Figure 17: Shares of different life cycle stages on external costs for typical present technologies – operation in Eu27

In Figure 16 can be seen that the conventional fossil fuelled power plants have quite high external costs due to the emission of greenhouse gases. On the other hand the bio fuelled technologies have low net emissions of greenhouse gases (i.e. low fossil greenhouse gas emission) but relatively high emission of main air pollutants and high external costs due to land use (or rather, land transformation). The renewable technologies wind, photo voltaic (PV) and solar thermal, i.e. concentrated solar power (CSP), and the nuclear power have very low external costs.

3.8.2. Future configurations 2025

The external cost results for selected technologies available in the year 2025 are displayed in Figure 18. For one PV configuration the value for operation in Central Europe and South Europe is shown. However, for all other PV configurations the relation is similar because of the same ratio of efficiency due to different sun radiation.

The evaluation of greenhouse gases (GHG and GHG_high) shows the values for Scenario 2 (GHG) and on top the addition costs if Scenario 1 is assumed (GHG high).

With regard to different CCS configuration for each technology there are results for storage in “depleted gasfield” (200 km distance and 2500 m depth and 400 km distance and 2500 m depth), and storage in “aquifer”(200 km distance and 800 m depth, and 400 km distance and 800 m depth). However, the external costs of these configurations vary only little.

Power plant (PP) configuration	Corresponding short cut
PP with CCS, 200 km & 2500 m depl. gasfield	= PP with CCS_A_dep_gasfield
PP with CCS, 400 km & 2500m depl. gasfield	= PP with CCS_B_dep_gasfield
PP with CCS, 200 km & 800 m aquifer	= PP with CCS_A_aquifer
PP with CCS, 400 km & 800 m aquifer	= PP with CCS_B_aquifer

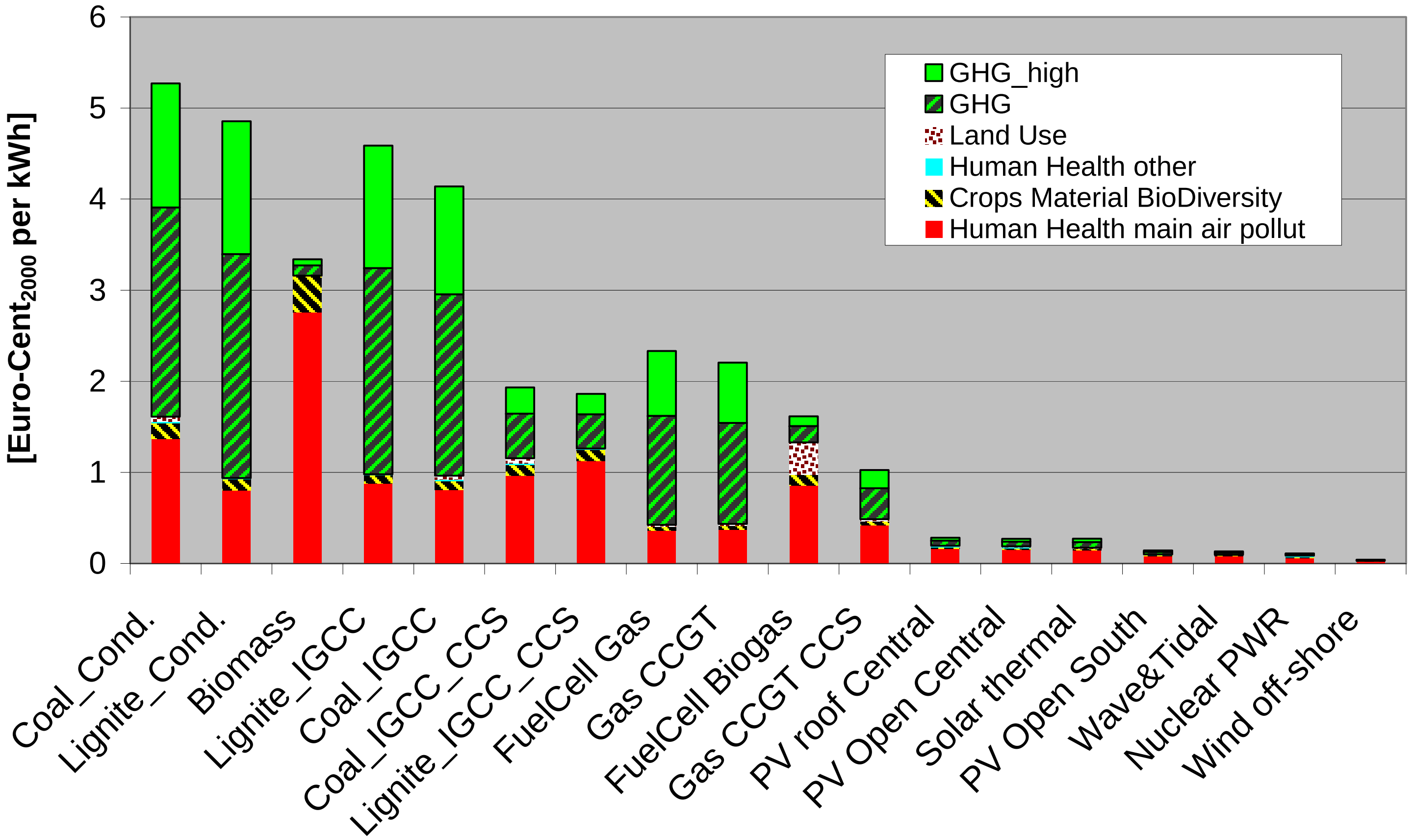


Figure 18: External costs in 2025 (RO) - operation in Eu27

In the Appendix in Table 10 results for all available technologies for the RO scenario are listed. In Table 7 the total external cost of the different technologies are summarised in order to show the range within one certain type of technology. Since the shares within the future energy mix is not know the average is just an arithmetic mean of the available LCI data.
The "values used" correspond to the selected technologies for which internal costs are available.

Table 7: External costs ranges of different configurations of technologies and values used in Figure 18

	GHG Scenario I				GHG Scenario II			
Technology	**Min**	**Max**	**Average**	**Values used**	**Min**	**Max**	**Average**	**Values used**
hard coal IGCC_CCS	1.92	3.18	2.34	1.93	1.63	2.78	2.04	1.64
hard coal IGCC	4.14	4.14	4.14	4.14	2.96	2.96	2.96	2.96
hard coal	5.27	5.27	5.27	5.27	3.91	3.91	3.91	3.91
lignite IGCC_CCS	0.85	2.44	1.86	1.86	0.77	2.13	1.63	1.64
lignite IGCC	4.59	4.59	4.59	4.59	3.24	3.24	3.24	3.24
lignite	4.85	4.85	4.85	4.85	3.40	3.40	3.40	3.40
Natural gas	2.20	3.26	2.82	2.20	1.54	2.31	1.99	1.54
Natural gas CCS	1.03	1.03	1.03	1.03	0.82	0.82	0.82	0.82
Nuclear	0.02	0.12	0.08	0.11	0.02	0.11	0.08	0.10
Bio fuel steam turbine	3.34	3.59	3.47	3.34	3.27	3.48	3.38	3.27
Fuel Cell	1.61	5.43	3.10	1.61 & 2.33	1.51	3.77	2.24	1.51 & 1.62
Wind Off Shore	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
PV Central	0.13	0.28	0.24	0.27	0.12	0.25	0.22	0.24
PV South	0.07	0.15	0.13	0.14	0.06	0.13	0.11	0.13
CSP	0.15	0.44	0.29	0.27	0.13	0.38	0.25	0.23
Wave&Tidal	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12

The differences between the technology scenarios are illustrated in Figure 19. This is base on application of GHG Scenario II. The results of external costs in 2025 (all operation in Eu27) of the scenarios PE and VO are compared relative to the results for RO. This is done by dividing the external costs of PE and VO by RO and subtracting 1. Hence, a negative value means: lower external costs than compared to "Realistic / Optimistic" scenario, a positive value means: higher external costs than compared to "Realistic / Optimistic" scenario.
One has to bear in mind that some technologies are not identical. For example, the size of the wind parks is different:
PE_2025 = 752 MW
RO_2025 = 1068 MW
VO_2025 = 1332 MW.

The bars corresponding to “PE 2025” are mainly positive; the bars corresponding to “VP 2025” are mainly negative. However, for “offshore wind park” the technology in VO has higher external costs than in the RO.

The technology “lignite IGCC 450 MW w/o CCS” VO has noticeable improvements from RO to VO.
Also, the technology “lignite 800 MW class oxfy CCS_B_aquifer” VO has noticeable improvements compared to RO.
There is no difference between PE and RO for many hard coal and lignite technologies.
The PV technologies improve from PE to RO very much, but not so much from RO to VO.

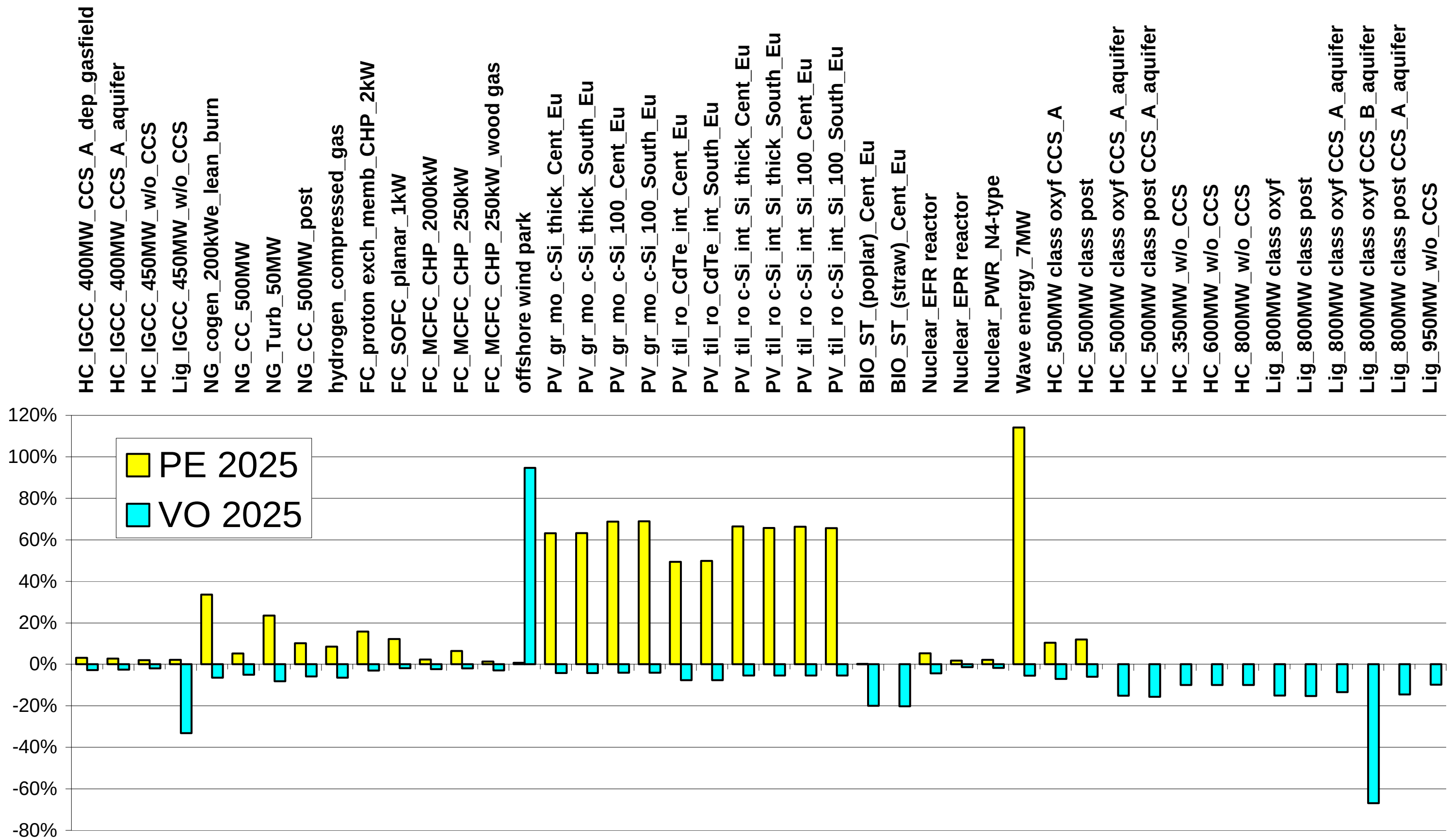


Figure 19: Relative difference of external costs of the scenarios PE and VO compared to RO in 2025 (operation in Eu27)

The next step is the calculation of external cost by multiplying the emissions from life cycle stage “operation” with country specific average external costs for all site dependent pollutants. This is done for a selection of countries ranging from high country specific costs to the low once. The countries Belgium, France, Germany, Greece, Norway, Spain and UK are selected to demonstrate the influence of the operation site.

For the technologies which have very small emissions in the operation phase, i.e. fuel cells, PV, CSP and wind energy converter the difference of external cost under application of country specific or application of EU27 average external costs, is close to zero.
However, as shown in Figure 20 and Figure 21 for the fossil fuelled and the bio fuelled power plants the difference can be up to plus 50% in Germany and minus 60% in Norway. The influence on the social costs and the ranking of technology is shown is be demonstrated in Chapter 4.

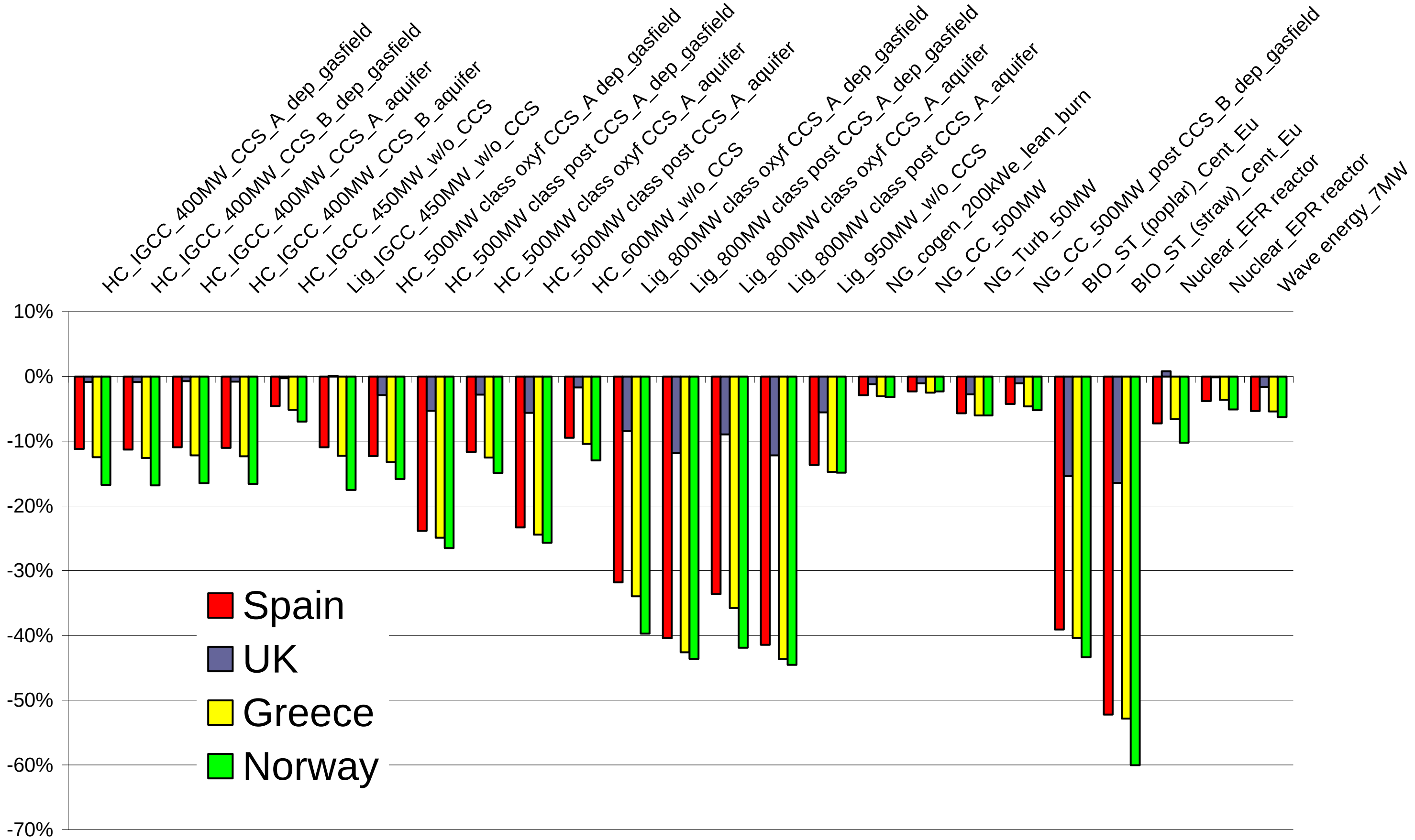


Figure 20: Relation of country specific ext. costs per kWh compared to EU27 aveage (selection of countries with lower costs) in 2025

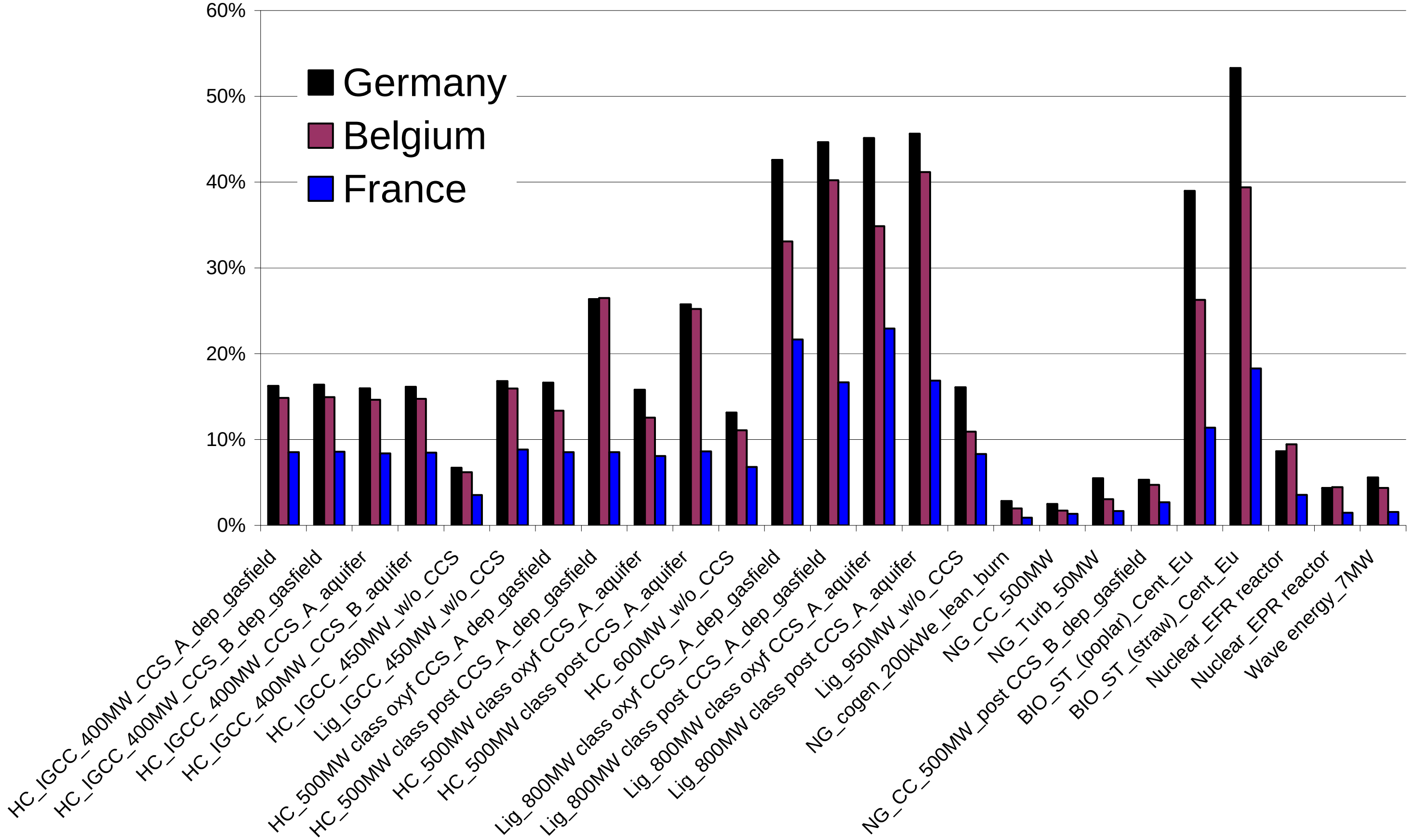


Figure 21: Relation of country specific ext. costs per kWh compared to EU27 aveage (selection of countries with higher costs) in 2025

3.8.3. Future configurations 2050

In analogy to the results for the year 2025 in Figure 22 the external cost results are listed for selected technologies operating in the year 2050. In the Appendix in Table 10 results for all available technologies for the RO scenario are listed.

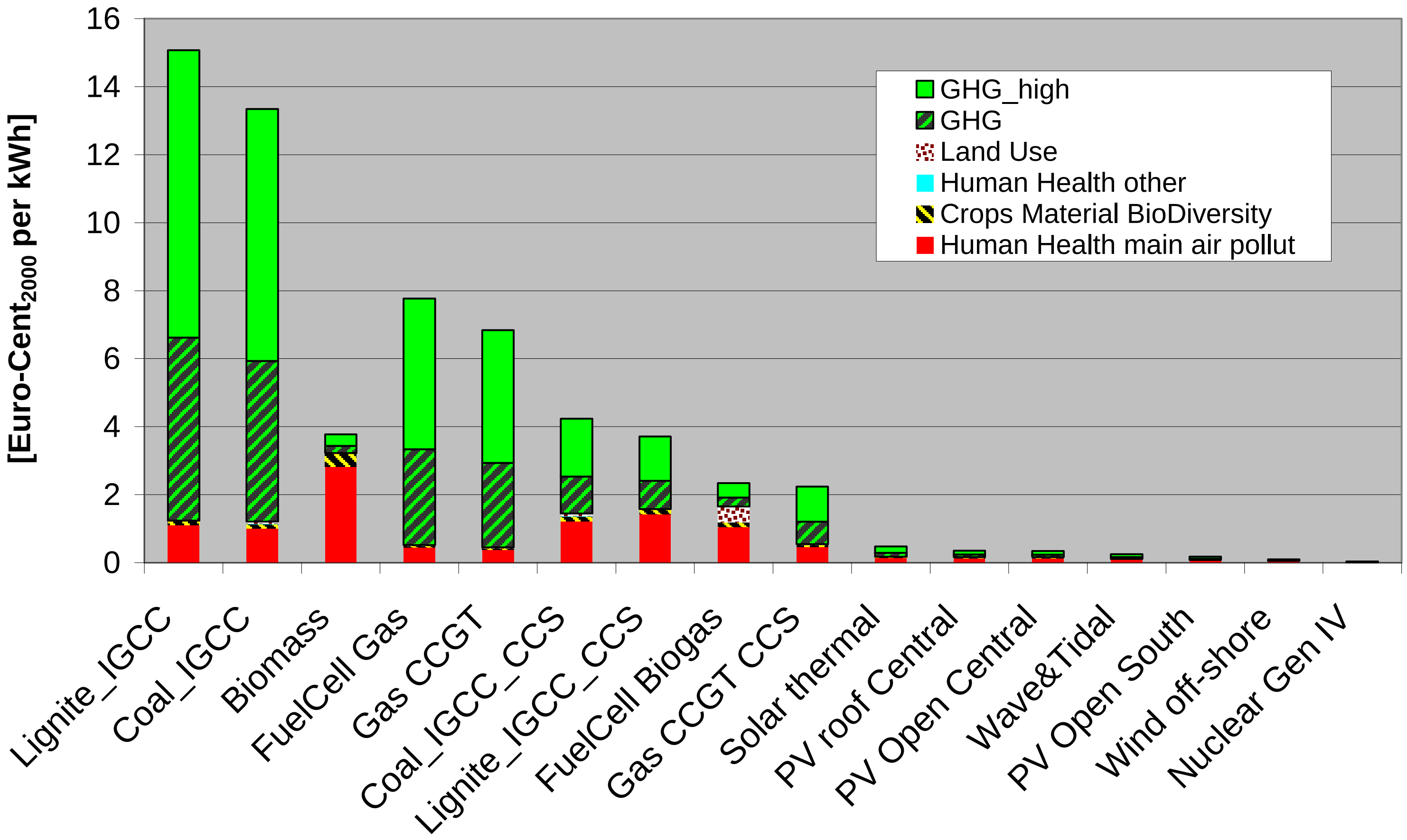


Figure 22: External costs in 2050 (RO) operation in Eu27

In the Appendix in Table 11 results for all available technologies for the RO scenario are listed. In Table 8 the total external cost of the different technologies are summarised in order to show the range within one certain type of technology. Since the shares within the future energy mix is not know the average is just an arithmetic mean of the available LCI data.
The "values used" correspond to the selected technologies for which internal costs were available or which probably will preferred compared to the other configurations.

Table 8: External costs ranges of different configurations of technologies and values used in Figure 18

GHG Scenario I					GHG Scenario II			
Technology	**Min**	**Max**	**Average**	**Values used**	**Min**	**Max**	**Average**	**Values used**
hard coal IGCC_CCS	3.05	5.15	4.16	4.24		2.08	3.34	2.66
hard coal IGCC	13.34	13.34	13.34	13.34		5.93	5.93	5.93
hard coal	14.06	14.07	14.06	not used		6.56	6.56	6.56
lignite IGCC_CCS	1.16	3.82	2.89	3.71		0.86	2.47	1.92
lignite IGCC	15.07	15.07	15.07	15.07		6.62	6.62	6.62
lignite	14.20	14.20	14.20	not used		6.16	6.16	6.16
Natural gas	6.84	9.64	8.59	6.84		2.94	4.12	3.69
Natural gas CCS	2.24	2.24	2.24	2.24		1.20	1.20	1.20
Nuclear	0.03	0.21	0.14	0.03		0.02	0.16	0.11
Bio fuel steam turbine	3.77	4.31	4.04	3.77		3.44	3.74	3.59
Fuel Cell	1.85	17.93	8.53	2.34 & 7.77		1.50	7.65	3.93
Wind Off Shore	0.10	0.10	0.10	0.10		0.07	0.07	0.07
PV Central	0.00	0.37	0.24	0.35		0.00	0.25	0.17
PV South	0.00	0.19	0.12	0.18		0.00	0.13	0.08
CSP	0.28	0.57	0.44	0.47		0.16	0.35	0.27
Wave&Tidal	0.25	0.25	0.25	0.25		0.16	0.16	0.16

The “social” costs (also called “real” or “full” costs) are calculated by addition of private cost also expressed as [Euro-Cent per kWh] to the external costs. The results are presented in Chapter 4.

3.9. Discussion on Uncertainties of External Costs

The estimation of external costs includes different models and therefore, different levels of uncertainty. The uncertainties have been discussed and quantified in the corresponding reports of Rs1b, Spadaro and Rabl (2007) and Rs3a, Spadaro and Rabl (2008).

As a rule of thumb the range of possible results (67% confidence interval) is estimated as to be ca. one third and up to three times the average values of external costs for main air pollutants. Regarding the estimates for heavy metals or impacts due to climate change this factor is even higher.

In order to show the influence of this uncertainty a factor of 2.5 and 0.4 will be applied and the influence on the ranking of technologies with regard to the social costs will be shown.

Due to application of generalised values, i.e. emission weighted country specific averages values the results are country specific averages. However, within each country the actual external costs of a certain power plant depend on the location. The range depends on also on the size of the country. This influence has been demonstrated in Chapter 2.

4. Influence of Country Specific External Costs of Operation on the Social Costs

Based on a range of European average private costs results (Preiss and Blesl, 2009) the social costs have been calculated for selected technologies in order to illustrate a corresponding ranking of future technologies in 2025 and 2050.

This has been done firstly, by using European average LCI data and application of Eu27 average damage factors for all emissions, i.e. assuming that also the emissions due to the operation phase take place dispersed in the Eu27 region. Secondly, results are provided based on the assumption that the emissions due to the operation phase take place in different countries, namely: Belgium, Germany, Great Britain, Greece, France, Norway and Spain.

In the following Figures the social costs of typical average technologies in 2025 and 2050 are presented in diagrams.

Bars show quantifiable social costs for technologies with the first year of operation in the year 2025 or 2050. Social costs are private cost plus external costs.

However, both summands span a range of uncertainty. The external costs include greenhouse gases (GHG) and other quantifiable externalities. The external costs of GHG are based on certain values for 2025 and 2050, as shown in Table 5. The blue bars exemplify the range of social costs based on the “best guess” of external costs plus the lower and the upper range of private costs. The red lines indicate the

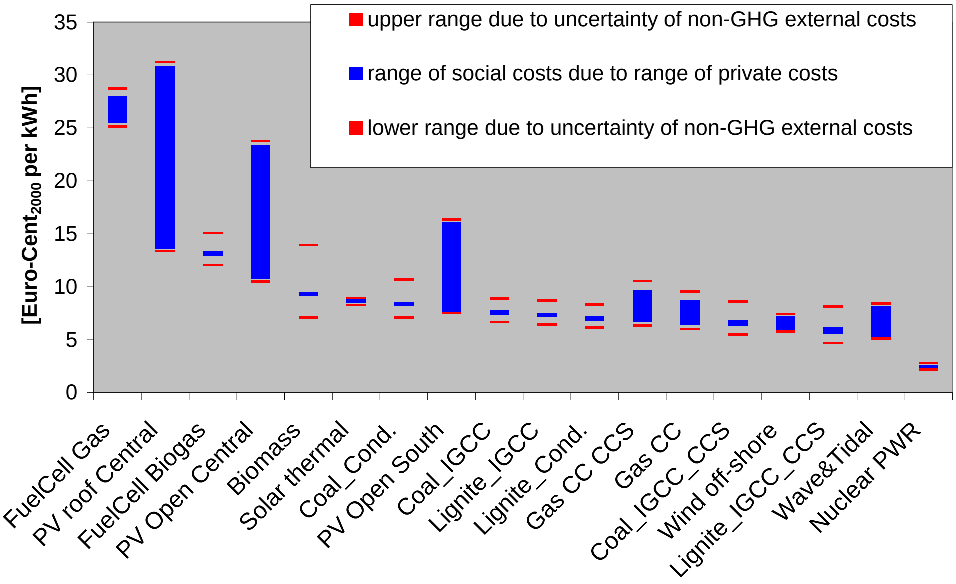
uncertainty range of external costs of non-greenhouse gases (i.e. application of factor of 2.5 and 0.4 to the external cost values).
The external costs are based on LCI data (RS1a) corresponding to the “440ppm” and Realistic / Optimistic scenario. Risk aversion is not included.
The private costs are based on 5 % discounting.
The range of values of private costs:
The lower end of the range represents values from the NEEDS stream 1a realistic-optimistic scenario. The upper bound uses

- a realistic but less optimistic estimation for renewables
- 70% higher prices for natural gas
- doubling of estimated costs for carbon transport and storage
- 20% (2025) respectively 80% (2050) higher investment costs for nuclear.

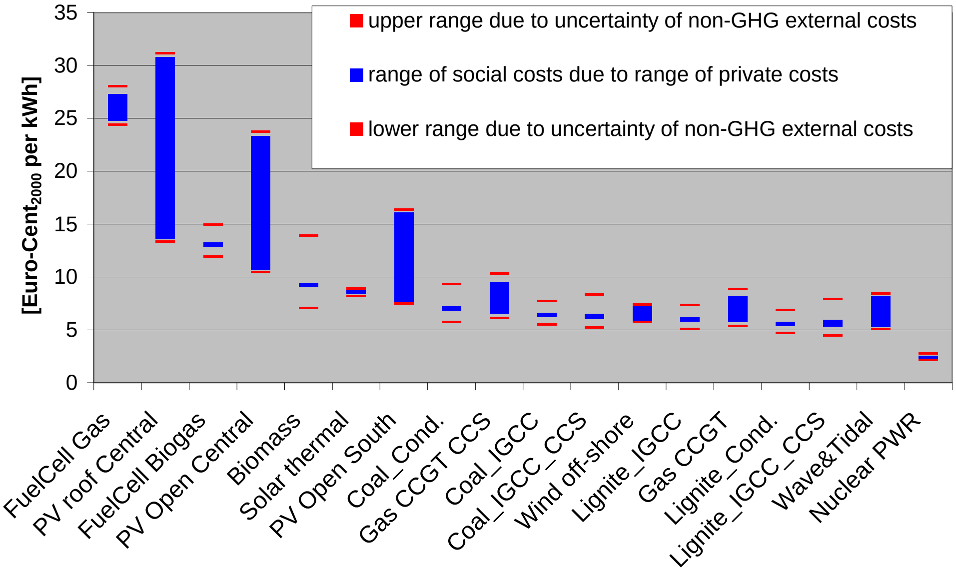
It has to be born in mind that all values, but especially the once for year 2050 are highly uncertain due to long time span in the future.

4.1. Future configurations 2025

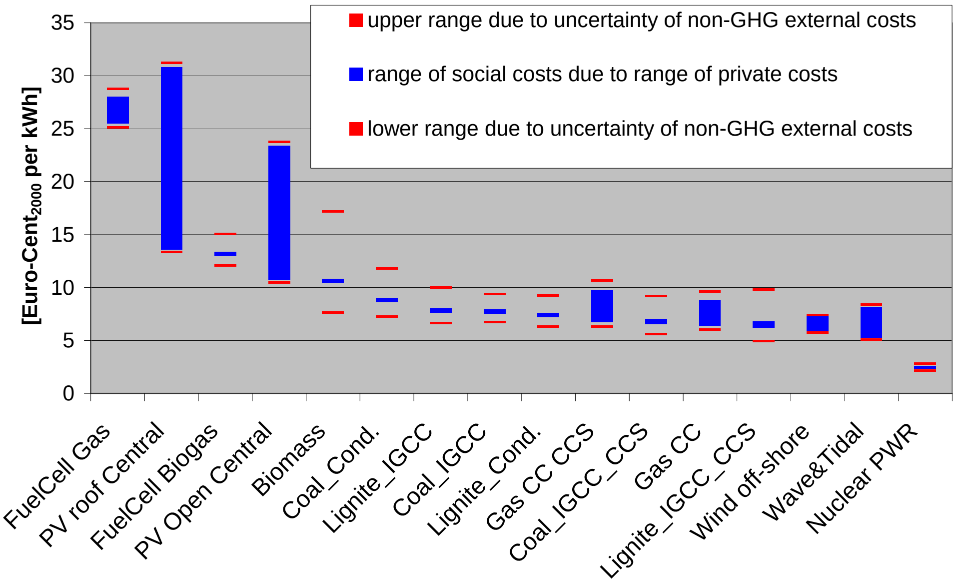
4.1.1. Eu27 – GHG Scenario I) in 2025



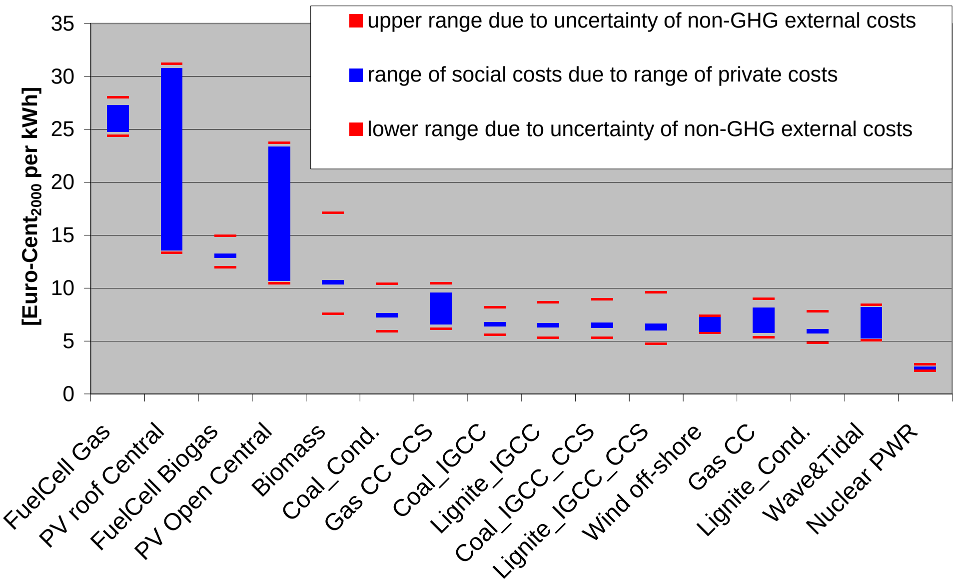
4.1.2. Eu27 – GHG Scenario II) in 2025



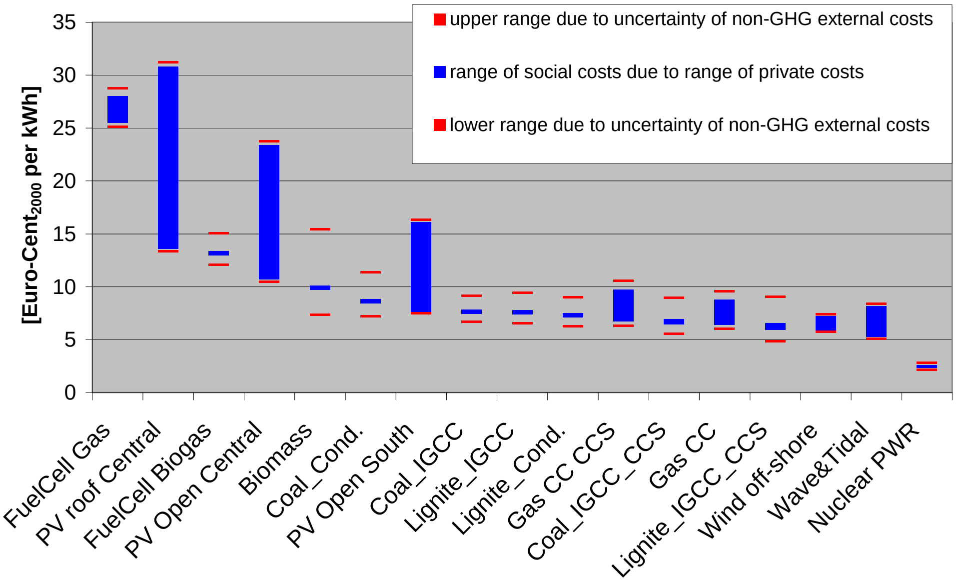
4.1.3. Belgium – GHG Scenario I) in 2025



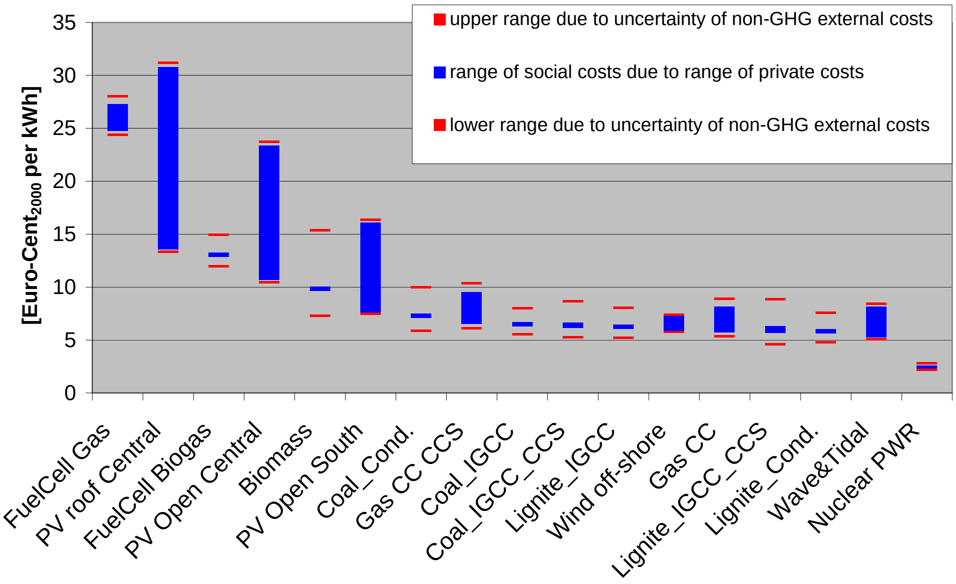
4.1.4. Belgium – GHG Scenario II) in 2025



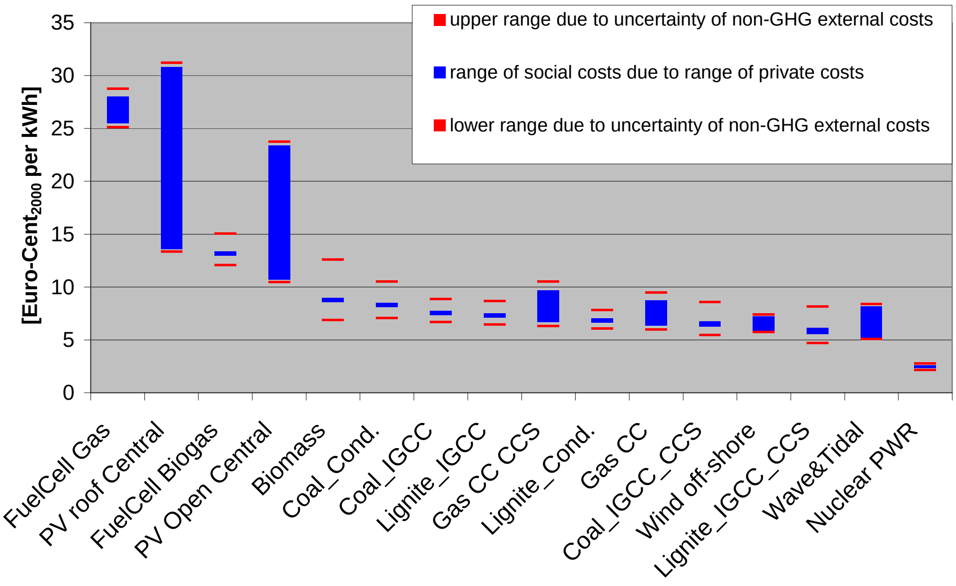
4.1.5. France – GHG Scenario I) in 2025



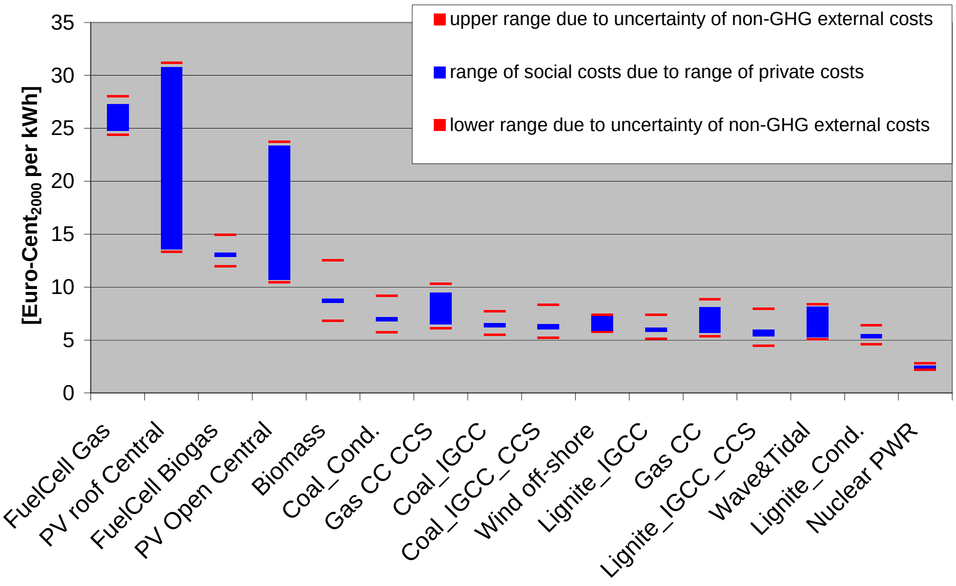
4.1.6. France – GHG Scenario II) in 2025



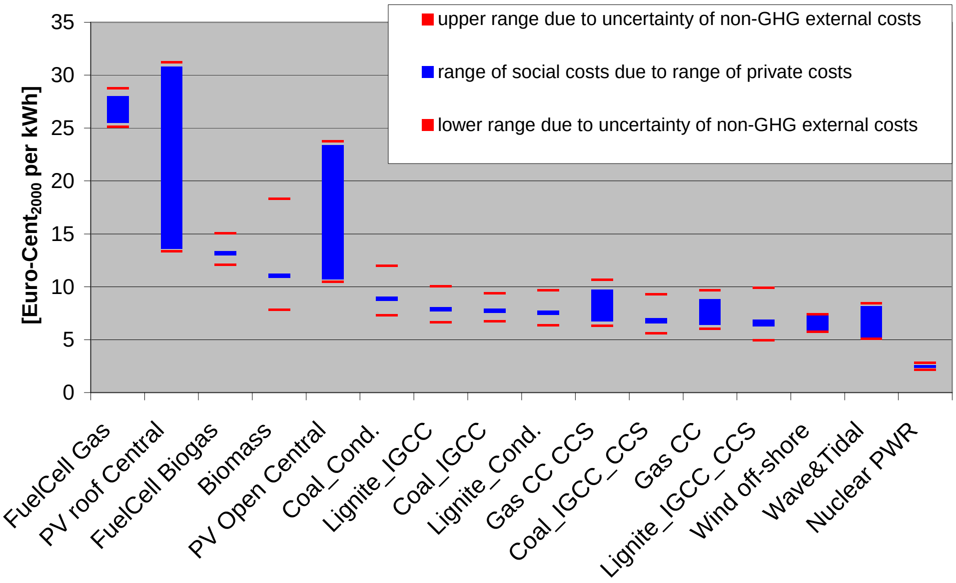
4.1.7. Great Britain – GHG Scenario I) in 2025



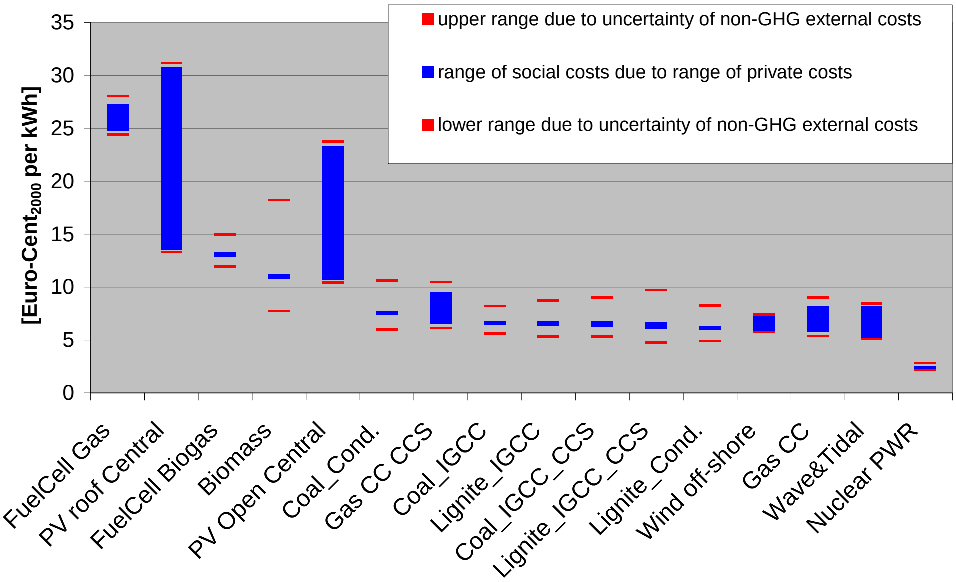
4.1.8. Great Britain – GHG Scenario II) in 2025



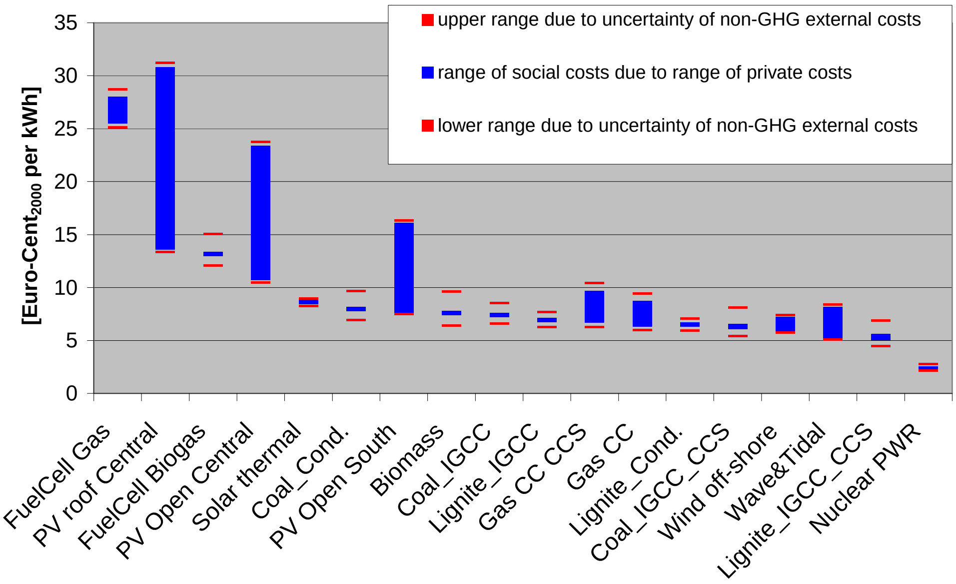
4.1.9. Germany – GHG Scenario I) in 2025



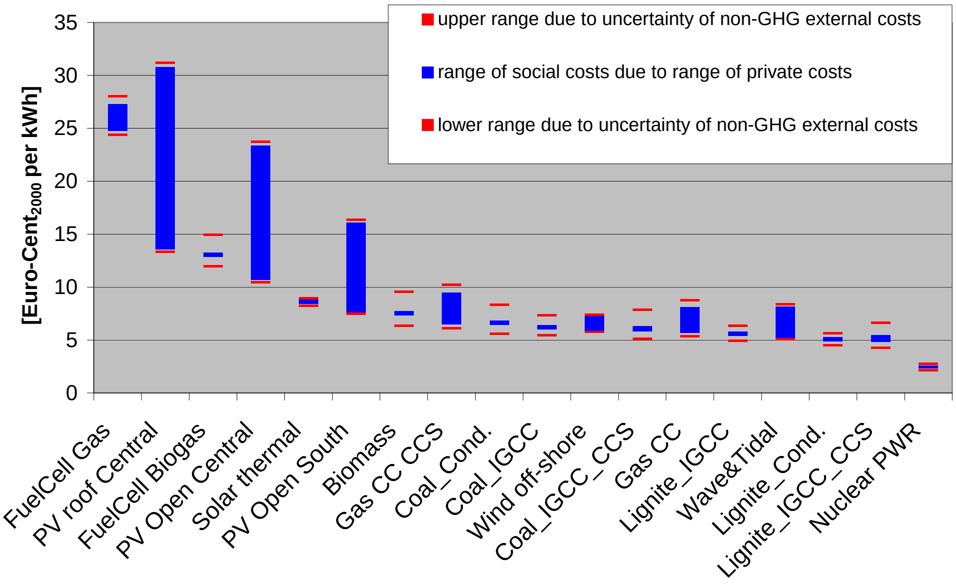
4.1.10. Germany – GHG Scenario II) in 2025



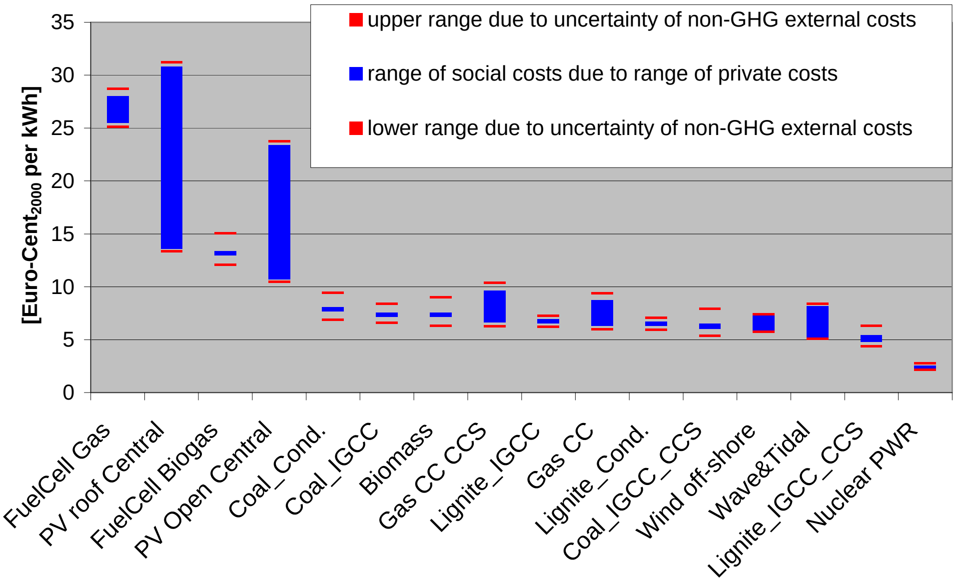
4.1.11. Greece – GHG Scenario I) in 2025



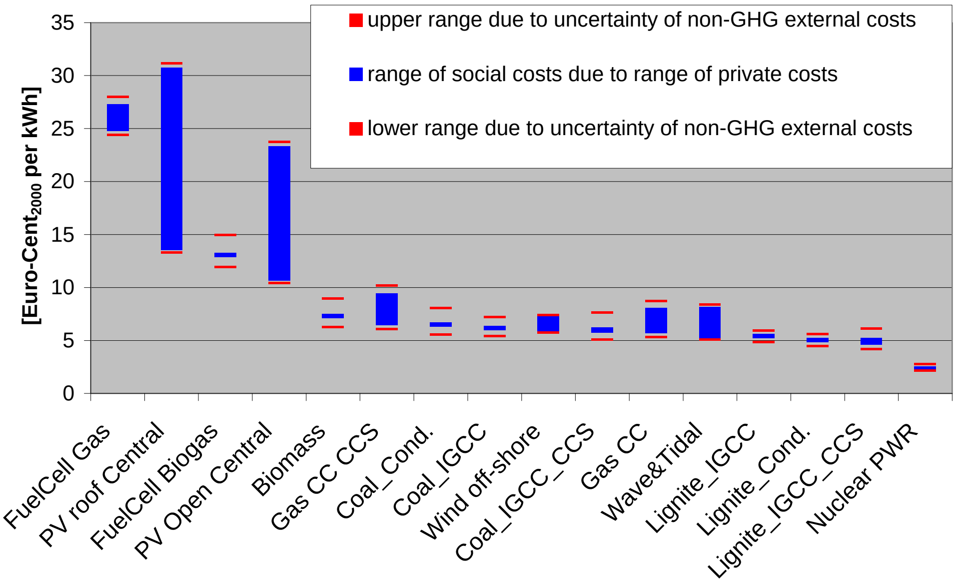
4.1.12. Greece – GHG Scenario II) in 2025



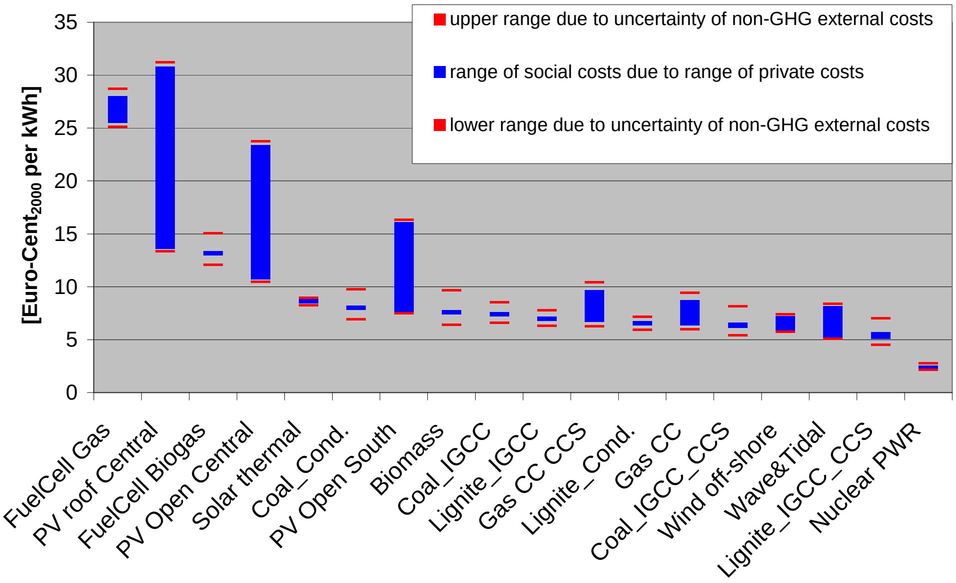
4.1.13. Norway – GHG Scenario I) in 2025



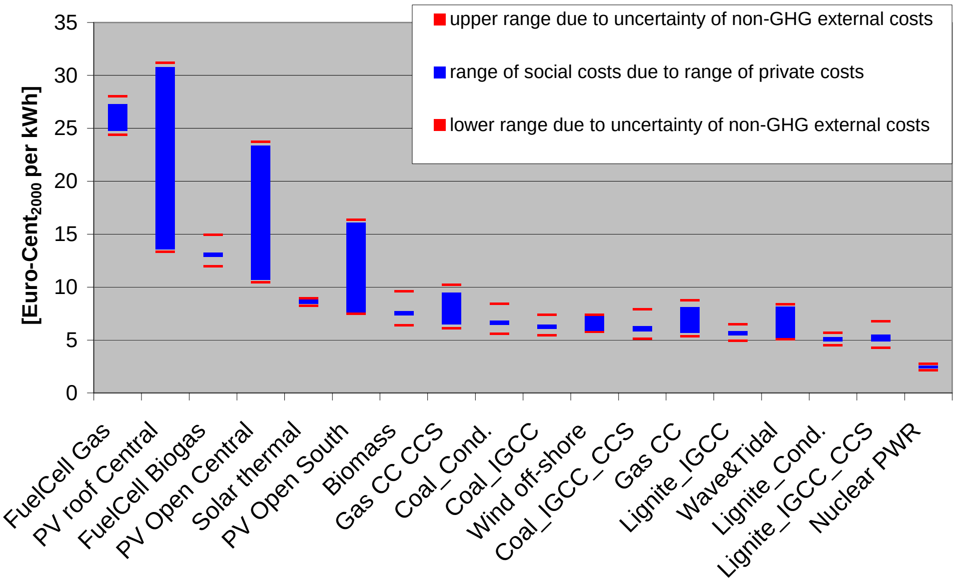
4.1.14. Norway – GHG Scenario II) in 2025



4.1.15. Spain– GHG Scenario I) in 2025

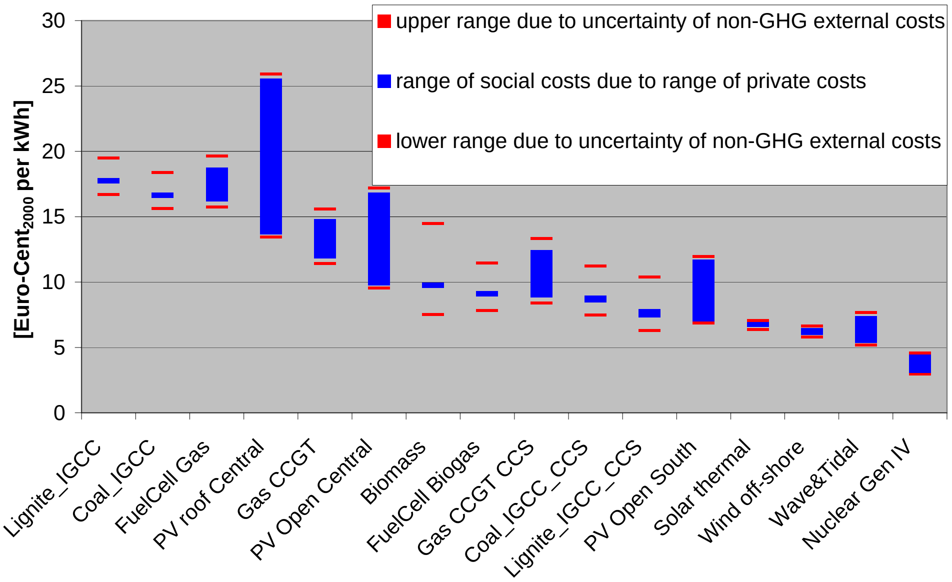


4.1.16. Spain – GHG Scenario II) in 2025

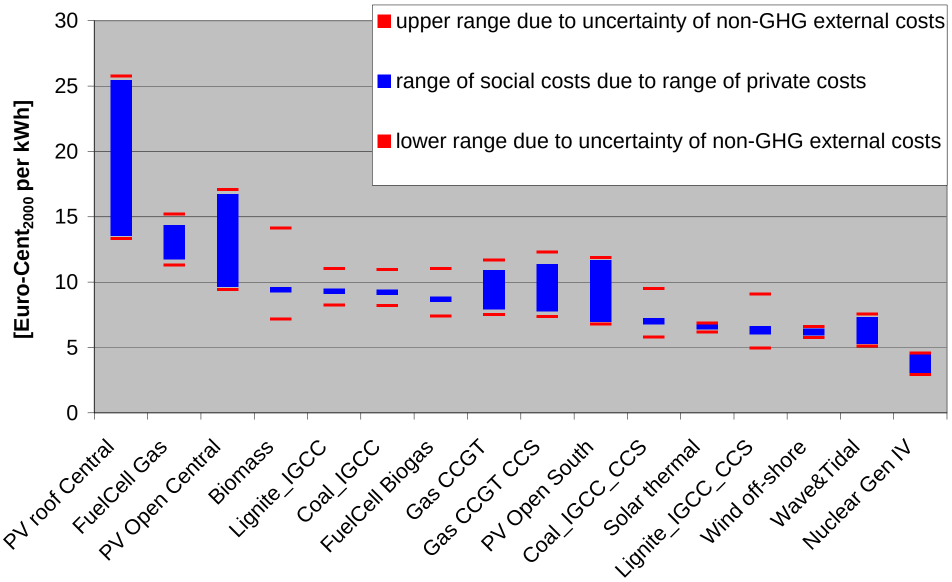


4.2. Future configurations 2050

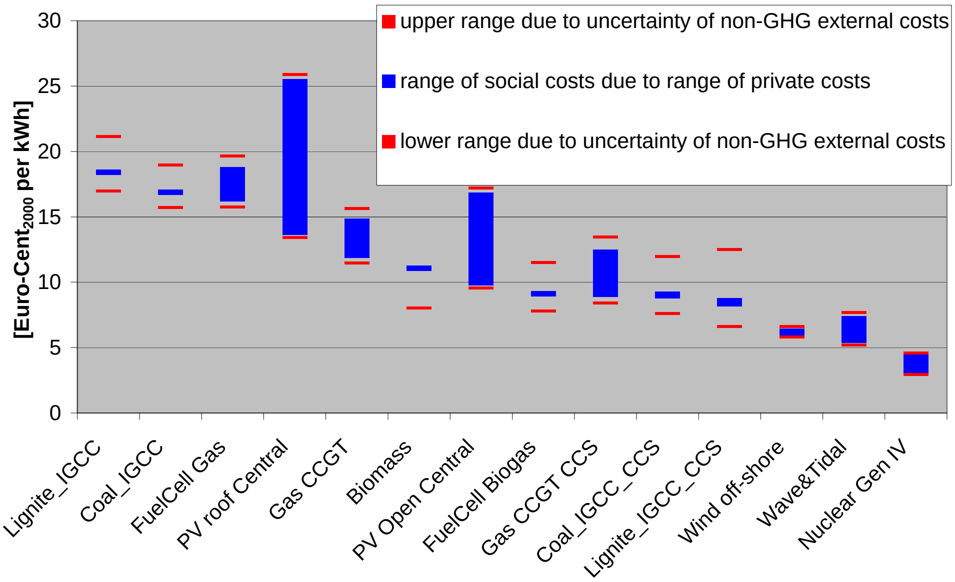
4.2.1. Eu27 – GHG Scenario I) in 2050



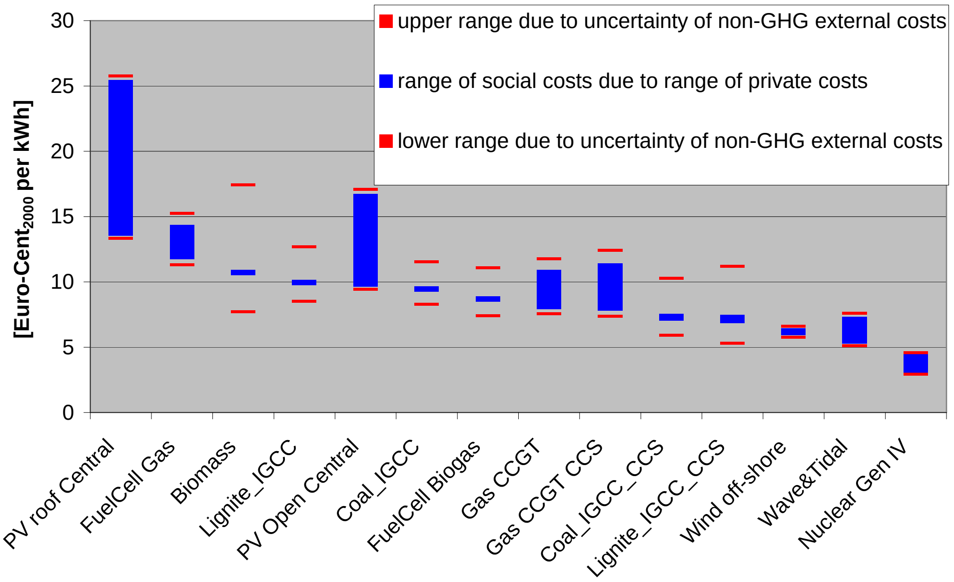
4.2.2. Eu27 – GHG Scenario II) in 2050



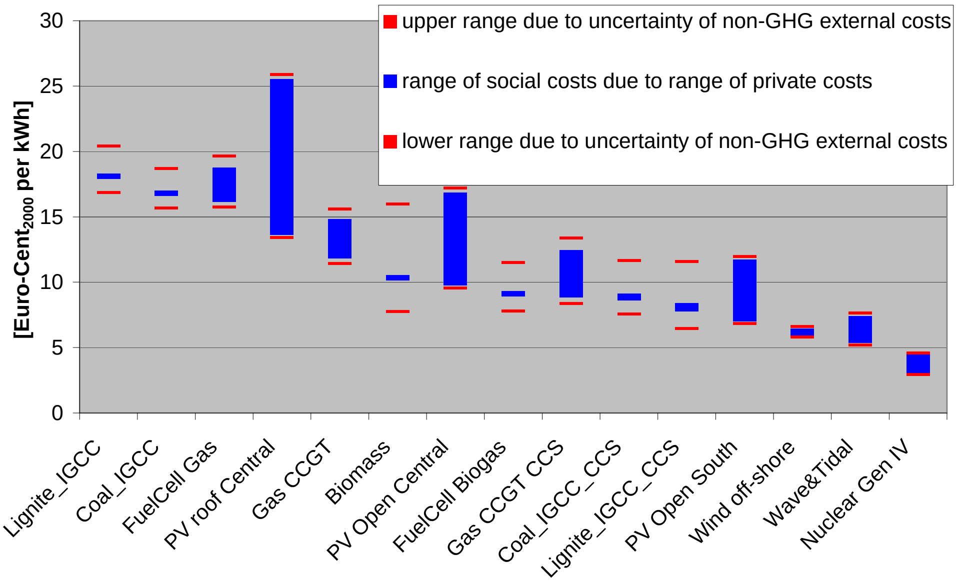
4.2.3. Belgium – GHG Scenario I) in 2050



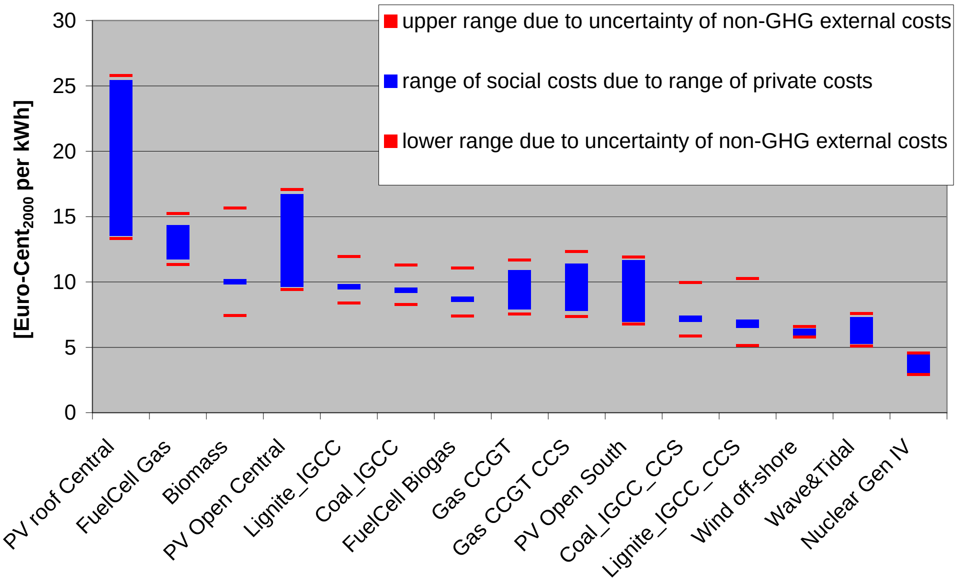
4.2.4. Belgium – GHG Scenario II) in 2050



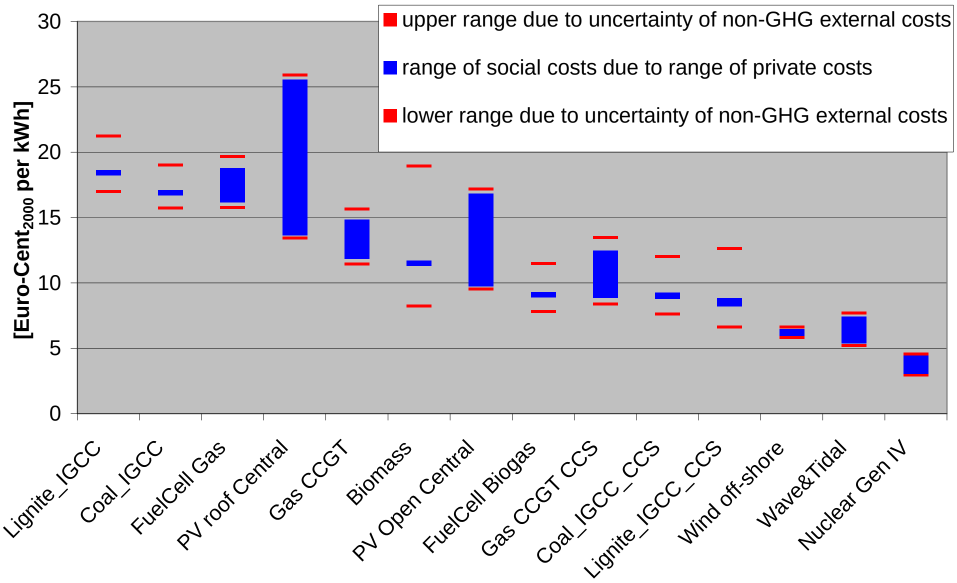
4.2.5. France – GHG Scenario I) in 2050



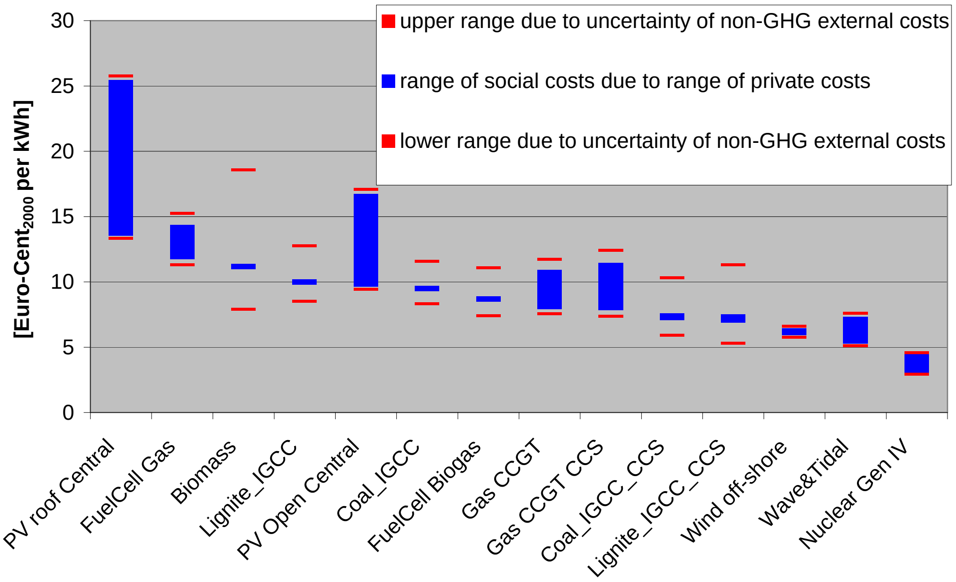
4.2.6. France – GHG Scenario II) in 2050



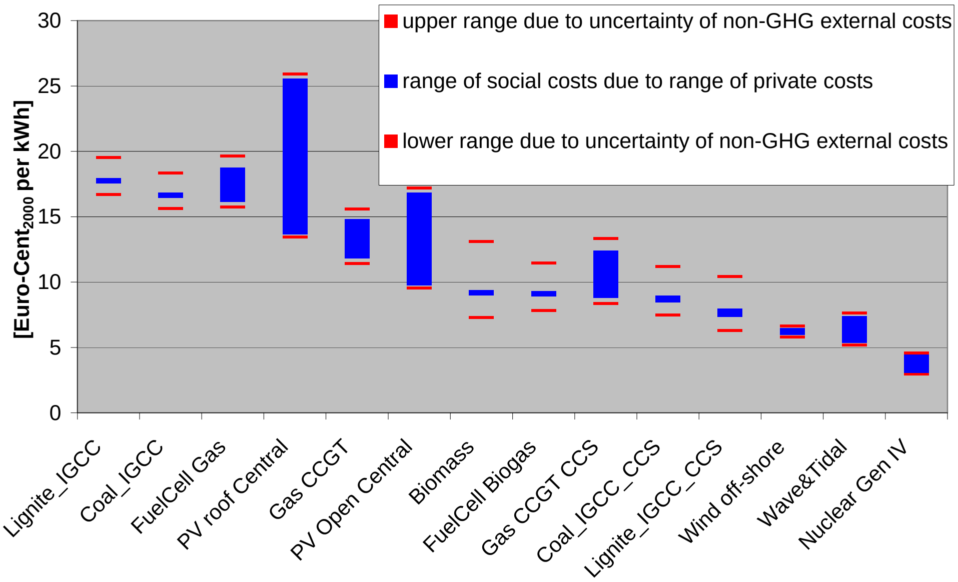
4.2.7. Germany – GHG Scenario I) in 2050



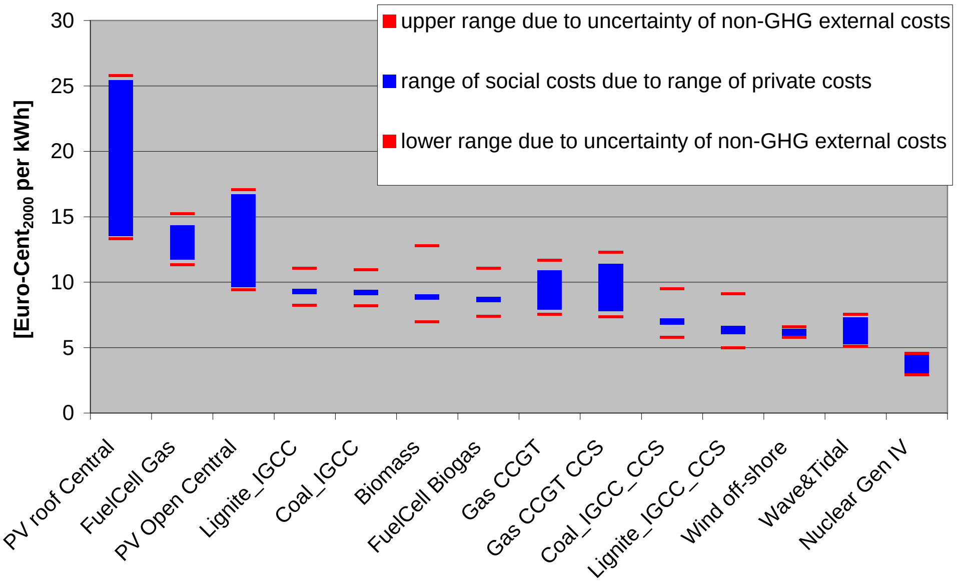
4.2.8. Germany – GHG Scenario II) in 2050



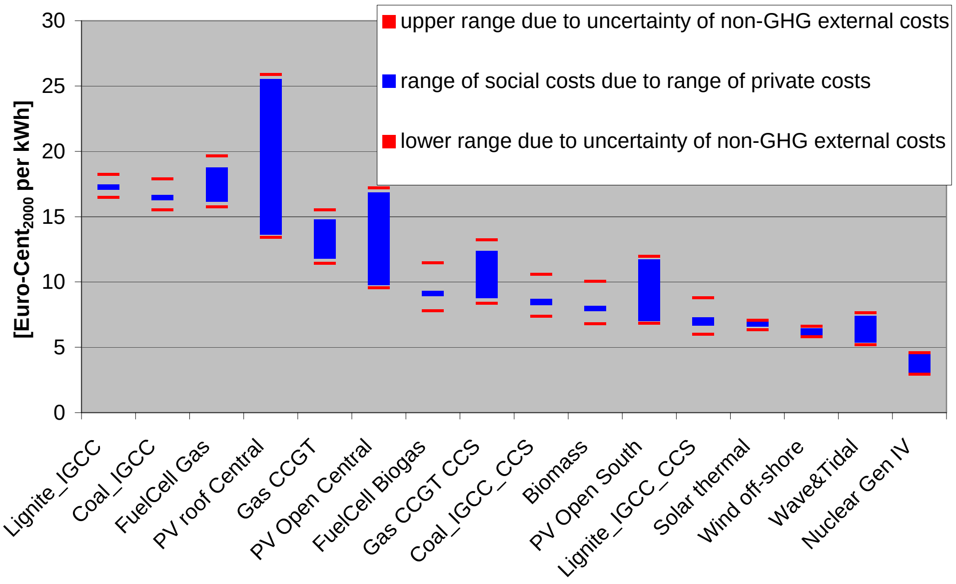
4.2.9. Great Britain – GHG Scenario I) in 2050



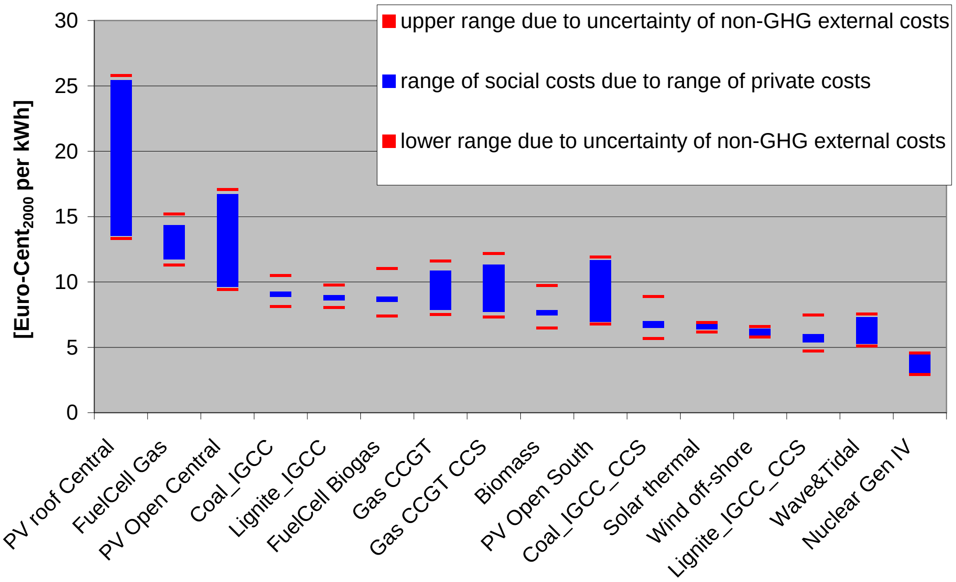
4.2.10. Great Britain – GHG Scenario II) in 2050



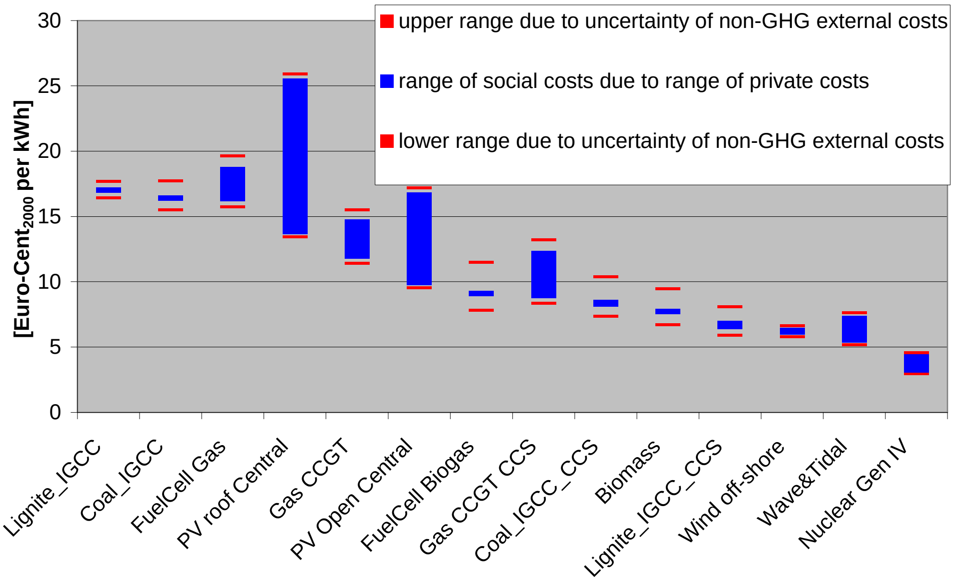
4.2.11. Greece – GHG Scenario I) in 2050



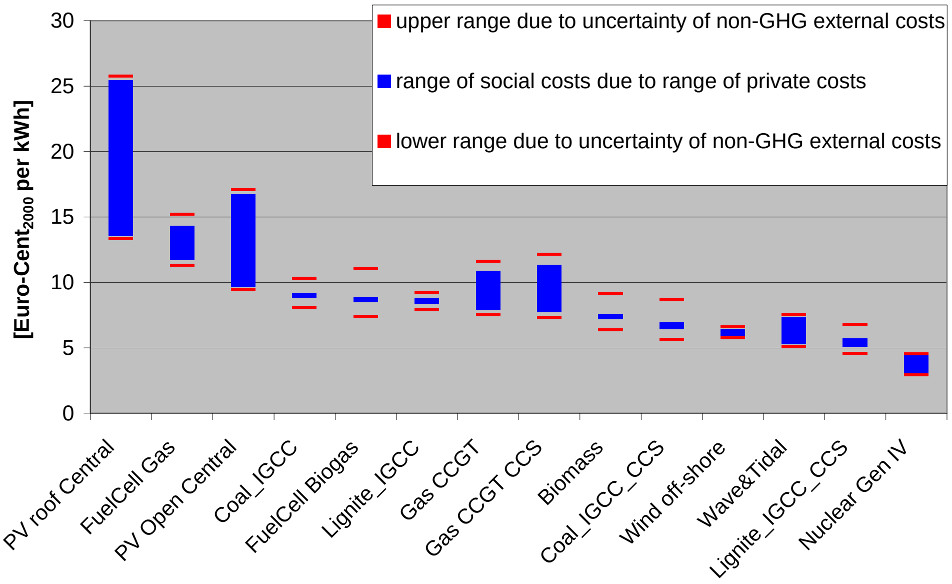
4.2.12. Greece – GHG Scenario II) in 2050



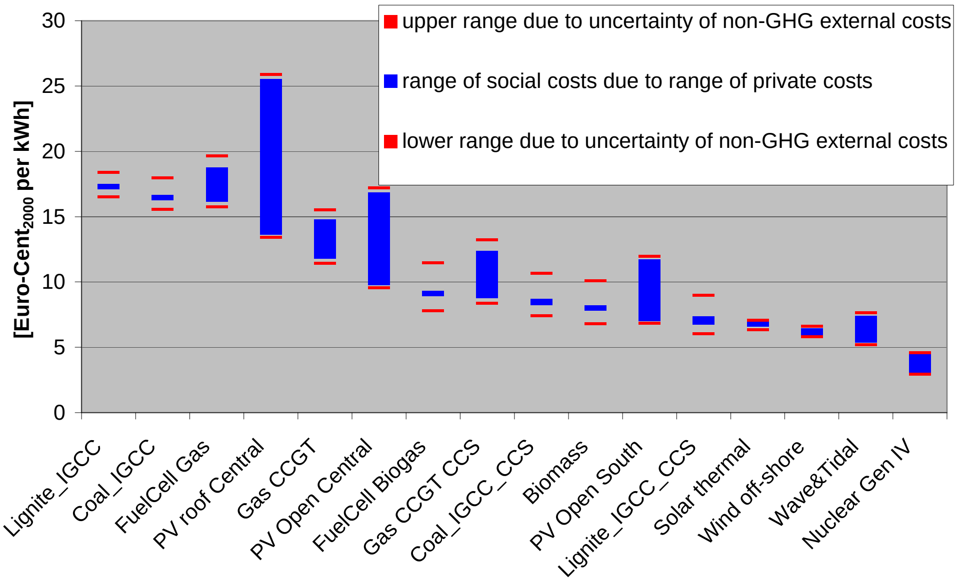
4.2.13. Norway – GHG Scenario I) in 2050



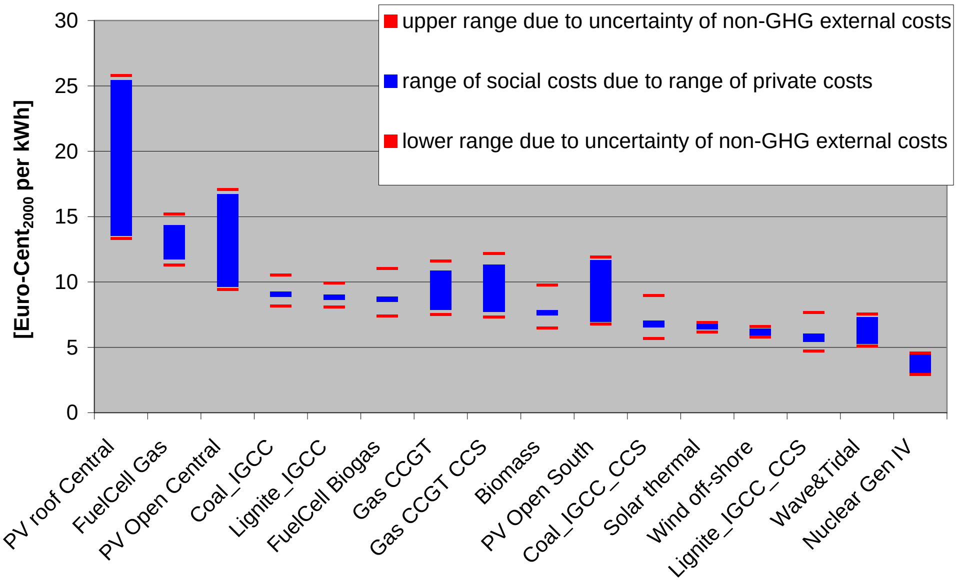
4.2.14. Norway – GHG Scenario II) in 2050



4.2.15. Spain – GHG Scenario I) in 2050



4.2.16. Spain – GHG Scenario II) in 2050



4.3. Summary of the influence on the ranking based on the social costs

5. Conclusions

The external costs per kWh vary between the countries and even within the countries.

For fossil fuel power plants the local effects on human health impacts in the vicinity around 50 km of the stacks are of small relevance – if the stack is high enough.

The external costs of new, innovative, and state-of-the-art, i.e. “cleaner” and more efficient technologies are in general very low. However, the more advanced the operation phase the more important become the other life cycle stages.

The Figures show that the location in different countries has a small influence on the ranking of technologies according to social costs due to the different external costs because either the private costs dominate the social costs, or the external costs of GHG dominate the social costs. However, the results are only an approximation because the LCI data and the private costs are derived for average European conditions. Efficiency and up- and downstream process will differ for different countries and hence, the LCI data and private costs per kWh. However, the difference due to efficiency because of ambient temperature will vary only up to 2% within Europe.

Nuclear, wind, run-off water, wave & tidal energy are electricity generating options with low external and social costs. However, especially run-off water has a limited potential.

Fluctuating technologies need back-up capacity, e.g. coal or gas or alternative renewable.

For nuclear (EPR now, Generation IV after 2030) and on-shore wind in some countries problems with the acceptance might occur.

Lignite, where available and coal will continue to play a major role, with CCS (if CCS turns out to have low environmental and technical risks), unless the costs for transport and storage are higher than anticipated and the level of ambition for climate protection is not too high.

Electricity production with solar plants continues to have the highest quantifiable social costs at least until 2025. In the 2050 future solar thermal systems in Mediterranean countries could be the next best option with high potential – especially, if the climate protection goals are very ambitious and CCS is not working efficiently or has a limited potential.

Natural gas will only play a role replacing coal, if the price for gas (and oil) is expected to stay moderate, then however without CCS.
Biomass has relatively high external and social costs. The use of residual biomass in large plants might still be a favorable option.

For the future energy mix other issues like availability, import dependency, public acceptance etc. have also be taken into account.

6. Outlook for Further Research and Application

Improvements and further development are in principle possible at all steps of the assessment chain, i.e. along the Impact Pathway. In the following most obvious examples are provided. However, the list is surely not comprehensive.

6.1. Dispersion and chemical transformation

For the assessment of main air pollutants it is desirable on the one hand, to further improve the dispersion and chemical transformation assessment by chemical transport models (CTM), and on the other hand, to improve the assessment of the actual exposure of the population. Regarding the regional scale parameterised results of sophisticated CTM can be used (so called source receptor matrices (SRM)). To achieve a higher accuracy for site specific assessment the European area could be distinguish into more and hence, smaller sub-regions instead of 66 sub-regions for NEEDS.

More different background emission scenarios should be used in order to better deal with the non-linearity effects, especially with regard to the secondary pollutants formation of ozone.

The lessons learned within NEEDS have shown that the parameterisation of CTM results it is quite useful because it combines the high accuracy of sophisticated models with a very fast application for more site dependent assessment. Therefore, for the assessment of different processes it would be desirable to either have SRM more sector specific or better distinguished regarding the release height.

If site specific assessment for certain sources with a relatively low stack height has to be made a more sophisticated local scale model could also increase the reliability of the results.

Finally, the parameterisation of CTM results should be derived for all relevant places in the world in order to better account for up- and downstream processes. This means an extension outside of Europe.

6.2. Impact categories

With regard to human health impacts concentration response functions for further pollutants are necessary in order to evaluate these pollutants and corresponding effects. However, also the research regarding primary and secondary pollutants has to be continued. On the one hand, the effect of the particle size has to be further investigated (perhaps only the very fine particles with diameter smaller than 1 µm or even below cause most effects). On the other hand, the influence of the particle composition has to be further investigated. For example, the epidemiological evidence of the toxicity of nitrates is very weak. It can be argued that the correlation between nitrate concentrations and impacts is actually related to the corresponding NO_x concentration. Hence, it is questionable whether nitrates caused by NH_3 emissions from agriculture have to be evaluated in the same way as NO_x emissions are.

The impacts due to emissions of pollutants directly into water and soil have to be evaluated. Therefore, fate and concentration response functions have to be derived.

A new methodology for evaluation of ecosystems has been introduced within NEEDS. However, this should be refined with regard to effects to flora and fauna on terrestrial but also aquatic area. Moreover, the complexity and interdependence of different ecosystems should be reflected in a better way.

The evaluation of nuclear fuel cycle is always seen very critical and controversial. The available research results of ExternE are restricted to quite few original data, e.g. (European Commission, 1995).

Generalised values, i.e. impact or exposure [pers.Sv] per unit of emission [Bq] or activity for different locations of the world, should be derived. Then external cost per kWh produced can be better derived. Such data are hardly available and difficult to apply. For example, in (UNSCEAR, 2000) values like persSv per Bq are not in one conceivable table but distributed in different chapters and annexes.

With regard to external costs of possible accidents during operation and because of final deposition experts' opinions are divergent. A thoroughly eta analysis of available results should be performed and gaps and uncertainties should be reduced. Moreover, other features, which are often motioned in conjunction with nuclear fuel cycle, are proliferation and risk of terrorism. These should also be tackled and discussed in a scientific discourse.

Finally, especially the issue and evaluation of risk aversion has to be re-assessed and addressed in future projects.

6.3. Monetary valuation

Within NEEDS the valuation of YOLL, i.e. years of lifetime lost, has been explicitly addressed with regard to air pollution. This is a context of relatively small probabilities and relatively short lifetime reduction per person. This has been done by explicitly developed and designed questionnaires. This new contingent valuation (CV) questionnaire has been applied to the a total sample size of 1463 persons in the 9 countries: France, Spain, UK, Denmark, Germany, Switzerland, Czech Republic, Hungary, and Poland as described in (Desaigues et al., 2007).

Firstly, in future, other impacts such as cancer or accidents, and also impacts due to nuclear power should perhaps also be addressed more explicitly in questionnaires.

Secondly, since it is also possible to evaluate mortality impacts by VSL the valuation of VSL has to be taken into account in CV.

Thirdly, morbidity human health impacts and evaluation of ecosystems should be addressed in corresponding CV.

Fourthly, a methodology of value transfer of these results to other countries, e.g. developing countries is often based on relatively simple methods (PPP purchasing power parity). However, in future and in order to better evaluate up- and downstream processes outside of Europe it is desirable to have also CV studies performed in other regions of the world, including developing countries.

6.4. In general

In general one can summarise that the ability and quality of the evaluation of processes and services, activities and system can be quite different. Since impacts are site specific it is valuable to investigate "hot spots" like the operation of a coal fired power station with a very large effort and as far as possible in order to reduce uncertainty. However, for many other examples, also outside of the energy sector life cycle analysis is more difficult and site specific data is often not available. Hence, life cycle impact assessment has to be based on generalised approaches. Here, an optimal trade-off has to be found between accuracy and applicability by generalising the damage factors but also the LCI data into archetypes, such as emissions from transport, distinguished into urban and non-urban, or emission from very high stacks. Moreover, it is important to recognise for example that with regard to primary pollutants such as particulate matter and in the case of very low height of release the population density in the vicinity is important but this is less important for very high stacks. One the other hand, with regard to the evaluation of external costs it is important in which country or even which continent the impacts occur.

7. Appendix

7.1. Results for NEEDS Rs2a Technologies - Present

Table 9: External costs [Euro-Cent$_{2000}$ per kWh$_{el}$] - Technologies for the 2010

Technologies according to present conditions	Total external costs (Scen I&II)
Lignite	2.70
Hard Coal	3.02
Gas CC	1.29
Nuclear	0.11
Bio fuelled ''typical' current	2.29
Fuel Cell' 'typical' current	1.60
Solar Thermal	0.22
PV tilted roof, sc-Si, retrofit	0.54
Wind offshore park 160MW	0.08

For the present technologies the Scenario I and the Scenario II have identical results because the external costs of GHG are valued by the same costs.

7.2. Results for NEEDS Rs1a Technologies [Euro-Cent per kWh] for the 2025 Technologies

Table 10: External costs [Euro-Cent$_{2000}$ per kWh$_{el}$] - Technologies for the 2025 "Realistic / Optimistic" scenario – operation in Eu27

Technologies according to 2025RO	**Human Health main air pollut**	**Crops Material BioDiversity**	**Human Health other**	**Land Use**	**GHG Scen I**	**GHG Scen II**	**Total external costs (Scen I)**	**Total external costs (Scen II)**
electricity, hard coal IGCC plant 400MW, CCS, 200km & 2500m depleted gasfield	0.98	0.12	0.02	0.05	0.83	0.52	2.00	1.69
electricity, hard coal IGCC plant 400MW, CCS, 400km & 2500m depleted gasfield	0.99	0.12	0.02	0.06	0.84	0.53	2.02	1.71
electricity, hard coal IGCC power plant 400MW, CCS, 200km & 800m aquifer	0.96	0.12	0.02	0.05	0.77	0.48	1.92	1.63
electricity, hard coal IGCC power plant 400MW, CCS, 400km & 800m aquifer	0.96	0.12	0.02	0.05	0.78	0.49	1.93	1.64
electricity, hard coal plant 500MW class oxyf CCS, 200km & 2500m deplet gasfield	1.11	0.14	0.02	0.07	0.61	0.38	1.95	1.72
electricity, hard coal plant 500MW class oxyf CCS, 400km & 2500m deplet gasfield	1.12	0.14	0.02	0.07	0.62	0.39	1.97	1.74
electricity, hard coal plant 500MW class post CCS, 200km & 2500m deplet gasfield	1.54	0.30	0.02	0.07	0.98	0.62	2.91	2.55
electricity, hard coal plant 500MW class post CCS, 400km & 2500m deplet gasfield	1.55	0.30	0.02	0.07	0.99	0.62	2.93	2.56
electricity, hard coal power plant 500MW class oxyf CCS, 200km & 800m aquifer	1.18	0.15	0.02	0.07	0.60	0.38	2.03	1.81
electricity, hard coal power plant 500MW class oxyf CCS, 400km & 800m aquifer	1.19	0.15	0.02	0.07	0.61	0.39	2.06	1.83
electricity, hard coal power plant 500MW class post CCS, 200km & 800m aquifer	1.69	0.32	0.02	0.08	1.04	0.65	3.16	2.77
electricity, hard coal power plant 500MW class post CCS, 400km & 800m aquifer	1.70	0.32	0.02	0.08	1.05	0.66	3.18	2.78
electricity, hard coal, at IGCC power plant 450MW	0.80	0.10	0.01	0.05	3.17	1.99	4.14	2.96
electricity, hard coal, at power plant 350 MW	1.37	0.17	0.02	0.06	3.66	2.29	5.27	3.91
electricity, hard coal, at power plant 600 MW	1.37	0.17	0.02	0.06	3.66	2.29	5.27	3.91
electricity, hard coal, at power plant 800 MW	1.37	0.17	0.02	0.06	3.66	2.29	5.27	3.91

electricity, lignite IGCC plant 400MW, CCS, 200km & 2500m depleted gasfield	1.15	0.12	0.01	0.01	0.67	0.42	1.95	1.70
electricity, lignite IGCC plant 400MW, CCS, 400km & 2500m depleted gasfield	1.16	0.12	0.01	0.01	0.68	0.42	1.97	1.72
electricity, lignite IGCC power plant 400MW, CCS, 200km & 800m aquifer	1.12	0.12	0.01	0.01	0.59	0.37	1.84	1.62
electricity, lignite IGCC power plant 400MW, CCS, 400km & 800m aquifer	1.13	0.12	0.01	0.01	0.60	0.38	1.86	1.64
electricity, lignite plant 800 MW class oxyf CCS, 200km & 2500m depl. gasfield	0.59	0.07	0.01	0.01	0.32	0.20	0.99	0.88
electricity, lignite plant 800 MW class oxyf CCS, 400km & 2500m depl. gasfield	0.60	0.07	0.01	0.01	0.33	0.21	1.02	0.90
electricity, lignite plant 800 MW class post CCS, 200km & 2500m depl. gasfield	1.29	0.28	0.01	0.01	0.82	0.51	2.42	2.11
electricity, lignite plant 800 MW class post CCS, 400km & 2500m depl. gasfield	1.30	0.29	0.01	0.01	0.83	0.52	2.44	2.13
electricity, lignite power plant 800 MW class oxyf CCS, 200km & 800m aquifer	0.55	0.06	0.01	0.01	0.22	0.14	0.85	0.77
electricity, lignite power plant 800 MW class oxyf CCS, 400km & 800m aquifer	1.32	0.17	0.02	0.03	0.83	0.52	2.38	2.07
electricity, lignite power plant 800 MW class post CCS, 200km & 800m aquifer	1.25	0.28	0.01	0.01	0.73	0.46	2.29	2.02
electricity, lignite power plant 800 MW class post CCS, 400km & 800m aquifer	1.26	0.28	0.01	0.01	0.74	0.47	2.31	2.04
electricity, lignite, at IGCC power plant 450MW	0.88	0.09	0.01	0.00	3.61	2.26	4.59	3.24
electricity, lignite, at power plant 950 MW	0.80	0.12	0.01	0.00	3.92	2.46	4.85	3.40
electricity, natural gas, at cogeneration 200kWe lean burn, allocation exergy	0.53	0.06	0.00	0.02	2.38	1.49	2.99	2.11
electricity, natural gas, at combined cycle plant, 500MWe	0.37	0.04	0.00	0.02	1.77	1.11	2.20	1.54
electricity, natural gas, at turbine, 50MWe	0.60	0.08	0.00	0.03	2.55	1.60	3.26	2.31
electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	0.42	0.04	0.00	0.02	0.54	0.34	1.03	0.82
electricity, nuclear, at EFR reactor	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.02
electricity, nuclear, at EPR reactor	0.06	0.01	0.02	0.00	0.02	0.01	0.11	0.10
electricity, nuclear, at power plant pressure water reactor (N4-type)	0.07	0.01	0.02	0.00	0.03	0.02	0.12	0.11
electricity, at steam turbine (poplar), emission ctrl., Centr. EU, alloc. exergy	2.03	0.36	0.00	0.90	0.30	0.19	3.59	3.48

electricity, at steam turbine (straw), emission ctrl., Centr. EU, alloc. exergy	2.76	0.40	0.00	0.00	0.18	0.11	3.34	3.27
hydrogen, compressed gas, at hydrogen fuelling station	28.67	3.24	0.38	1.74	60.67	38.07	94.70	72.09
electricity, at proton exchange membrane fuel cell CHP 2kW	0.85	0.08	0.00	0.05	4.44	2.79	5.43	3.77
electricity, at SOFC, planar, 1kW	0.58	0.06	0.00	0.03	3.19	2.00	3.87	2.68
electricity, at SOFC, tubular CHP, hybrid, 300kW	0.36	0.04	0.00	0.02	1.91	1.20	2.33	1.62
electricity, at MCFC CHP 2000kW	0.74	0.06	0.01	0.02	1.99	1.25	2.82	2.08
electricity, at MCFC CHP 250kW	0.41	0.04	0.00	0.02	2.07	1.30	2.55	1.78
electricity, at MCFC CHP 250kW, from wood gas	0.85	0.12	0.00	0.35	0.29	0.18	1.61	1.51
electricity, at offshore wind park 1068MW	0.02	0.00	0.00	0.00	0.01	0.01	0.04	0.04
electricity, pv, ground mounted power plant, c-Si, thick, Central Europe	0.15	0.01	0.02	0.01	0.08	0.05	0.27	0.24
electricity, pv, ground mounted power plant, c-Si, thick, Southern Europe	0.08	0.01	0.01	0.00	0.04	0.03	0.14	0.13
electricity, pv, ground mounted power plant, sc-Si, 100, Central Europe	0.15	0.01	0.02	0.01	0.08	0.05	0.26	0.23
electricity, pv, ground mounted power plant, sc-Si, 100, Southern Europe	0.08	0.01	0.01	0.00	0.04	0.03	0.14	0.12
electricity, pv, tilted roof, CdTe, integrated, Central Europe	0.08	0.01	0.01	0.00	0.03	0.02	0.13	0.12
electricity, pv, tilted roof, CdTe, integrated, Southern Europe	0.04	0.00	0.01	0.00	0.02	0.01	0.07	0.06
electricity, pv, tilted roof, c-Si, integrated, thick, Central Europe	0.16	0.02	0.02	0.00	0.09	0.06	0.28	0.25
electricity, pv, tilted roof, c-Si, integrated, thick, Southern Europe	0.08	0.01	0.01	0.00	0.05	0.03	0.15	0.13
electricity, pv, tilted roof, sc-Si, integrated, 100, Central Europe	0.16	0.01	0.02	0.00	0.08	0.05	0.28	0.24
electricity, pv, tilted roof, sc-Si, integrated, 100, Southern Europe	0.08	0.01	0.01	0.00	0.05	0.03	0.15	0.13
electricity, solar tower, with salt storage, at power plant, 180MW	0.07	0.01	0.00	0.00	0.06	0.04	0.15	0.13
electricity, solar trough, PCM-storage, at power plant, 200MW	0.14	0.02	0.00	0.01	0.10	0.06	0.27	0.23
electricity, Fresnel, with PCM-storage, at power plant, 200MW	0.23	0.03	0.01	0.02	0.16	0.10	0.44	0.38
electricity, from wave energy, 7MW	0.08	0.01	0.00	0.00	0.04	0.02	0.13	0.12

7.3. Results for NEEDS Rs1a Technologies [Euro-Cent per kWh] for the 2050 Technologies

Table 11: External costs [Euro-Cent$_{2000}$ per kWh$_{el}$] - Technologies for the 2050 "Realistic / Optimistic" scenario – operation in Eu27

Technologies according to 2050RO	Human Health main air pollut	Crops Material BioDiversity	Human Health other	Land Use	GHG Scen I	GHG Scen II	Total external costs (Scen I)	Total external costs (Scen II)
electricity, hard coal IGCC plant 400MW, CCS, 200km & 2500m depleted gasfield	1.23	0.14	0.02	0.07	2.84	1.10	4.30	2.57
electricity, hard coal IGCC plant 400MW, CCS, 400km & 2500m depleted gasfield	1.24	0.14	0.02	0.07	2.87	1.11	4.34	2.59
electricity, hard coal IGCC power plant 400MW, CCS, 200km & 800m aquifer	1.21	0.14	0.02	0.07	2.78	1.08	4.22	2.52
electricity, hard coal IGCC power plant 400MW, CCS, 400km & 800m aquifer	1.21	0.14	0.02	0.07	2.79	1.09	4.24	2.53
electricity, hard coal plant 500MW class oxyf CCS, 200km & 2500m deplet gasfield	1.24	0.15	0.02	0.08	1.65	0.64	3.14	2.13
electricity, hard coal plant 500MW class oxyf CCS, 400km & 2500m deplet gasfield	1.25	0.15	0.02	0.08	1.66	0.65	3.16	2.15
electricity, hard coal plant 500MW class post CCS, 200km & 2500m deplet gasfield	1.74	0.34	0.02	0.07	2.96	1.15	5.13	3.33
electricity, hard coal plant 500MW class post CCS, 400km & 2500m deplet gasfield	1.75	0.34	0.02	0.08	2.97	1.15	5.15	3.34
electricity, hard coal power plant 500MW class oxyf CCS, 200km & 800m aquifer	1.22	0.14	0.02	0.07	1.59	0.62	3.05	2.08
electricity, hard coal power plant 500MW class oxyf CCS, 400km & 800m aquifer	1.23	0.15	0.02	0.08	1.60	0.62	3.08	2.10
electricity, hard coal power plant 500MW class post CCS, 200km & 800m aquifer	1.72	0.34	0.02	0.07	2.90	1.13	5.06	3.28
electricity, hard coal power plant 500MW class post CCS, 400km & 800m aquifer	1.73	0.34	0.02	0.07	2.91	1.13	5.08	3.30
electricity, hard coal, at IGCC power plant 450MW	1.02	0.12	0.02	0.06	12.13	4.72	13.34	5.93

electricity, hard coal, at power plant 350 MW	1.52	0.18	0.02	0.06	12.28	4.78	14.07	6.56
electricity, hard coal, at power plant 600 MW	1.52	0.18	0.02	0.06	12.28	4.77	14.06	6.56
electricity, hard coal, at power plant 800 MW	1.52	0.18	0.02	0.06	12.28	4.77	14.06	6.56
electricity, lignite IGCC plant 400MW, CCS, 200km & 2500m depleted gasfield	1.44	0.14	0.01	0.01	2.19	0.85	3.79	2.45
electricity, lignite IGCC plant 400MW, CCS, 400km & 2500m depleted gasfield	1.45	0.14	0.01	0.01	2.21	0.86	3.82	2.47
electricity, lignite IGCC power plant 400MW, CCS, 200km & 800m aquifer	1.41	0.14	0.01	0.01	2.11	0.82	3.68	2.39
electricity, lignite IGCC power plant 400MW, CCS, 400km & 800m aquifer	1.42	0.14	0.01	0.01	2.13	0.83	3.71	2.41
electricity, lignite plant 800 MW class oxyf CCS, 200km & 2500m depl. gasfield	0.61	0.07	0.01	0.01	0.56	0.22	1.26	0.91
electricity, lignite plant 800 MW class oxyf CCS, 400km & 2500m depl. gasfield	0.62	0.07	0.01	0.01	0.58	0.23	1.29	0.93
electricity, lignite plant 800 MW class post CCS, 200km & 2500m depl. gasfield	1.32	0.30	0.01	0.01	2.07	0.81	3.72	2.45
electricity, lignite plant 800 MW class post CCS, 400km & 2500m depl. gasfield	1.33	0.30	0.01	0.01	2.09	0.81	3.74	2.47
electricity, lignite power plant 800 MW class oxyf CCS, 200km & 800m aquifer	0.58	0.06	0.01	0.01	0.49	0.19	1.16	0.86
electricity, lignite power plant 800 MW class oxyf CCS, 400km & 800m aquifer	0.59	0.06	0.01	0.01	0.51	0.20	1.18	0.87
electricity, lignite power plant 800 MW class post CCS, 200km & 800m aquifer	1.30	0.30	0.01	0.01	2.01	0.78	3.63	2.40
electricity, lignite power plant 800 MW class post CCS, 400km & 800m aquifer	1.31	0.30	0.01	0.01	2.02	0.79	3.65	2.42
electricity, lignite, at IGCC power plant 450MW	1.11	0.11	0.01	0.00	13.84	5.38	15.07	6.62
electricity, lignite, at power plant 950 MW	0.89	0.13	0.01	0.00	13.17	5.12	14.20	6.16
electricity, natural gas, at cogeneration 200kWe lean burn, allocation exergy	0.58	0.06	0.00	0.03	8.63	3.36	9.30	4.02
electricity, natural gas, at combined cycle plant, 500MWe	0.39	0.04	0.00	0.02	6.39	2.49	6.84	2.94
electricity, natural gas, at turbine, 50MWe	0.52	0.05	0.00	0.03	9.04	3.51	9.64	4.12
electricity, natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield	0.47	0.05	0.00	0.03	1.69	0.66	2.24	1.20
electricity, nuclear, at EFR reactor	0.01	0.00	0.00	0.00	0.02	0.01	0.03	0.02

electricity, nuclear, at EPR reactor	0.07	0.01	0.03	0.00	0.07	0.03	0.18	0.14
electricity, nuclear, at power plant pressure water reactor (N4-type)	0.09	0.01	0.02	0.00	0.09	0.03	0.21	0.16
electricity, at steam turbine (poplar), emission ctrl., Centr. EU, alloc. exergy	2.07	0.36	0.00	0.94	0.94	0.37	4.31	3.74
electricity, at steam turbine (straw), emission ctrl., Centr. EU, alloc. exergy	2.83	0.39	0.00	0.00	0.55	0.21	3.77	3.44
hydrogen, compressed gas, at hydrogen fuelling station	25.02	2.55	0.53	1.78	60.85	23.66	90.73	53.55
electricity, at proton exchange membrane fuel cell CHP 2kW	0.96	0.09	0.00	0.06	16.82	6.54	17.93	7.65
electricity, at SOFC, planar, 1kW	0.71	0.07	0.00	0.04	12.08	4.70	12.90	5.52
electricity, at SOFC, tubular CHP, hybrid, 1000kW	0.81	0.11	0.00	0.35	0.58	0.22	1.85	1.50
electricity, at SOFC, tubular CHP, hybrid, 300kW	0.45	0.04	0.00	0.03	7.25	2.82	7.77	3.34
electricity, at MCFC CHP 2000kW	0.91	0.06	0.01	0.03	7.49	2.91	8.51	3.93
electricity, at MCFC CHP 250kW	0.50	0.04	0.00	0.03	7.85	3.05	8.43	3.63
electricity, at MCFC CHP 250kW, from wood gas	1.06	0.14	0.00	0.45	0.69	0.27	2.34	1.92
electricity, at offshore wind park 1944MW	0.04	0.00	0.01	0.00	0.04	0.02	0.10	0.07
electricity, pv, ground mounted power plant, c-Si, low eff., Central EU	0.13	0.01	0.01	0.01	0.18	0.07	0.35	0.24
electricity, pv, ground mounted power plant, c-Si, low eff., Southern EU	0.07	0.01	0.01	0.00	0.09	0.04	0.18	0.12
electricity, pv, concentrator, GaInP/GaAs, short, Central Europe	0.15	0.01	0.00	0.01	0.20	0.08	0.37	0.25
electricity, pv, concentrator, GaInP/GaAs, short, Southern Europe	0.07	0.01	0.00	0.00	0.10	0.04	0.19	0.13
electricity, pv, tilted roof, CdTe, integrated, short, Central Europe	0.07	0.00	0.01	0.00	0.06	0.02	0.14	0.10
electricity, pv, tilted roof, CdTe, integrated, short, Southern Europe	0.03	0.00	0.00	0.00	0.03	0.01	0.07	0.05
electricity, pv, tilted roof, c-Si, integrated, low eff., Central Europe	0.14	0.01	0.01	0.00	0.19	0.07	0.36	0.24
electricity, pv, tilted roof, c-Si, integrated, low eff., Southern Europe	0.07	0.01	0.01	0.00	0.10	0.04	0.18	0.12
electricity, solar tower, with salt storage, at power plant, 180MW	0.07	0.01	0.00	0.00	0.20	0.08	0.28	0.16
electricity, trough, with PCM-storage, at power plant, 400MW	0.14	0.02	0.00	0.01	0.30	0.12	0.47	0.29
electricity, Fresnel, at power plant, with PCM-storage, 400MW	0.18	0.02	0.00	0.02	0.35	0.14	0.57	0.35
electricity, from wave energy, 7MW	0.09	0.01	0.00	0.00	0.14	0.06	0.25	0.16

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