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NEEDS

New Energy Externalities Developments for Sustainability

INTEGRATED PROJECT

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PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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1 Introduction

Within the EU Integrated Project NEEDS (New Energy Externalities Developments for Sustainability), the central objective of Research Stream RS2b "Energy Technology Roadmap and Stakeholder Perspectives" is to broaden the basis for decision support beyond the assessment of external costs and to extend the integration of the central analytical results generated by other Research Streams. The ultimate results of the technology roadmap will include mapping the sensitivity of sustainability performance of technological options to stakeholder preference profiles.

Two approaches will be used for the evaluation of the options. The first approach is based on total costs calculations (direct + external); estimation of total costs will be based on the information that is expected to be available from other research streams. The second approach will use Multi-Criteria Decision Analysis (MCDA), combining in a structured manner knowledge of specific attributes of the various technologies with stakeholder preferences.

The main efforts undertaken in RS2b concern the development of a framework for the implementation of MCDA. The approach is based on measuring the performance of competing technologies by different decision-making criteria. Performance for each criterion is judged by what may be called "indicators" or "measures" or "metrics." Such indicators may be either quantitative or qualitative. Quantitative measures can be ascertained with relative objectivity, given stated contributing assumptions. Qualitative measures must still be assigned a value for the multi-criteria assessment, but are based at least partially on subjective judgment. Each indicator attempts to quantify a certain aspect of a given criterion.

A fundamental part of such a framework is the establishment of a set of criteria and indicators to be used for the evaluation, and the creation of a database of indicators that actually embody the indicators that have been established. A separate report has provided an overview and description of the criteria set and associated indicators selected for use within NEEDS for the evaluation of electricity generating technologies and the associated fuel cycles. The present report describes how the indicators were collected from other Work Packages, completed with calculations within the present Work Package, combined into a database embodied in spreadsheet form and exported to the partner institution (IIASA) hosting the online web survey for the purpose of establishing stakeholder preferences.

The database includes 36 separate indicators for 26 future technologies (in the year 2050) in four countries, i.e. France, Germany, Italy and Switzerland.

The present report focuses on the process of combining and extending results obtained and documented in a number of Work Packages within RS2b, which in turn profited from a variety of experiences with criteria and indicators, accounted for in the literature. For the details we refer to the supporting RS2b publications; here the focus will be on presenting the requirements and process of creating the NEEDS sustainability database for future generating technologies.

Section 2 of this report describes the database requirements. Section 3 discusses the structure of the database, the data collected from contributors, the assumptions calculations necessary to extend the database to complete the full set of indicators, and the process of exporting data for the online survey of stakeholder preferences. Section 5 contains text descriptions of the 26 individual technologies. Section 5 contains summary remarks and conclusions, and the Appendices contain graphics, tables and figures describing the technologies and presenting the contents of the database for the four countries.

2 Database Requirements

The database draws together data on a wide range of future electricity generation technologies, including fossil technologies (coal, lignite and natural gas), nuclear technologies (pressurized water and breeder reactors), and a range of renewable resources (biomass, solar and wind). The 36 indicators cover a wide range of concerns in the three major areas of sustainability - the environment, the economy and society overall. The database that contains this wide range of information has a number of functional and practical requirements.

2.1 Functionality:

The functional requirements of the database include the following;

- *Complete:* It is of course rather trivial to state that the database needs to include all the indicators contained within the criteria hierarchy developed for NEEDS. However, the data delivered from the various technical contributors did not contain all or exactly the same indicators as called for. In particular, a number of economic indicators were calculated and several social indicators adjusted for use in the final database. Developing or adjusting these indicators could technically be regarded as part of parallel work packages performed by PSI, but in practical terms these efforts were highly integrated with the database development.
- *Differentiated:* The database includes data for four different countries, and these countries differ in a number of ways. These differences include technology (or resource) availability, variations in operating conditions, and general or site-specific differences in impacts on the surrounding environment. These differences are discussed more specifically in Section 3 below.
- *Comprehensible:* The database must be structured so that it will be easy to understand and use, particularly as it will also be available as a stand-alone reference product of the NEEDS project.
- *Flexible:* It is a functional requirement of the database that it should be easy to update to reflect ongoing changes in database values, due to either updated contributions or error corrections. This means that the database will be easy to update in the future, but it is also true that the database should be lockable, so that it may only be updated by authorized users.

2.2 Practicality:

In order to implement the functional requirements above, it is useful to translate them into some related practical requirements;

- *Editable:* The data in the database must be easily edited, but each datum should only need to be changed in one location.
- *Linked:* The data supplied by contributors to the database is usually delivered in the form of Excel spreadsheets. These should be linked to the database in order to make the transfer of data easier, reduce the chance of introducing errors, and facilitate updates.
- *Data Export:* The contents of the database must be easily exportable to the text files used as inputs to the multi-criteria analysis using inputs from the online survey of stakeholder preferences.
- *Graphs:* As graphs of the individual indicators are by far the easiest way to present and understand the contents of the database, the database should automatically generate new graphs whenever the contents of the database are updated.

In practice, these requirements influenced the decision to structure the database in the form of a spreadsheet with multiple pages or worksheets. This choice was also supported by two factors related to the problem description;

- *Size*: The database size is relatively modest size (4 countries x 26 technologies x 36 indicators = 3744 individual entries), and
- *Use*: The primary use of the data is simply to be exported for use in the multi-criteria analysis, rather than being directly searched or analyzed.

Both of these factors meant that there was relatively little benefit to using specific, specialized database software. The spreadsheet format also addressed specific requirements in the following ways;

- *Linking:* By linking the data automatically from the relevant cells in the source sheets to cells in the database, it is possible to easily update the database (as long the format of the source spreadsheets remains constant). Within the database spreadsheet, indicators that are constant for all countries are contained in a master, generic country worksheet that is linked to four separate country-specific worksheets.
- E*xporting:* Data export for the multi-criteria analysis has the requirements that 1) any empty columns (with zero values) for specific technologies missing from the different countries must be eliminated, 2) the format must preserve enough significant digits -in practice, this means formatting in scientific notation, and 3) the matrix of data must be transposed, since the multi-criteria stakeholder survey input requires that rows contain technologies and columns contain indicators. The resulting text block is cut-and-pasted into the text data file, and spreadsheet delimiter character (tab) is replaced with the standard data file delimiter (;).

3 Presentation and Discussion of Results

3.1 Presentation of Results

The contents of the NEEDS database are presented below in four sections. The first, Table 1, presents a summary of descriptive characteristics of the technologies present in the database, which are also described in Section 5. Appendix 1 then presents a summary description of the technologies using brief text, tables and representative pictures and diagrams. Appendix 2 shows the data contents of the database in the form of 16 pages of tables. Finally, Appendix 3 presents the contents of the database as a series of 36 graphs. There is one bar graph for each indicator, showing the results for each technology by a group of 4 columns, one for each country.

Table 1 – This table shows a very brief column of technical data describing each technology, in order from nuclear plants to fossil to renewables. The data includes fuel, plant size, efficiency, annual generation, construction time, plant life, capital cost and average cost per kWh. This table is intended to simply make this database report somewhat more self standing – a more complete reference to the NEEDS technologies is also available in the links section of this website that also supplies more descriptive text, including socially relevant factors and representative photographs and diagrams for each technology.

The basic LCA and cost data for each technology that have been supplied by other NEEDS collaborators includes data for the years 2000, 2025 and 2050. For the future years of 2025 and 2050 they contain three scenarios; "pessimistic," "realistic-optimistic" and "very optimistic." All indicators within the NEEDS database have been either taken from or based upon the "realistic-optimistic" scenario. These scenario descriptions do not have strict and consistent definitions between the various collaborators, and some technology developments are considerably more speculative than others – so the degrees of optimism contained in the data may vary (e.g. between renewables and more conventional fossil technologies). Readers must apply their own judgment of possible progress by 2050 to the contents of the NEEDS database.

Appendix 1 – The technologies contained in NEEDS database are presented briefly in Appendix 1 as a series of brief text descriptions, table and graphics (pictures and diagrams). These elements are intended to serve as an introduction to the database technologies for those who are unfamiliar with them. This appendix was also used as part of the documentation for the online Multi-Criteria Analysis application that was used to obtain inputs for the multi-criteria analysis.

Appendix 2 – The contents of the NEEDS database are presented in Appendix 2 as a series of 16 tables. These are presented in the country order of France, Germany, Italy and Switzerland. There are four pages for each country. Pages 1 and 2 present the environmental and economic indicators for technologies 1 through 12 and 13 through 26, respectively. Pages 3 and 4 then present the social indicators for technologies 1 through 12 and 13 through 26, respectively. The criteria hierarchy is presented in the leftmost columns, including criterion number, name and units. The criteria are consistently color-coded using green for environment, yellow for economy and blue for social.

All levels of the criteria hierarchy are shown, but indicators are only quantified for the lowest level (each leaf of the branching hierarchical tree). For this reason, some lines of the tables are grayed out and do not contain any numbers. The values that are common to all four countries reference a separate worksheet of the spreadsheet that has not been shown. These indicator values are in cells on four lines that contain numbers, but have been slightly grayed out.

A complete description of the development of the NEEDS criteria hierarchy, and the full background and definition of each individual indicator is beyond the scope of this database report. For this description, the reader is referred to "Final set of sustainability criteria and indicators for assessment of electricity supply options" by Hirschberg, et al (NEEDS Deliverable No. D3.2 - RS 2b).

Appendix 3 – The contents of the NEEDS database are presented in Appendix 3 in the form of vertical bar graphs. There are four bars (or columns) for each technology, reflecting the values for France, Germany, Italy and Switzerland (as labeled by the legend). As explained below, some technologies are not considered appropriate for all the different countries. In these cases, there may be three or even two columns for some technologies. The order of the columns is the same as for the tables presented in Appendix 2, i.e. nuclear followed by fossil and renewable technologies.

3.2 Country Differentiation

As has just been mentioned, there are reasons why the results shown in the tables and figures of Appendices 1 and 2 may vary between the four different countries. These reasons fall into the four different categories described below.

- *Resource availability:* Some technologies were eliminated from consideration as future technology options in 2050 based on assumed resource availability. The largest case of this assumption was for the fuel lignite. It was assumed that there would be no commercially available sources of lignite for Italy and Switzerland. Because lignite has a low energy content by weight, plants are normally located within a relatively short radius of a surface mine (often with transport by conveyor belt). Italy and Switzerland were assumed to have no lignite mines in 2050. Similarly the relatively low quality of the solar resource in Germany and Switzerland is the reason for eliminating the solar thermal technology (parabolic trough collectors), although solar photovoltaic technologies were retained. Offshore wind was also eliminated from landlocked Switzerland. It may be noted here that onshore wind and hydro were also eliminated from consideration in 2050, since these technologies were not covered in the LCA stream of NEEDS, which only addressed advanced electricity generation options.
- *Resource quality:* Hours per year of operation were varied by country for both wind and solar technologies, based on country-specific weather conditions.
- *Thermal efficiency:* Weather conditions (i.e. average annual ambient temperatures) were also assumed to affect the generation efficiency of technologies relying on thermal cycles where waste heat must be rejected to the environment. High summer temperatures can lead to derating (reducing) generation capacity, but this factor was handled by assuming that thermal efficiencies were approximately 3% lower in Italy, as compared to France, Germany and Switzerland. This rather crude assumption ignores climate variations with countries, but it was judged better to at least acknowledge the major differences between northern and southern Europe. Lower efficiency implies higher fuel consumption and higher results for a range of indicators related to the fuel supply chain. Non-thermal technologies were not affected by this assumption.
- *Environment related:* Environment, health and safety risk impacts all depend upon how a technology relates to its surrounding environment, including how emissions travel (wind direction), the presence of potentially affected species or population, etc. For most technologies, a rather generic site was defined for each country so that such indicators could be calculated. For some technologies (e.g. nuclear) a more specific site definition was required so that indicators like potential fatalities from an accident could be calculated.

3.3 Adjustments Made to Social Indicators

Many of the social indicators were quantified on an ordinal scale, based upon the opinions of social experts. The basic assumption of this survey was that the survey group would provide their expert opinions of what public attitudes or opinions would be in the year 2050.

Primarily due to the continuing development of the NEEDS criteria hierarchy during the project, there were some discrepancies between the technologies and indicators covered in the telephone survey, and the final data needed for the NEEDS database. These differences and the way that they were reconciled fall into the following categories.

- *Excess technologies:* The survey questions covered a number of technologies that were eliminated from the final NEEDS technology set, including hydro, onshore wind, geothermal, and wave power. These results were simply not incorporated in the final database.
- *Missing technologies:* The survey experts were asked their opinions of technologies separately that must in practice be combined, i.e. carbon capture and sequestration (CCS) must be combined with the relevant fossil generation technology. The results for these separate questions were combined for generation options where both elements were present. In addition, the generation technology of biomass-fueled cogeneration present in the final NEEDS technology set was not present in the expert survey. For this case, the social indicators related to security of supply, social conflict, participative decision-making and acceptance were set equal to those for another renewable (solar), and the social indicators related to waste, technology innovation, health, perceived risk, proliferation, landscape degradation and noise were set equal to those for a fossil technology (pulverized coal).
- *Excess indicators:* The NEEDS indicator for perceived risk was based on three factors asked separately during the expert survey, i.e. perceived technological familiarity, personal control and catastrophic potential. These three factors were weighted equally in calculating the final indicator for perceived risk. Also, an original educational training indicator was cut from the final NEEDS database criteria set. The originally proposed indicator related to the likelihood of public mobilization against (or for) a technology was also eliminated, leaving the other originally proposed indicator estimating the necessity of public participation in the decision-making process for construction approval.

4 Technology Descriptions

This section presents technical summary descriptions of the 26 technologies contained in the NEEDS database. The full name at the head of each description is followed by an abbreviated name in parentheses. These abbreviations are used as labels in the graphs that are presented in Appendix 3.

1. Nuclear: European Pressurized Reactor (EPR) (Lecointe et al., 2007)

This 'Generation III' design of nuclear reactor uses either uranium oxide enriched to 4.9% fissile material (uranium-235) or a mix of uranium-235 and mixed uranium plutonium oxide (MOX), with pressurized water as the moderator and cooling agent. The heat from the reaction is used to produce steam to drive a steam turbine generator. It features not only superior reliability and safety over its current 'Generation II' counterparts but also higher efficiency. This results in less high-level radioactive waste per unit of electricity generated that requires either reprocessing or long term storage in geological repositories.

EPR's are currently undergoing intensive development with the first two reactors under construction in Finland and France, and with other countries involved in planning processes. Once operational, an EPR is expected to have a lifetime of 60 years. EPR technology does not completely rule out the risks of a severe accident or the possibility for the proliferation of fissile material to unauthorized third parties. Visual disturbance will not be greater than existing nuclear plants and, other than mining activities, remains most dependant on the type of end cooling used, i.e. a cooling tower or access to a large water resource.

2. Nuclear: European Fast Reactor (EFR) (Lecointe et al., 2007)

The EFR is a 'Generation IV' design of nuclear reactor where the term "fast" refers to the reduced moderation of the free neutrons. Fast neutrons do not cause fission as efficiently as moderated free neutrons, which allows a greater quantity of fissile material to be used. This causes around 25% more neutrons to be produced in each fission reaction, a fraction of which are absorbed by some of the non-fissile uranium-238, converting it into fissile plutonium-239. By 'breeding' fissile material, a fast neutron reactor is able to operate with a closed-fuel cycle where the spent fuel and plutonium products from co-existing Generation III reactors are recycled as MOX fuel elements, containing around 20% fissile material.

The EFR will use liquid metal (sodium) as the coolant, which acts as a very efficient heat transfer medium while avoiding any moderation of the neutrons. The operational lifetime of the EFR is expected to be around 40 years. Although the inherent safety feature of a fast neutron reactor is that fission reduces with increased temperature, the risk of a severe contamination release to the environment cannot be ruled out completely. Visual disturbance factors are similar to the EPR.

3. Fossil: Pulverized Coal (Hard coal PC) (Bauer et al., 2009)

Coal is pulverized and then burned in a tall boiler with watertube walls. The steam produced is then used to drive a turbine generator. The combustion of coal causes very significant quantities of carbon dioxide (CO_2) and atmospheric pollutants, although sulfur dioxide and particulate emissions are almost all removed by the use of filters. These scrubbers may be chemical, fabric filters and/or electrostatic precipitators. The filtered materials and coal ash are either recycled or landfilled. For operation in 2050, a power plant net efficiency of 54% was assumed in line with the 'realistic-optimistic' technology development scenario.

Transporting the large amounts of coal required can cause significant noise pollution in rail-freight transit regions while the power plant and atmospheric emissions in particular can be visible from a considerable distance. The operational lifetime of a PC power plant is around 35 years.

4. Fossil: Pulverized Coal with post combustion Carbon Capture and Storage (Hard coal PC, post comb. CCS) (Bauer et al., 2009)

This technology uses the same pulverized coal combustion and electricity generation technology, but the carbon dioxide CO_2 is separated from the other flue gases. This is achieved by cooling the flue gases to around 50°C and then using a solvent containing absorber. The most common solvents used for neutralizing CO_2 in chemical absorption systems are alkanolamines such as monoethanolamine (MEA), diethanolamine (DEA), and methyldiethanolamine (MDEA). The solvent-bound carbon dioxide is then re-heated to around 120°C in order to enable the solvent to be stripped from the CO_2 inside a regeneration vessel. This uses steam generated in the process as the stripping gas. The stripped solvent is cooled and returns to the absorber whilst the steam is condensed and returns to the regeneration vessel. The separated CO_2 can then be dehydrated and compressed for efficient transportation and sequestered in various types of geological formations, on the deep ocean seabed or converted to solid mineral form.

For the NEEDS Integrated Project, the scenario of transportation via pipeline to a geological sequestration site[a] was used. This involves a 400km pipeline requiring one recompression process at the halfway point. Transport of CO_2 in pipelines is cheaper than shipping over short distances due to relatively high fixed costs for harbors, loading and unloading. Shipping only becomes competitive at distances between 1000 km and 2000 km. The CO_2 gas is then injected into a saline aquifer approximately 800 m below the earth's surface. Deep saline aquifers are widely distributed below the continents and the ocean floor and are within easy access to a number of power plants. This process is technically feasible and is currently in the demonstration phase.

The major drawbacks of CCS are the significant costs involved and the overall reduction of efficiency for the power plant as energy from the combustion process is required to capture the CO_2. The overall net efficiency of the PC-post CCS power plant was assumed to be 49% with a plant lifetime of 35 years.

5. Fossil: Pulverized Coal with oxyfuel combustion and CCS (Hard coal PC, oxyfuel CCS) (Bauer et al., 2009)

Oxyfuel combustion involves burning the pulverized coal in an environment of oxygen instead of ambient air. However, combustion with pure oxygen would make the temperature too high so oxygen derived from an air separation unit is mixed with CO_2 recycled from the exhaust in order to control the combustion temperature. The exhaust from oxyfuel combustion is flue gas with a very high CO_2 concentration (no nitrogen oxides are formed) that enables simple and low cost CO_2 purification methods to be used and a more efficient CCS process. Particles are removed from the flue gas using an electrostatic charge before entering a flue gas desulfurization process requiring inputs of limestone and water (this produces gypsum as a marketable by-product). Furthermore, the volume of inert gas is reduced which can increase the thermal efficiency of the boiler. Although the oxyfuel combustion technique can be applied to conventional boilers, the major drawback of this approach is that the production of oxygen typically involves an air separation unit with a complex, costly and energy-intensive super-cooling (cryogenic) process to extract oxygen from the air. For the NEEDS Integrated

[a] Due to the highest potential in Europe, saline aquifers were chosen as the reference storage medium.

Project, the same transportation scenario using a 400 km pipeline to a saline aquifer sequestration site was used.

Oxyfuel combustion with CCS suffers similar drawbacks to that of post combustion CCS, but due to the necessary production of oxygen the overall net efficiency of the PC-oxyfuel CCS technology was set marginally lower at 47%, with the same plant lifetime of 35 years.

6. Fossil: Pulverized Lignite (Lignite PC) (Bauer et al., 2009)

This lignite plant uses larger but similar power plant technology as the pulverized hard coal plant, with the same net power plant efficiency. An important added impact from the use of lignite as opposed to coal is the effect on the landscape due to large open pit mining. Lignite also contains a larger proportion of incombustible impurities that must be removed as ash and disposed. However, fuel transport over long distances is not necessary as with hard coal, since lignite power plants are uneconomic unless operated either at the mine or within a short distance from it.

7. Fossil: Pulverized Lignite with post combustion Carbon Capture and Storage (Lignite PC, post comb. CCS) (Bauer et al., 2009)

This lignite plant uses larger but similar power plant technology as the pulverized hard coal plant with post-combustion CCS, with the same power plant net efficiency. Modeling of CO_2 transport and storage is identical.

8. Fossil: Pulverized Lignite with oxyfuel combustion and CCS (Lignite PC, oxyfuel CCS) (Bauer et al., 2009)

This lignite plant uses larger but very similar power plant technology as the pulverized hard coal plant with oxyfuel combustion CCS, with the same power plant net efficiency. Modeling of CO_2 transport and storage is identical.

9. Fossil: Integrated Gasification Combined Cycle coal (Hard coal IGCC) (Bauer et al., 2009)

Integrated Gasification Combined Cycle (IGCC) technology is an emerging advanced power generation system having the potential to generate electricity from coal with high efficiency and lower air pollution (NO_x, SO_2, CO and PM_{10}) than other current coal-based technologies.

An IGCC power plant consists of a gasification unit in which the quantity of oxygen is insufficient to completely burn the coal and, due to the high temperature and pressure, the resulting gas has a high level of hydrogen (H_2), carbon monoxide (CO). Oxides of nitrogen and sulfur are not formed in the (reducing) environment of the gasifier but, instead, react with hydrogen to form ammonia and hydrogen sulfide. The ammonia and sulfur are then easily extracted to become marketable byproducts. The synthesis gas (syngas) is cleaned before being fired in a gas turbine to generate electricity. The high temperature exhaust of the gas turbine still has enough heat to produce super-heated steam in a steam generator as part of a conventional steam cycle. It is this use of two thermodynamic cycles in a cascade that gives the name "combined cycle".

Minerals in the fuel (i.e., the rocks, dirt and other impurities that don't gasify like carbon-based constituents) separate and for the most part leave the bottom of the gasifier either as an inert glass-like slag or other marketable solid byproducts. Although oxygen-blown coal gasifiers can be more efficient and pure oxygen is not diluted by the large quantities of nitrogen present in air, making oxygen using conventional cryogenic air separation plants is expensive; both in terms of capital cost and energy consumption (see also oxyfuel combustion technologies). IGCC power plants are also relatively inflexible in that they have to be designed for a specific type of coal or solid fuel in order to provide a high reliability. On the other hand, IGCC technology offers the environment related advantages of high efficiency and very low emissions of SO_2, NO_x and particulates. The power plant net efficiency of this technology was determined to be 54.5%.

10. Fossil: Integrated Gasification Combined Cycle coal with CCS (Hard coal IGCC CCS) (Bauer et al., 2009)

IGCC technology lends itself very well to carbon capture and storage (CCS) due to the higher pressure of the gas stream and the possibility to achieve the highly concentrated formation of CO_2 prior to combustion. For this to be possible then after having been cleaned of particulates the syngas enters a shift reaction unit in which the methane is reacted with steam to produce hydrogen and CO_2. The preferred technique for CO_2 separation in applications at higher pressure (i.e. IGCC) is currently physical absorption using solvents commonly used in commercial processes. Once captured, the CO_2 can then be treated in the same way as for the other technologies incorporating CCS. The resulting power plant net efficiency for this technology scenario is 48.5%. CO_2 transport and storage is modeled in the same way as for PC power plants.

11. Fossil: Integrated Gasification Combined Cycle lignite (Lignite IGCC) (Bauer et al., 2009)

This used a larger but very similar power plant technology as for the IGCC-coal plant but with a marginally lower overall efficiency of 52.5%. An important additional impact from the use of lignite as opposed to coal is the effect on the landscape due to large open pit mining activities as well as the higher quantity of ash requiring disposal. However, the transportation of fuel over long distances is not necessary, because lignite power plants are operated mine-mouth.

12. Fossil: Integrated Gasification Combined Cycle lignite with CCS (Lignite IGCC, CCS) (Bauer et al., 2009)

This used a larger but very similar power plant technology as for the IGCC-coal plant but with a marginally lower overall efficiency of 46.5%. CO_2 transport and storage is modeled in the same way as for PC power plants.

13. Fossil: Gas Turbine Combined Cycle (Nat. gas CC) (Bauer et al., 2009)

A gas turbine combined cycle (GTCC) power plant involves the direct combustion of natural gas in a gas turbine generator. The waste heat generated by this process is then used to create steam for use in a steam generator, in a similar manor to that of IGCC technologies. In this combined cycle power plant around two-thirds of the overall plant capacity is provided by the gas turbine. Further efficiency developments of the gas turbine will be mainly driven by material research in order to increase the firing temperature and the pressure ratio. Although GTCC plants have relatively low CO_2 emissions per unit of generated electricity compared to other fossil power plants, they can be the source of significant NO_x emissions due to the high combustion temperature that is desirable for high efficiencies. Therefore, whilst primary fuel prices will remain to be the decisive factor in the development and future of natural gas generated electricity, political decisions regarding environmental targets will also play a decisive role in their economic competitiveness.

One of the main advantages of a GTCC power plant is its flexibility of operation. This means that it can provide both base load power as well as being available to cover the shorter duration peak loads and unexpected shortfalls in supply. The net power plant efficiency of this technology is predicted to be 65% in 2050.

14. Fossil: Gas Turbine Combined Cycle with CCS (Nat. gas CC, post comb. CCS) (Bauer et al., 2009)

The electricity generation aspect of this technology is exactly the same as the GTCC without CCS. The flue gas from the GTCC then enters the same CO_2 separation, stripping, drying, transportation and sequestration process to that used for coal and lignite CO_2 capture. However, CO_2 is assumed to be stored not in aquifers, but in depleted gas fields with a depth of 2500m. Owing to the energy requirements of the CCS process the net power plant efficiency of this form of electricity generation is 61%.

15. Fossil: Internal Combustion Combined Heat and Power (Nat gas CHP) (Bauer et al., 2009)

This is a decentralized form of co-generation for use in situations where not only the electricity but also the heat produced in the combustion process is a desired product. Using an internal combustion engine as opposed to a turbine generator, this technology is suited to provide heat and power to single buildings such as public buildings, small industry, etc. or to groups of residential buildings sharing a distribution network where the product in most demand can be the heat produced. They are most efficiently used to cover a simultaneous electricity and heat demand rather than for use to meet peak in only electricity demand. Heat produced by combustion of the gas can be transferred to a water or air medium depending on the specific requirement. The electricity generator is directly coupled to the internal combustion engine. The efficiency of electricity generation is 44%.

16. Fossil: Molten Carbonate Fuel Cells using Natural Gas 0.25 MW (Nat. gas MCFC, small) (Gerboni et al., 2008)

Molten carbonate fuel cells are a moderately high temperature form of fuel cell and can achieve a relatively high overall efficiency compared to those operating at lower temperatures. In a molten carbonate fuel cell, the electrolyte is made up of lithium-potassium carbonate salts heated to about 650°C. At these temperatures, the salts melt into a molten state that can conduct charged particles, called ions, between two porous electrodes. The high concentration of methane (CH_4) in natural gas is combined with steam and converted into a hydrogen-rich gas within the fuel cell. At the anode, hydrogen reacts with the carbonate ions to produce water, carbon dioxide, and electrons. The electrons travel through an external circuit creating electricity and return to the cathode. There, oxygen from the air and carbon dioxide recycled from the anode react with the electrons to form carbonate ions that replenish the electrolyte and provide ionic conduction through the electrolyte, completing the circuit (DOE, 2009). A fuel cell therefore uses an efficient electro-chemical reaction to convert the chemical energy of the natural gas into electricity rather than the less efficient and more polluting combustion of the natural gas. This also means that the energy conversion process is very quiet as well as being dependable and stable due to the non-mechanical nature of the process.

For the NEEDS project, the insufficiently high temperature of the exhaust gas as well as the small decentralized scale of this technology meant that the waste heat from the fuel cell would be used as useful heat rather than to create steam for a steam generator. The efficiency of electricity generation is 50% for this particular technology.

17. Biomass: Molten Carbonate Fuel Cell using wood derived gas 0.25 MW (Wood gas MCFC) (Gerboni et al., 2008)

Using a gasification process similar to that for previously described fossil fuel gasification, this technology uses gas generated with sustainable sources of harvested wood or from waste wood streams. Cleaned of particulates the methane rich synthetic natural gas (SNG) can be used in the same way as natural gas and fuels the MCFC in the same way as with natural gas. The efficiency of generating electricity with this form of gas is then the same as when using natural gas (50%). The conversion efficiency from potential energy in the wood to potential energy in the wood gas is not included in this determination because obtaining the wood gas is considered as an economic consideration similar to obtaining natural gas. Here, the waste heat is also used for space heating, drying, etc.

18. Fossil: Molten Carbonate Fuel Cells using Natural Gas 2MW (Nat. gas MCFC, big) (Gerboni et al., 2008)

The same decentralized technology as for the 0.25 MW plant but scaled up to deliver an electricity generation capacity of 2MW. Due to the size of plant and technological advancement by 2050, it is expected that the MCFC will be part of a hybrid plant that features the use of the waste heat to power steam turbine as a secondary electricity generation method. At 55%, the energy conversion to electricity is therefore slightly higher than for the smaller plant.

19. Fossil: Solid Oxide Fuel Cells using Natural Gas 0.3 MW (Nat. gas SOFC) (Gerboni et al., 2008)

Although they also use an electrochemical conversion process Solid Oxide Fuel Cells (SOFC’s) operate at a relatively high temperature (1000°C) and use a semi permeable solid oxide (ceramic) electrolyte rather than a liquid one. Furthermore, an SOFC can be fuelled by liquid or gaseous fuels and which are reformed into a hydrogen rich gas within the cell. Although a small-scale, decentralized plant, the higher operating temperature means that the exhaust gas can be used to power a steam generator giving the SOFC a better electricity generating efficiency (58%) than even a larger MCFC.

20. Biomass: Combined Heat and Power using short rotation coppiced poplar (Poplar CHP) (Gärtner, 2008)

As has been previously described, combined heat and power is a co-generational form of converting the potential energy stored in the fuel. The power plant is designed to generate electricity whilst the waste heat produced is provided to an external heat demand in close proximity to the plant. Whereas the small scale IC CHP used a gas fired internal combustion engine, the CHP plant modeled here uses the direct feed of woody biomass and is significantly larger. Here, then, the use of short rotation coppiced (SRC) poplar as the biomass feed stock is modeled and the conversion efficiency of the potential energy in the wood to electrical energy is determined.

Poplar can be commercially grown as an energy crop using the practice of SRC. Within 1-2 years of the initial planting of poplar cuttings, they are cut back to encourage the growth of multiple stems from a stool at ground level. Further cultivation for 2-4 years results in the growth of sufficient woody material for it to be mechanically harvested by clear-cutting the stems above the stool. The development of the root system encourages the further shooting of new stems and the harvesting of these after the same time period. It is this continuous cycle and the periodic harvesting of naturally regenerating biomass on the same area of land that enables the sustained supply of this commercial fuel source (Tubby and Armstrong, 2002).

Once dried and chipped, the biomass is fed into a gasification process very similar to those previously described. The scale is smaller however, with the gas turbine of the biomass CHP plant having a capacity of 9MW of electricity. The overall conversion efficiency into electricity is 30%.

21. Biomass: Combined Heat and Power using straw (Straw CHP) (Gärtner, 2008)

Straw accumulates as a co-product with the harvest of feed and food grain as well as oil producing plants. It often remains on the field as a soil and nutrient enhancer, but in many cases it is also used as litter or fodder for animals. It is therefore not considered as an energy crop because it is not specifically cultivated for this purpose and which means that the transportation distances of straw to a CHP plant are less predictable than for energy crops such as SRC poplar. Straw can be crushed and then fed into a biomass gasifier in the same way as for the poplar and the processes from here on are the same with the same overall efficiency of conversion to electricity of 30%.

22. Solar: Photovoltaic, ribbon crystalline Silicon - power plant (PV, c-Si, ground) (Taken from Frankl et al., 2006)

Currently, around 85 to 90% of the total installed global photovoltaic (PV) capacity uses wafer-based crystalline silicon semi-conductor technologies. Wafer-based cells are ether a single, homogenous slice of a grown silicon crystal ingot known as mono- or single-crystalline silicon and which deliver the highest efficiencies. More commonly, they are the single slice from a casted block of many small silicon crystals known as poly- or multi-crystalline silicon and which are slightly less efficient. An alternative and advancing method for producing crystalline silicon semi-conductors, however, is ribbon technology. Here, a ribbon of substrate material is pulled directly from a bath of molten silicon causing the silicon to crystallize on the ribbon. There is therefore no requirement to produce an ingot and to saw it into wafers, which avoids significant material losses. This technology tends to have similar efficiencies to multi-crystalline silicon wafers but a much better utilization rate of the silicon feedstock. For the NEEDS Integrated Project it was determined that under a realistic-optimistic development scenario until 2050, ribbon technology will advance sufficiently to occupy a significant share of the crystalline silicon market and offers advantages due to its efficient use of resources. For this particular technology scenario a centralized power plant size was modeled with an electricity generating capacity of 46.6MW using an average PV module efficiency of 22%.

23. Solar: Photovoltaic, ribbon crystalline Silicon - building integrated (PV, c-Si, rooftop) (Frankl et al., 2006)

Here the PV technology is exactly the same as for 22 but the size of the installation is significantly smaller and integrated onto a new or existing building. At 420 kW, this is suited to the roof of a public or commercial building and is too large for most domestic residences.

24. Solar: Photovoltaic Cadmium Telluride – building integrated (PV, CdTe, rooftop) (Frankl et al., 2006)

It has been described that 85 to 90% of the total installed global photovoltaic (PV) capacity uses wafer-based crystalline silicon semi-conductor technologies. The remaining 10 to 15% is largely made up of thin-film technologies. These are manufactured by depositing extremely thin layers (less than half the thickness of a silicon wafer) of photosensitive materials on a low cost backing such as glass, stainless steel or plastic. Although the first thin-film PV semi-conductors also used silicon, there are now various material compositions used. Of these, cadmium-telluride (CdTe) is deposited as a film less than one tenth the thickness of a silicon wafer and offers a relatively good resource requirement to efficiency ratio (Frankl, 2005).

Following the optimistic-realistic development scenario until 2050, a CdTe thin-film module is expected to operate with an efficiency equal to that of the ribbon crystalline silicon modules. This technology is also at the building integrated scale.

25. Solar: Concentrating thermal – power plant (Solar thermal) (Viebahn et al., 2008)

There are now several large-scale solar thermal power generation systems installed, mainly in Europe and the U.S., which use a variety of methods to capture energy from solar radiation, transform it into heat, and generate electricity from the heat using either steam turbines, gas turbines, Stirling engines, or pressure staged turbines. Only locations with irradiations of more than 2,000 kWh/(m^2a) are suited to a reasonable economic solar thermal performance. For the NEEDS Integrated Project, the optimistic realistic scenario development for 2050 used a 400MW parabolic trough collector system in combination with an overnight thermal energy storage system for 24-hour solar-only power generation.

Parabolic trough systems consist of trough solar collector arrays, at the horizontal focal point of which is a fluid filled pipe. This heat transfer fluid (HTF) is heated to around 400 °C which is sufficient to power a conventional steam turbine and generator, and by 2050 the HTF will be steam (currently synthetic thermo oil).

The use of steam as the HTF would enable the direct propulsion of the turbine by the solar heated fluid without the use of an intermediary exchange medium whilst presenting a high cost reduction potential. The implementation of direct steam technology, however, requires the development of a new latent heat storage medium for the evaporation process of the cycle and which necessarily means the use of phase change materials (PCM). A PCM based storage system for this application would consist of salt, concrete, and aluminum. Furthermore, to have the ability to continue electricity generation overnight and through the hours of insufficient solar radiation, the concrete and PCM based storage must be have the capacity to maintain 16 hours of high pressure steam.

Based on laboratory-scale trials, a concrete/PCM storage system operates in three steps:

- During the *preheating* step a conventional thermal mass storage unit of concrete is heated up (sensible heat storage).

- This step is followed by the *evaporation* phase. The increasing heat causes the salt to undergo phase changes (e.g. from solid to liquid) but does not increase the storage temperature. Aluminum plates in the salt increase the thermal conductivity.

- In the last step, the *superheating* phase, a concrete storage is again used to heat the steam to the required temperature.

The net power plant efficiency of this technology is expected to be 18.5%.

26. Wind: Offshore Wind (Offshore wind) (Dong, 2008)

The exploitation of wind energy has increased exponentially during the last decades, and there is still large unexploited wind energy potential in many parts of the world – both onshore and offshore. However, the success story of onshore wind energy has led to a shortage of land sites in many parts of Europe, particular in northwestern Europe, and has spurred the interest in exploiting offshore wind energy. Regarding offshore wind farms particularly, economies of scale mean that farms consisting of multiple wind turbines all connected to a single transformer station are more financially viable than individual turbines. Offshore sites also enjoy the advantage of having significantly more stable and higher wind speeds than onshore sites and which leads to a longer turbine life. In addition, modern offshore wind turbines can also be remotely monitored and controlled, which gives unique advantages when regulating the power output.

The size, capacity, material structure and anchoring of offshore wind turbines in 2050 can only be extrapolated from recent developments as well as logistical and financial parameters. The emphasis will be on reducing weight, material consumption, handling costs and production costs, whilst the individual capacities of wind turbines will continue to grow, potentially reaching 30 – 50 MW by 2050 (by comparison, largest currently available are in the 5-6MW range). As the development moves further off shore and into water depths of more than 30 meters, the monopile design used most often up to now will need to be replaced by other designs including floating turbines.

For the NEEDS project, a realistic/optimistic development scenario resulted in a turbine capacity of 24MW, located in a farm of around 80 turbines. The foundation system is a guyed steel monopile for an unspecified water depth. It is expected to have an operational lifetime of 30 years.

5 Summary and Conclusions

The NEEDS database is an essential step in combining the technology analysis contributions from many different NEEDS participants and passing them along to the NEEDS multi-criteria analysis effort. It also serves the role of summarizing these contributions in one place, and making them readily available to the NEEDS stakeholders and general public for information and discussion. The design and execution of the database in its spreadsheet format has fulfilled the basic design requirements, and is well suited to future revisions and dissemination.

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Note: Data originating from Research Streams 1a and 1b were compiled from the several reports produced by these streams, including primarily those cited above. We refer the reader to the NEEDS website to download these reports,
(http://www.needs-project.org/index.php?option=com_content&task=view&id=42&Itemid=66).

Table 1 - NEEDS Technologies for 2050

Characteristics	Units	1	2	3	4	5	6	7	8	9	10	11	12
		Nuclear Plants		**Advanced Fossil**						**Integrated Gasification Combined Cycle**			
		EPR	**EFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
		European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
Type of fuel		U235, 4.9%	Mixed Oxide	hard coal	hard coal	hard coal	lignite	lignite	lignite	hard coal	hard coal	lignite	lignite
Electric efficiency	%	0.37	0.4	0.54	0.49	0.47	0.54	0.49	0.47	0.545	0.485	0.525	0.465
Electric generation capacity	MW	1590	1450	600	500	500	950	800	800	450	400	450	400
Load factor (expected hours/yr)	hours/year	7916	7889	7600	7600	7600	7760	7760	7760	7500	7500	7500	7500
Annual generation (expected)	kWh/year	1.26E+10	1.14E+10	4.56E+09	3.80E+09	3.80E+09	7.37E+09	6.21E+09	6.21E+09	3.38E+09	3.00E+09	3.38E+09	3.00E+09
Construction time	years	4.8	5.5	3	3	3	3	3	3	3	3	3	3
Capital cost (net present value)	€/kWe	1498	1900	983	1560	1560	989	1560	1560	1209	1505	1209	1209
Total capital cost (net present value)	M€	2383	2756	590	780	780	939	1248	1248	544	602	544	483
Plant life	years	60	40	35	35	35	35	35	35	35	35	35	35
Average cost of electricity	€cents/kWhe	3.01	2.68	2.96	3.94	4.00	3.01	4.08	4.16	6.17	7.26	6.57	6.78

Characteristics	Units	13	14	15	16	17	18	19	20	21	22	23	24	25	26
					Fuel Cells				**Biomass CHP**		**Solar**				**Wind**
		GTCC	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
		Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	IC engine cogeneration	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
Type of fuel		natural gas	natural gas	natural gas	natural gas	wood gas	natural gas	natural gas	SRF poplar	waste straw	sun	sun	sun	sun	wind
Electric efficiency	%	0.65	0.61	0.44	0.5	0.5	0.55	0.58	0.3	0.3	0	0	0	0.185	0
Electric generation capacity	MW	1000	1000	0.2	0.25	0.25	2	0.3	9	9	46.6375	0.4197375	0.839475	400	24
Load factor (expected hours/yr)	hours/year	7200	7200	5000	5000	5000	5000	5000	8000	8000	984	984	984	4518	4000
Annual generation (expected)	kWh/year	7.20E+09	7.20E+09	1.00E+06	1.25E+06	1.25E+06	1.00E+07	1.50E+06	7.20E+07	7.20E+07	4.59E+07	4.13E+05	8.26E+05	1.81E+09	9.60E+07
Construction time	years	3	3	1	0.83	0.83	0.83	0.83	2	2	2	0.5	0.5	3	2
Capital cost (net present value)	€/kWe	440	615	879	1544	1544	1235	1030	2280	2280	848	927	927	3044	1130
Total capital cost (net present value)	M€	440	615	0	0	0	2	0	21	21	40	0	1	1217	27
Plant life	years	25	25	20	5	5	5	5	15	15	40	40	35	40	30
Average cost of electricity	€cents/kWhe	5.99	8.69	11.10	8.74	8.44	7.29	6.73	7.29	6.51	6.30	6.92	7.15	6.31	7.27

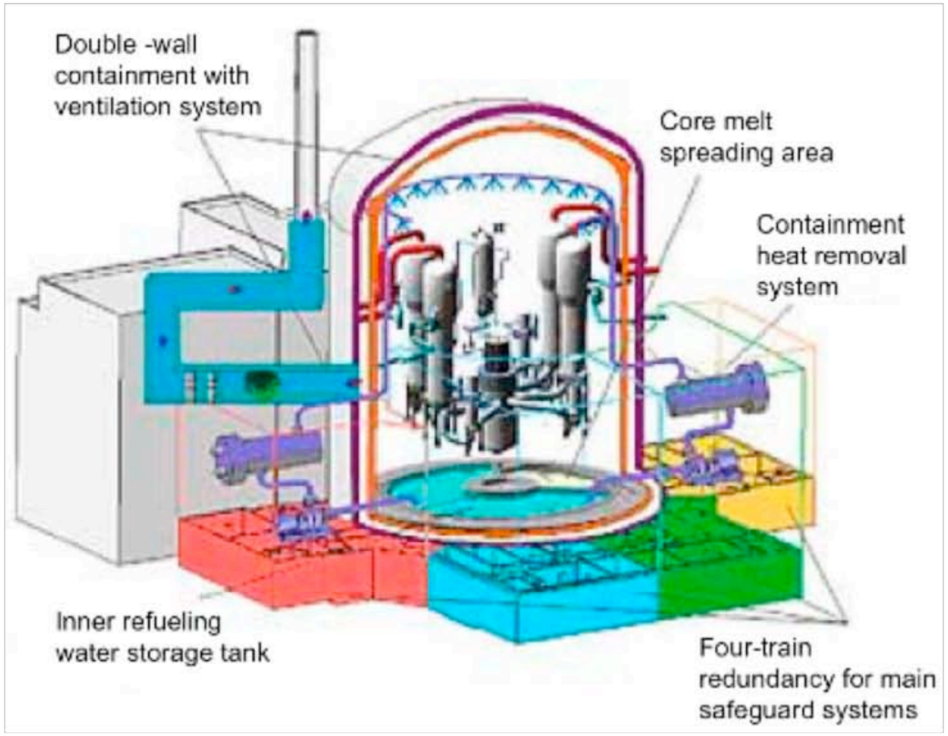
Technology Descriptions for Web Survey on Multi-Criteria Analysis

This series of slides gives general descriptions of the 26 generation technologies contained in the NEEDS database for multi-criteria evaluation. It includes 2 nuclear, 16 fossil (10 coal & lignite, and 6 natural gas) and 8 renewable (biomass, solar and wind) technologies.

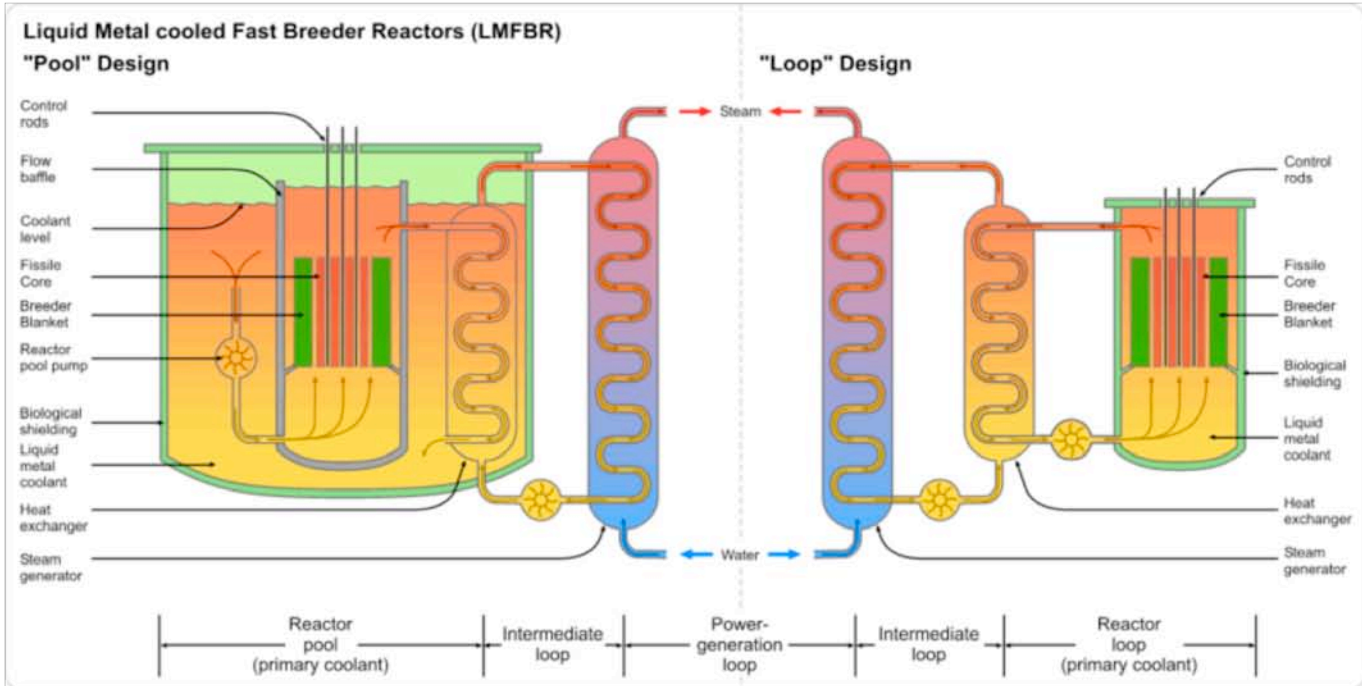
The intent is to introduce these technologies to readers who are not familiar with them by presenting pictures, a table of technical data and a brief description of the technology and related social factors.

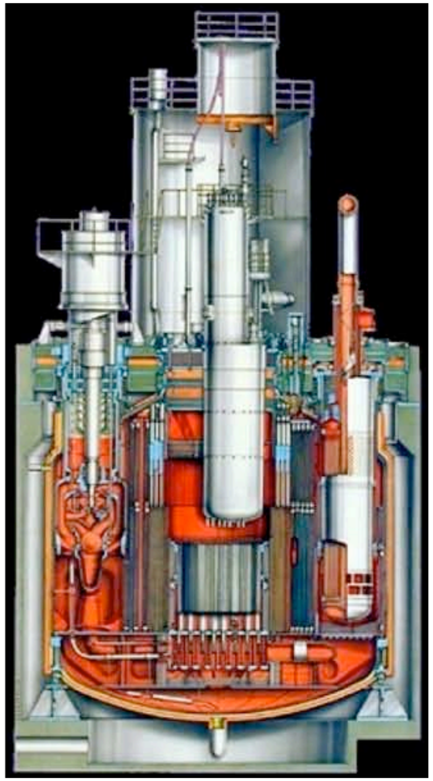
Some technologies are also illustrated separately (i.e. CO_2 separation and sequestration, and biomass gasification) that in practice must be combined combined with a power plant (as shown in the data tables). These descriptions follow the plants to which they are attached.

Nuclear, European Pressurized Reactor (EPR) - Illustrations



Nuclear, European Fast Reactor (EFR) – Illustrations





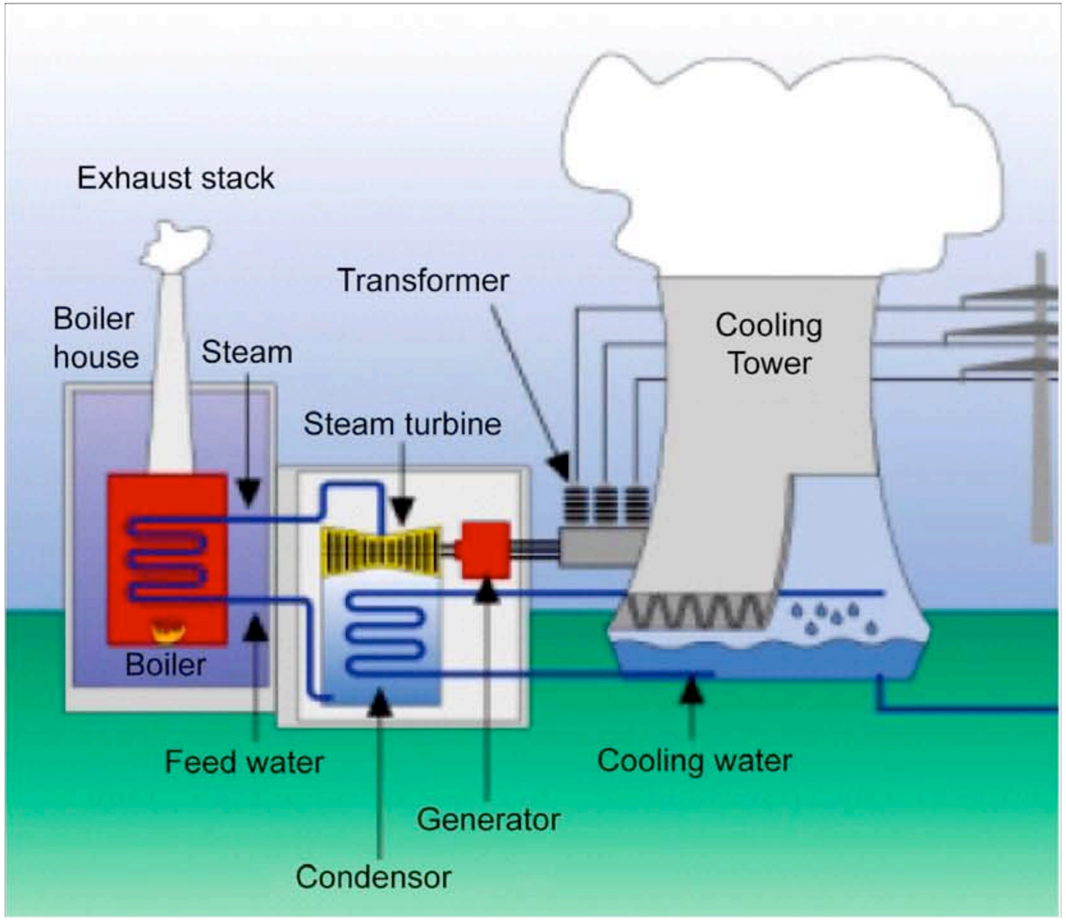
Nuclear, EPR and EFR – Technical Characteristics

Characteristics	Units	1 **Nuclear Plants** **EPR** European Pressurized Reactor	2 **EFR** Sodium Fast Reactor (Gen IV Fast Breeder Reactor
Type of fuel		U235, 4.9%	Mixed Oxide
Electric efficiency	%	0.37	0.4
Electric generation capacity	MW	1590	1450
Load factor (expected hours/yr)	hours/year	7916	7889
Annual generation (expected)	kWh/year	1.26E+10	1.14E+10
Construction time	years	4.8	5.5
Capital cost (net present value)	€/kWe	1498	1900
Total capital cost (net present value)	M€	2383	2756
Plant life	years	60	40
Average cost of electricity	€cents/kWhe	3.01	2.68

Nuclear, European Pressurized Reactor – Description and social factors

Generation Technology	**Nuclear Power, EPR**
Technical description	European Pressurized Reactor. Generation 3 pressurized water reactor (PWR) with enhanced reliability & safety.
Primary energy source	Uranium.
Form of waste requiring storage	Low to high level radioactive waste (spent fuel depends on fuel cycle and reprocessing). Low chemical waste from full technology chain.
Record of past public acceptance	No EPRs yet in service, so acceptance is limited to a few construction permits. Past nuclear acceptance in general has been mixed to poor. Accident risks, waste storage & proliferation may remain controversial.
Possible proliferation or misuse	Possible misuse of fissile materials for making weapons.
Labor mix for technology chain	Fuel cycle, plant operation construction & demolition, waste storage.
Visual disturbance	Low to moderate, mainly dependent on whether or not cooling tower is present.
Noise	Low.

Coal & Lignite Steam Power Plants – Illustrations



Lignite Open Pit Mining – Illustrations

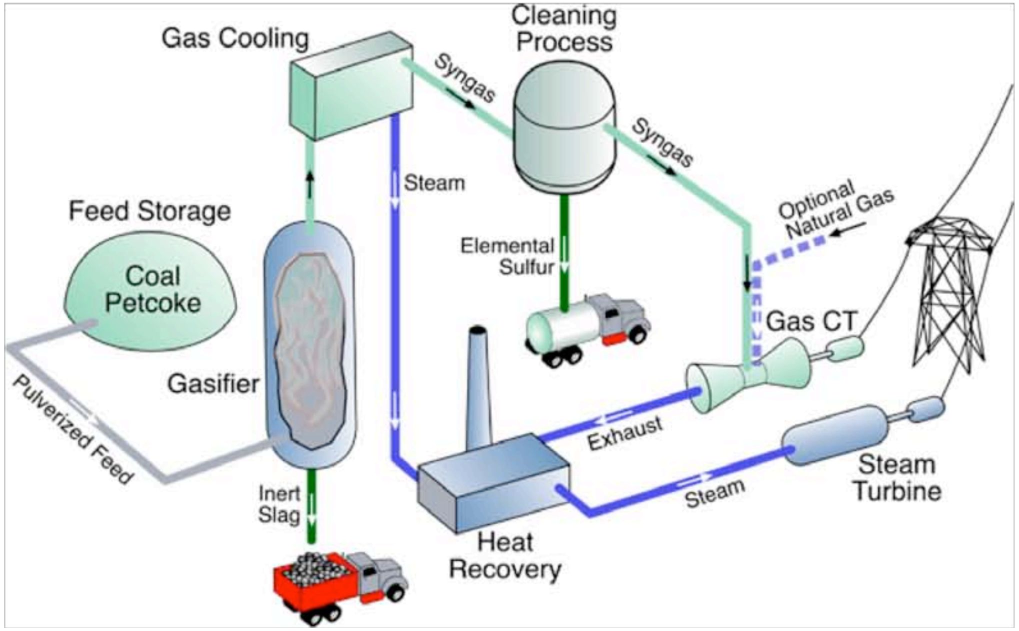
Coal & Lignite Steam Power Plants – Technical Characteristics

Characteristics	Units	3 Advanced Fossil **PC** Pulverized Coal (PC) steam plant	4 **PC-post CCS** Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	5 **PC-oxyfuel CCS** Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	6 **PL** Pulverized Lignite (PL) steam plant	7 **PL-post CCS** Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	8 **PL-oxyfuel CCS** Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion
Type of fuel		hard coal	hard coal	hard coal	lignite	lignite	lignite
Electric efficiency	%	0.54	0.49	0.47	0.54	0.49	0.47
Electric generation capacity	MW	600	500	500	950	800	800
Load factor (expected hours/yr)	hours/year	7600	7600	7600	7760	7760	7760
Annual generation (expected)	kWh/year	4.56E+09	3.80E+09	3.80E+09	7.37E+09	6.21E+09	6.21E+09
Construction time	years	3	3	3	3	3	3
Capital cost (net present value)	€/kWe	983	1560	1560	989	1560	1560
Total capital cost (net present value)	M€	590	780	780	939	1248	1248
Plant life	years	35	35	35	35	35	35
Average cost of electricity	€cents/kWhe	2.96	3.94	4.00	3.01	4.08	4.16

Coal & Lignite Steam Power Plants – Description and social factors

Generation Technology	**Coal & Lignite Steam Plants**
Technical description	Coal or lignite is pulverized and then burned in a tall boiler with watertube walls. The steam produced is used to drive a turbine generator. Polluting SO2 and particulate emissions are filtered by chemical scrubbers, fabric filters and/or electrostatic precipitators. Coal ash and scrubber by-products are recycled or landfilled. Higher boiler temperatures and pressures continue to produce higher efficiencies. CO2 separation and sequestration can be combined with technology chain.
Primary energy source	Coal or lignite.
Form of waste requiring storage	Direct waste is flyash and scrubber byproducts (gypsum). Total chemical waste for full technology chain is high, relative to other technologies.
Record of past public acceptance	Acceptance dependent on tradition, emissions controls and growing concerns about CO2. Energy chain has also required acceptance of coal mining and related health burdens.
Possible proliferation or misuse	None.
Labor mix for technology chain	Mining, transport, plant construction, generation.
Visual disturbance	Mining and generation can be visually objectionable.
Noise	Locally significant at mine and plant.

Coal & Lignite IGCC Power Plants – Illustrations



Coal & Lignite IGCC Power Plants – Technical Characteristics

Characteristics	Units	9 **Integrated Gasification Combined Cycle** **IGCC coal** Integrated Gasification Combined Cycle (IGCC)	10 **IGCC coal** Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	11 **IGCC lig** Integrated Gasification Combined Cycle (IGCC)	12 **IGCC lig** Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
Type of fuel		hard coal	hard coal	lignite	lignite
Electric efficiency	%	0.545	0.485	0.525	0.465
Electric generation capacity	MW	450	400	450	400
Load factor (expected hours/yr)	hours/year	7500	7500	7500	7500
Annual generation (expected)	kWh/year	3.38E+09	3.00E+09	3.38E+09	3.00E+09
Construction time	years	3	3	3	3
Capital cost (net present value)	€/kWe	1209	1505	1209	1209
Total capital cost (net present value)	M€	544	602	544	483
Plant life	years	35	35	35	35
Average cost of electricity	€cents/kWhe	6.17	7.26	6.57	6.78

Coal & Lignite IGCC Power Plants – Description and social factors

Generation Technology	Coal & Lignite IGCC Plants
Technical description	Integrated gasification combined cycle. Coal is transformed to a syngas fuel that is burned directly in a combustion turbine generator. The recovered waste heat is then used to drive a steam turbine generator. CO2 separation and sequestration can be combined with technology chain.
Primary energy source	Coal or lignite.
Form of waste requiring storage	Ash and other waste. Some byproducts (i.e. sulfur) are sold. Chemical waste for full technology chain is low, relative to other technologies.
Record of past public acceptance	IGCC still under development, but higher acceptance can be expected than for conventional coal plants, given fewer impacts. Energy chain has also required acceptance of coal mining and related health burdens.
Possible proliferation or misuse	None.
Labor mix for technology chain	Mining, transport, plant construction, generation.
Visual disturbance	Mining and generation can be visually objectionable.
Noise	Locally significant at mine and plant.

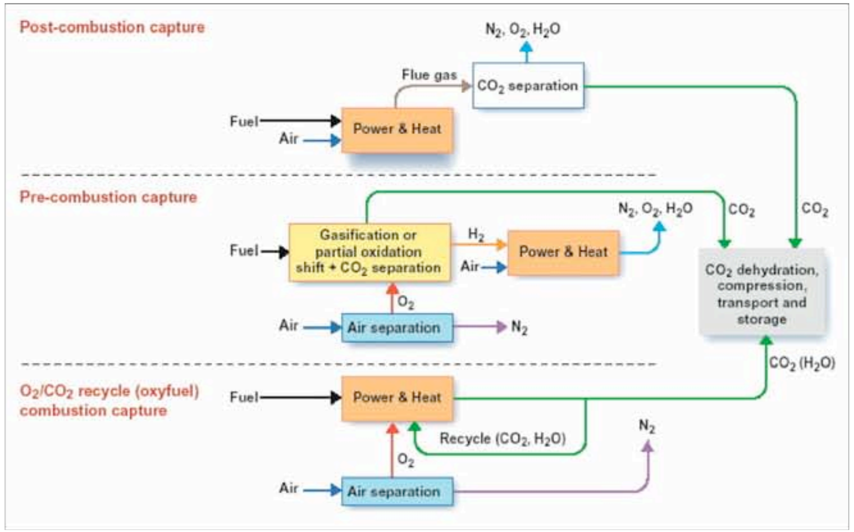
Carbon Capture & Sequestration (CCS) – Illustrations

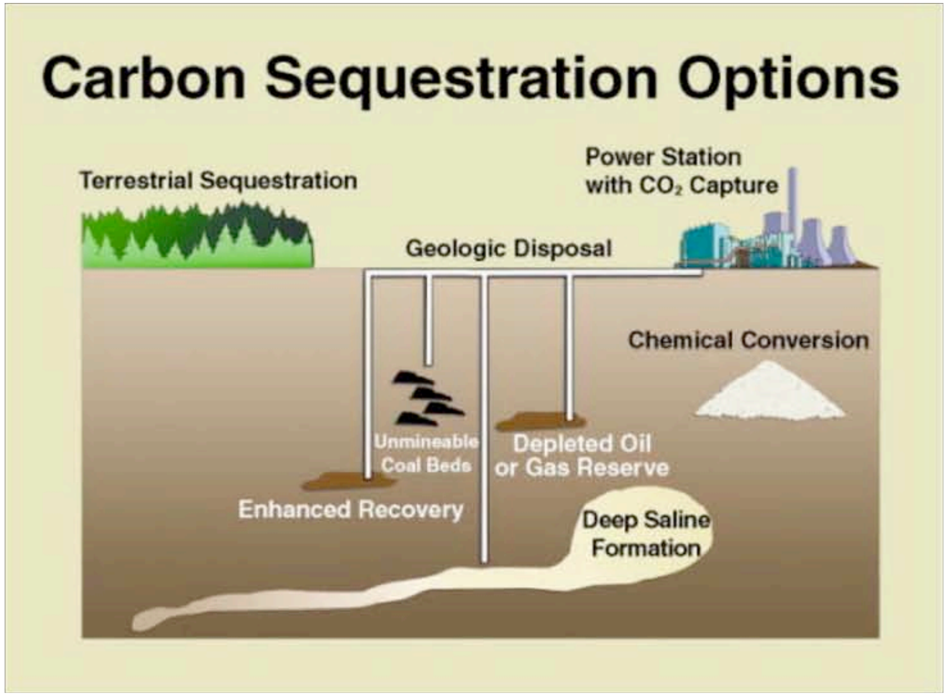
CO_2 may be separated by:

•pre-combustion capture,

•oxyfuel combustion capture, or

•post-combustion capture.



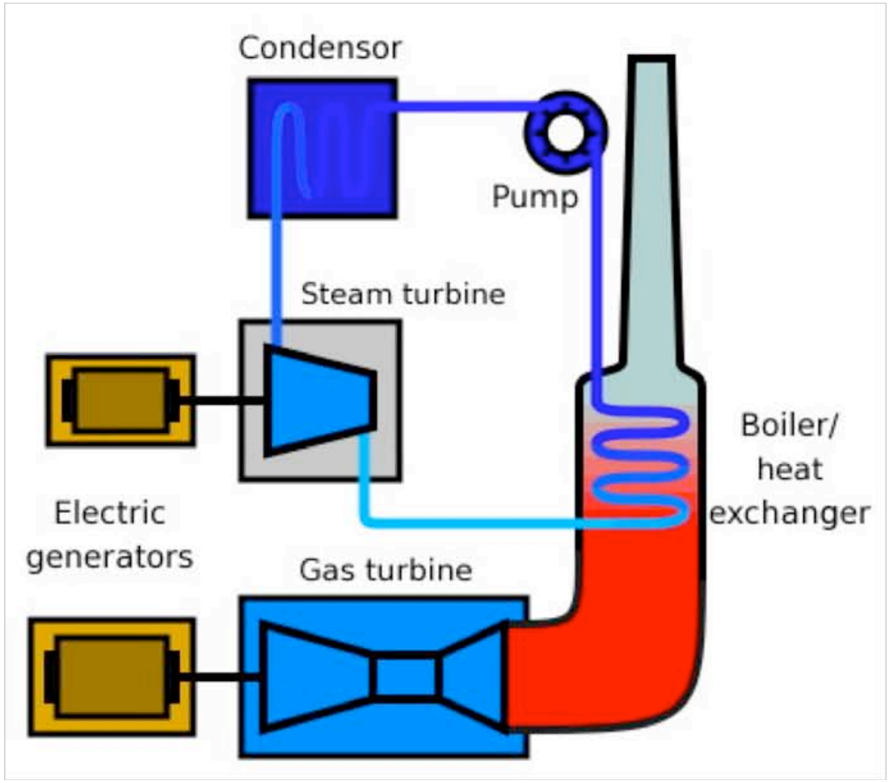


CO_2 may be sequestered
in a variety of repositories.

Carbon Capture & Sequestration – Description and social factors

Generation Technology	**Carbon Capture & Sequestration, CCS**
Technical description	CO2 can be separated by using pure O2 to preprocess the fuel before final combustion, using pure O2 and recycling some of the combustion exhaust, or by separating the CO2 from the exhaust gases from normal combustion. The separated CO2 can be sequestered in geological formations, in the deep ocean, or by conversion to solid mineral form.
Primary energy source	Dependent upon base plant technology. Decreases net generation efficiency and raises primary energy required.
Form of waste requiring storage	CO2 sequestered. Type of CSS can increase or decrease total chemical waste from entire technology chain.
Record of past public acceptance	Process(es) still under development; local acceptance problems expected.
Possible proliferation or misuse	None expected.
Labor mix for technology chain	Separation plant, pipeline transport and well or conversion.
Visual disturbance	Little extra disturbance at plant. May cause disturbance at sequestration site.
Noise	Little extra noise at generation plant. Local noise at sequestration site.

Gas Turbine Combined Cycle (GTCC) – Illustrations



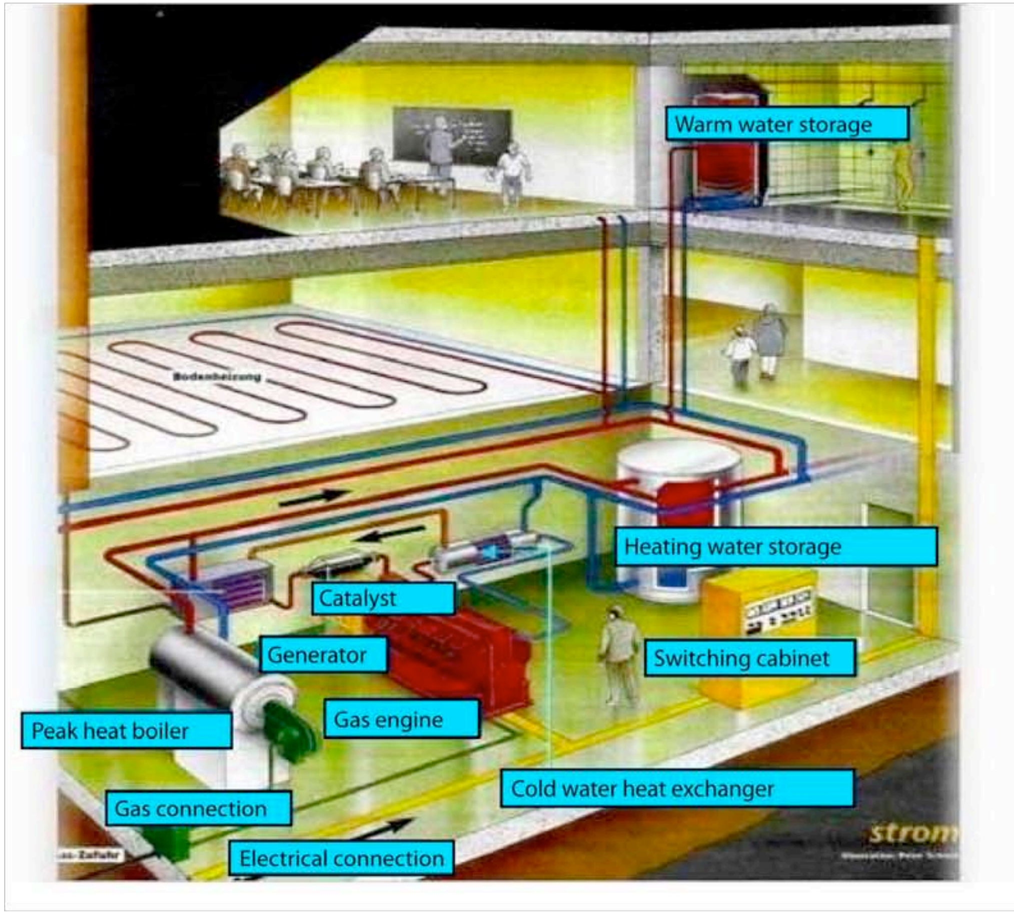
Gas Turbine Combined Cycle – Technical Characteristics

Characteristics	Units	13 **GTCC** Combined Cycle	14 **GTCC CCS** Combined Cycle with Carbon Capture & Storage (CCS), post combustion
Type of fuel		natural gas	natural gas
Electric efficiency	%	0.65	0.61
Electric generation capacity	MW	1000	1000
Load factor (expected hours/yr)	hours/year	7200	7200
Annual generation (expected)	kWh/year	7.20E+09	7.20E+09
Construction time	years	3	3
Capital cost (net present value)	€/kWe	440	615
Total capital cost (net present value)	M€	440	615
Plant life	years	25	25
Average cost of electricity	€cents/kWhe	5.99	8.69

Gas Turbine Combined Cycle – Description and social factors

Generation Technology	Gas Turbine Combined Cycle, GTCC
Technical description	Gas turbine combined cycle. Natural gas is burned directly in a combustion turbine generator, and the recovered waste heat is then used to also drive a steam turbine generator.
Primary energy source	Natural gas.
Form of waste requiring storage	Moderate chemical waste for full technology chain.
Record of past public acceptance	Moderate for generating plant. Growing concerns about CO2 emissions. Also requires acceptance of natural gas pipeline network.
Possible proliferation or misuse	None.
Labor mix for technology chain	Drilling, pipeline transport, plant construction & operation.
Visual disturbance	Low local disturbance. Pipeline networks largely underground.
Noise	Low local noise levels.

Cogeneration, Small Engine – Illustrations



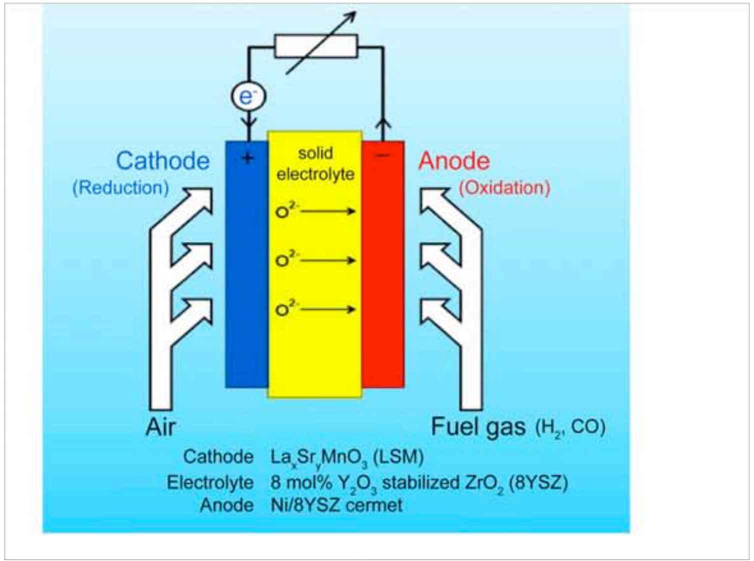
Cogeneration, Small Engine – Technical Characteristics

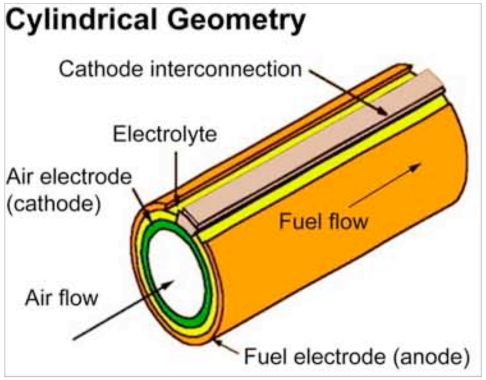
Characteristics	Units	15 **IC CHP** IC engine cogeneration
Type of fuel		natural gas
Electric efficiency	%	0.44
Electric generation capacity	MW	0.2
Load factor (expected hours/yr)	hours/year	5000
Annual generation (expected)	kWh/year	1.00E+06
Construction time	years	1
Capital cost (net present value)	€/kWe	879
Total capital cost (net present value)	M€	0
Plant life	years	20
Average cost of electricity	€cents/kWhe	11.10

Cogeneration, Small Engine – Description and social factors

Generation Technology	Small Internal Combustion Engine Cogeneration, Distributed
Technical description	Small internal combustion engine drives generator and provides heat. Used in distributed residental & commercial applications.
Primary energy source	Natural gas, wood (synthesized gas) or biomass (digester gas).
Form of waste requiring storage	Moderate chemical waste for full technology chain.
Record of past public acceptance	Distributed nature means public acceptance is not a critical issue. Natural gas fuel requires acceptance of drilling & pipeline transport. Biogas requires acceptance of biomass harvest & transport.
Possible proliferation or misuse	None.
Labor mix for technology chain	Manufacturing, installation.
Visual disturbance	None (inside buildings).
Noise	Minimal, local.

Fuel Cells, Cogeneration – Illustrations





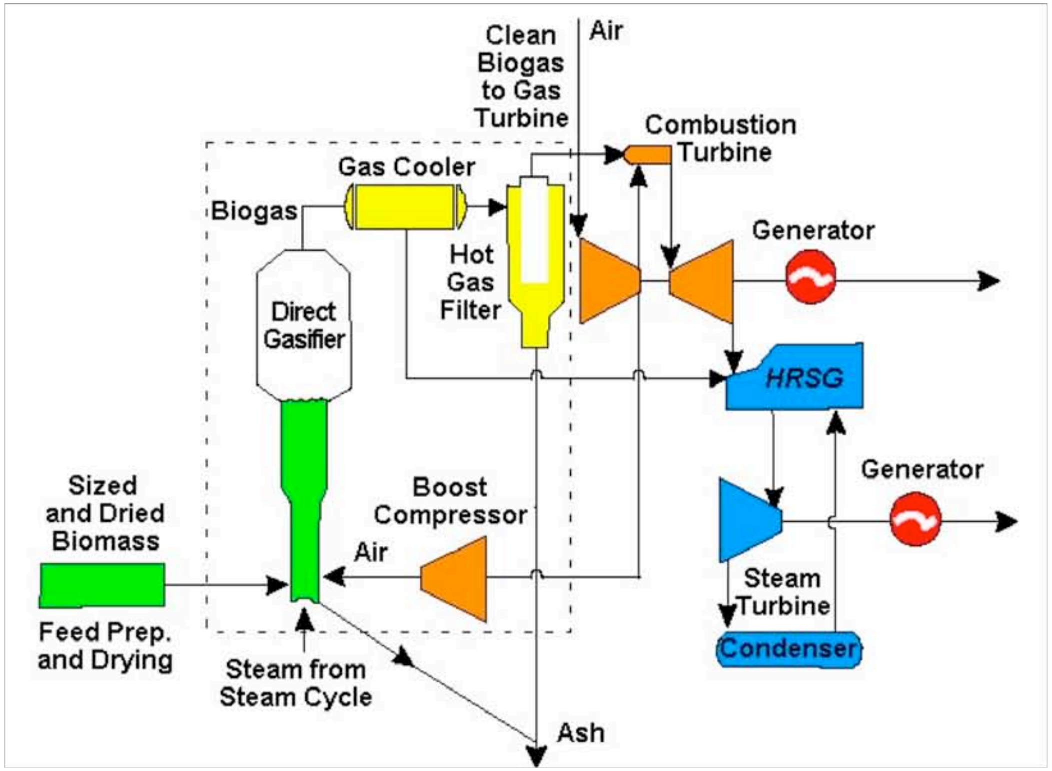
Fuel Cells, Cogeneration – Technical Characteristics

Characteristics	Units	16 **Fuel Cells** **MCFC NG** Molten Carbonate Fuel Cells, natural gas	17 **MCFC wood gas** Molten Carbonate Fuel Cells, wood gas	18 **MCFC NG** Molten Carbonate Fuel Cells, natural gas	19 **SOFC NG** Solid Oxide Fuel Cells (tubular, natural gas
Type of fuel		natural gas	wood gas	natural gas	natural gas
Electric efficiency	%	0.5	0.5	0.55	0.58
Electric generation capacity	MW	0.25	0.25	2	0.3
Load factor (expected hours/yr)	hours/year	5000	5000	5000	5000
Annual generation (expected)	kWh/year	1.25E+06	1.25E+06	1.00E+07	1.50E+06
Construction time	years	0.83	0.83	0.83	0.83
Capital cost (net present value)	€/kWe	1544	1544	1235	1030
Total capital cost (net present value)	M€	0	0	2	0
Plant life	years	5	5	5	5
Average cost of electricity	€cents/kWhe	8.74	8.44	7.29	6.73

Fuel Cells, Cogeneration – Description and social factors

Generation Technology	Fuel Cell Cogeneration, Distributed
Technical description	Polymer electrolyte, molten carbonate and solid oxide fuel cells. Direct conversion of chemical energy to electricity, and use of heat in distributed residential and commercial applications.
Primary energy source	Natural gas or wood (synthesized gas).
Form of waste requiring storage	Moderate chemical wastes for full technology chain, with relatively less for wood gas.
Record of past public acceptance	Distributed nature means public acceptance is not a critical issue. Natural gas fuel requires acceptance of drilling & pipeline transport. Syngas requires acceptance of wood harvest & transport.
Possible proliferation or misuse	None.
Labor mix for technology chain	Manufacturing, installation for plant. Gas-drilling & pipelines. Syngas-logging & transport.
Visual disturbance	None (inside buildings).
Noise	Minimal, local.

Biomass Gasification, Heat & Power – Illustrations



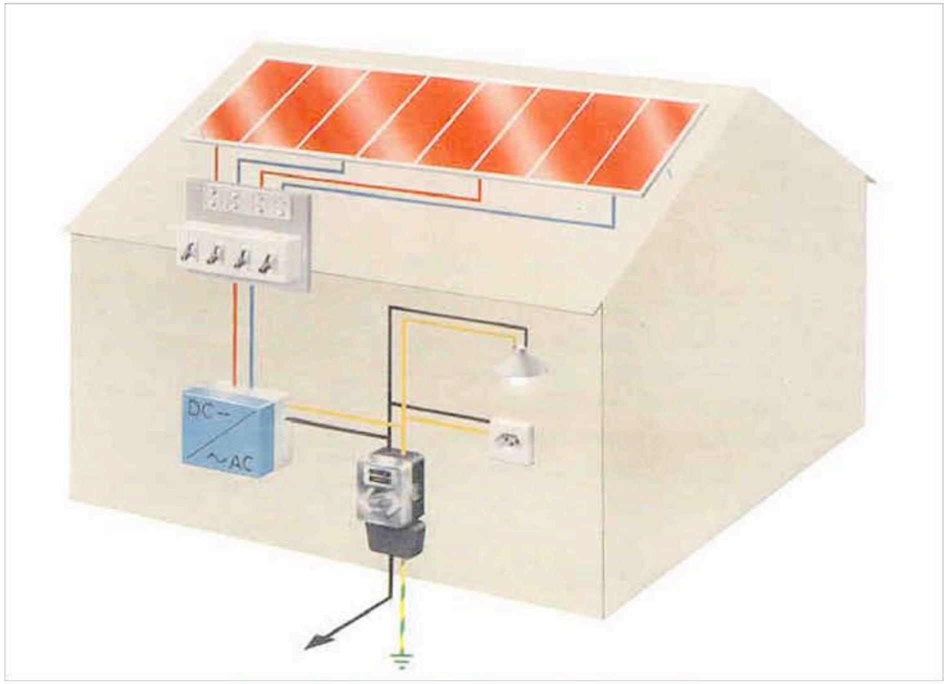
Biomass Gasification, Heat & Power – Technical Characteristics

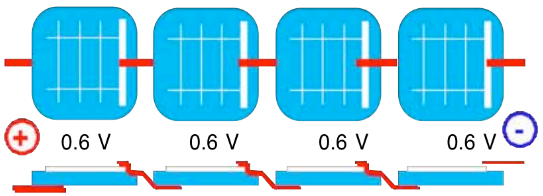
Characteristics	Units	20 **Biomass CHP** **CHP poplar** Steam turbine cogeneration, short rotation forestry poplar	21 **CHP straw** Steam turbine cogeneration, agricultural waste wheat straw
Type of fuel		SRF poplar	waste straw
Electric efficiency	%	0.3	0.3
Electric generation capacity	MW	9	9
Load factor (expected hours/yr)	hours/year	8000	8000
Annual generation (expected)	kWh/year	7.20E+07	7.20E+07
Construction time	years	2	2
Capital cost (net present value)	€/kWe	2280	2280
Total capital cost (net present value)	M€	21	21
Plant life	years	15	15
Average cost of electricity	€cents/kWhe	7.29	6.51

Biomass Gasification, Heat & Power – Description and social factors

Generation Technology	Biomass Gasification, Combined Cycle
Technical description	Wood or crop waste biomass is gasified and burned in a boiler and the steam used to drive a turbine generator. The waste heat is recovered and used.
Primary energy source	Wood (poplar) from short rotation forestry, and crop waste (wheat straw). Forestry requires land use and wood transport. Crop waste requires no additional land use, but requires transport and depletes soil of crop nutrients.
Form of waste requiring storage	Low chemical waste for full technology chain.
Record of past public acceptance	Moderate for gasification and generation plant. Requires acceptance of biomass harvest & transport.
Possible proliferation or misuse	None.
Labor mix for technology chain	Forestry, harvest, transport, plant construction & operation.
Visual disturbance	Periodic clear cutting for wood, truck traffic for transport.
Noise	Local plant noise. Traffic noise, if through populated areas.

Solar Power, PV – Illustrations





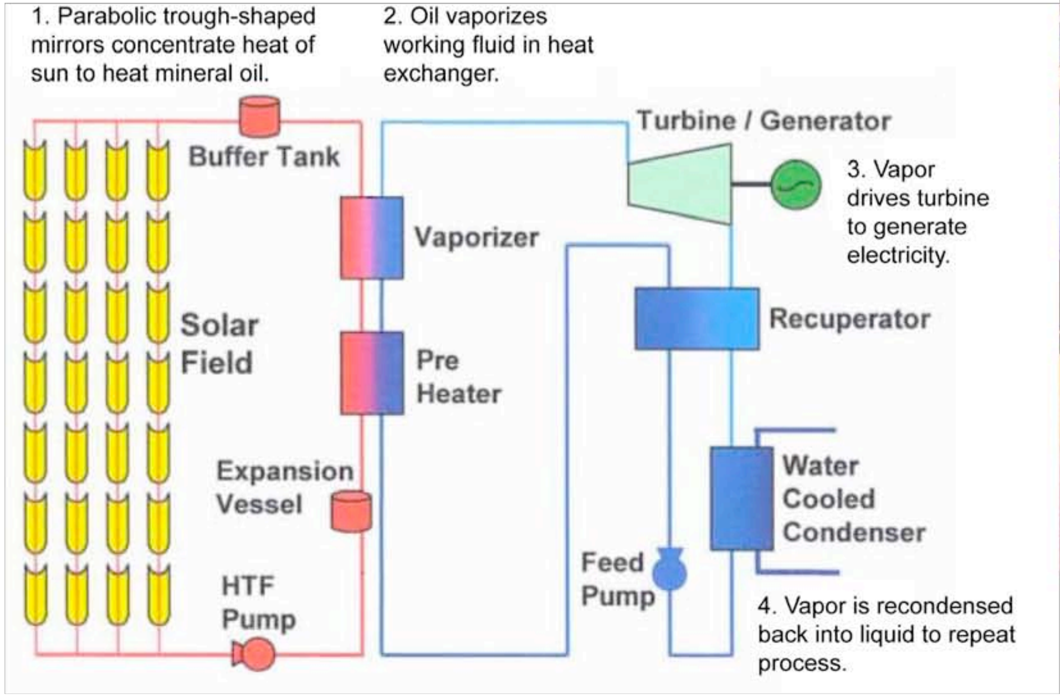
Solar Power, PV – Technical Characteristics

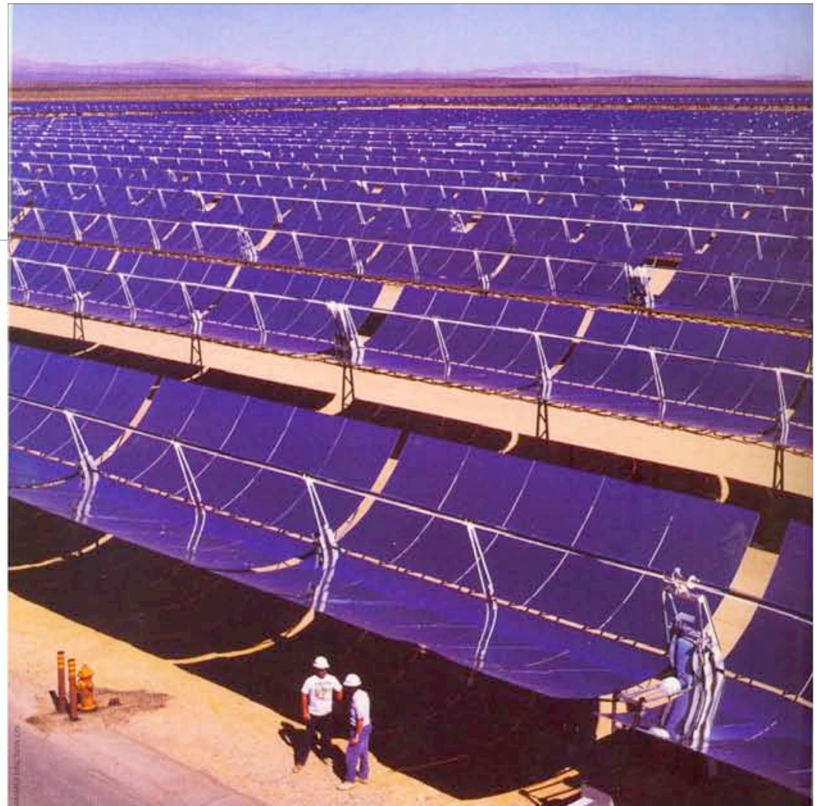
Characteristics	Units	22 **Solar PV-Si plant** PV, Mono-crystalline Si, Plant Size	23 **PV-Si building** PV, Mono-crystalline Si, Building Integrated	24 **PV-CdTe building** CdTe, Building Integrated
Type of fuel		sun	sun	sun
Electric efficiency	%	0	0	0
Electric generation capacity	MW	46.6375	0.4197375	0.839475
Load factor (expected hours/yr)	hours/year	984	984	984
Annual generation (expected)	kWh/year	4.59E+07	4.13E+05	8.26E+05
Construction time	years	2	0.5	0.5
Capital cost (net present value)	€/kWe	848	927	927
Total capital cost (net present value)	M€	40	0	1
Plant life	years	40	40	35
Average cost of electricity	€cents/kWhe	6.30	6.92	7.15

Solar Power, PV –
Description and social factors

Generation Technology	Solar, PV
Technical description	Direct photovoltaic generation. Different possible cell types. Location may be dedicated site, or on existing rooftops.
Primary energy source	Sun.
Form of waste requiring storage	No direct wastes for panels. Medium to medium low chemical wastes for full technnology chain.
Record of past public acceptance	Generally very good for roof-mounted installations. Possible local opposition to dedicated site installations.
Possible proliferation or misuse	None.
Labor mix for technology chain	Manufacture & fabrication, transport & installation.
Visual disturbance	Significant (self standing) to low (rooftop).
Noise	None.

Solar Power, Thermal Trough – Illustrations





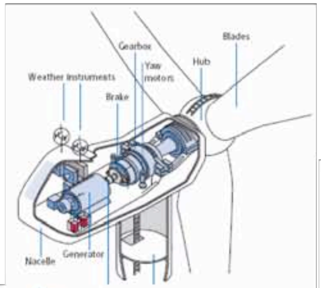
Solar Power, Thermal Trough – Technical Characteristics

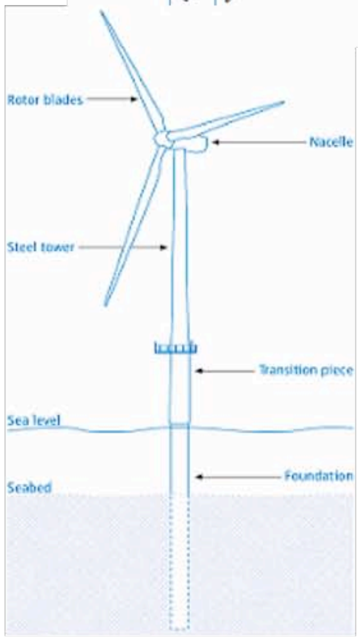
Characteristics	Units	25 **Solar thermal** Concentrating solar thermal power plant
Type of fuel		sun
Electric efficiency	%	0.185
Electric generation capacity	MW	400
Load factor (expected hours/yr)	hours/year	4518
Annual generation (expected)	kWh/year	1.81E+09
Construction time	years	3
Capital cost (net present value)	€/kWe	3044
Total capital cost (net present value)	M€	1217
Plant life	years	40
Average cost of electricity	€cents/kWhe	6.31

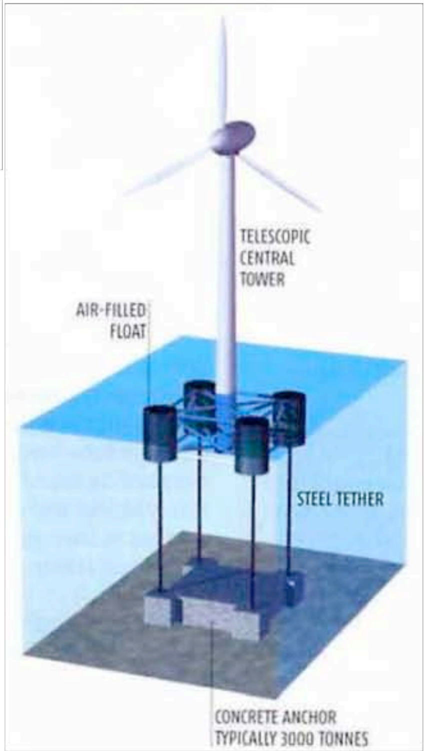
Solar Power, Thermal – Description and social factors

Generation Technology	Solar, Thermal Trough
Technical description	Parabolic trough concentrates sun to heat oil in pipe. Oil is used to drive rankine cycle generator, which may be steam or an organic working fluid depending upon temperature. Some heat storage may be used.
Primary energy source	Sun.
Form of waste requiring storage	Medium level of chemical waste from full technology chain.
Record of past public acceptance	Generally good, but limited historic experience.
Possible proliferation or misuse	None.
Labor mix for technology chain	Plant construction.
Visual disturbance	Significant, but in generally remote location.
Noise	Minimal local noise.

Wind Power, Offshore – Illustrations







Wind Power, Offshore – Technical Characteristics

Characteristics	Units	26 **Wind** **Wind-offshore** Wind
Type of fuel		wind
Electric efficiency	%	0
Electric generation capacity	MW	24
Load factor (expected hours/yr)	hours/year	4000
Annual generation (expected)	kWh/year	9.60E+07
Construction time	years	2
Capital cost (net present value)	€/kWe	1130
Total capital cost (net present value)	M€	27
Plant life	years	30
Average cost of electricity	€cents/kWhe	7.27

Wind Power, Offshore – Description and social factors

Generation Technology	Wind, Offshore
Technical description	Offshore park of large, moored wind turbines.
Primary energy source	Wind.
Form of waste requiring storage	No direct waste from turbines. Medium low chemical waste from full technology chain.
Record of past public acceptance	Quite good, local opposition.
Possible proliferation or misuse	None.
Labor mix for technology chain	Turbine manufacture, towing, cable laying.
Visual disturbance	Remote, depends on distance offshore.
Noise	None from shore.

Table A2.1 - NEEDS Database for France, Environmental & Economic Indicators for Technologies 1-12

France

	Criterion	Units												
Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
1	ENVIRONMENT													
1.1	Resources													
1.1.1	Energy													
1.1.1.1	Fossil Fuels	MJ/kWh	6.76E-02	1.47E-02	6.99E+00	7.99E+00	8.18E+00	7.59E+00	8.67E+00	8.86E+00	6.90E+00	7.87E+00	7.82E+00	8.97E+00
1.1.1.2	Uranium	MJ/kWh	1.29E+01	7.45E-03	9.35E-02	2.00E-01	2.09E-01	3.07E-02	1.47E-01	1.54E-01	9.34E-02	1.93E-01	3.72E-02	1.50E-01
1.1.2	Minerals													
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	5.22E-08	2.42E-08	1.32E-07	2.75E-07	2.62E-07	8.80E-08	2.48E-07	2.30E-07	1.19E-07	2.13E-07	7.47E-08	1.82E-07
1.2	Climate													
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	4.25E-03	9.14E-04	6.85E-01	1.58E-01	8.43E-02	7.38E-01	1.11E-01	2.58E-02	6.76E-01	1.47E-01	7.60E-01	1.08E-01
1.3	Ecosystems													
1.3.1	Normal Op.													
1.3.1.1	Biodiversity	PDF*m2*a/kWh	2.19E-04	5.62E-05	5.14E-03	6.30E-03	6.51E-03	7.09E-04	1.52E-03	1.50E-03	5.25E-03	6.39E-03	1.02E-03	1.86E-03
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	5.28E-04	2.83E-04	2.06E-03	2.87E-03	2.66E-03	7.67E-04	1.27E-03	1.10E-03	1.71E-03	2.07E-03	2.53E-03	2.98E-03
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.68E-04	1.92E-05	5.35E-03	9.29E-03	4.57E-03	3.44E-03	7.59E-03	1.65E-03	3.88E-03	4.55E-03	2.82E-03	3.60E-03
1.3.2	Severe Acc.													
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0
1.3.2.2	Land contam.	km2/GWe-yr	3.15E-06	6.95E-05	0	0	0	0	0	0	0	0	0	0
1.4	Waste													
1.4.1	Chem waste	kg/kWh	6.90E-10	2.17E-10	1.36E-08	1.58E-08	7.27E-09	2.13E-08	2.43E-08	9.14E-09	4.96E-10	6.60E-10	2.28E-10	3.92E-10
1.4.2	Rad waste	m3/kWh	1.03E-08	3.22E-09	7.58E-11	1.62E-10	1.70E-10	2.49E-11	1.18E-10	1.25E-10	7.56E-11	1.56E-10	3.01E-11	1.21E-10
2	ECONOMY													
2.1	Customers													
2.1.1	Gen Cost	€/MWh	30.1	26.8	29.6	39.4	40.0	30.1	40.8	41.6	61.7	72.6	65.7	67.8
2.2	Society													
2.2.1	Jobs	Person-years/GWh	61	71	54	77	78	69	94	95	63	76	80	84
2.2.2	Fuel Autonomy	Ordinal	8	8	6	6	6	0	0	0	6	6	0	0
2.3	Utility													
2.3.1	Financial													
2.3.1.1	Financing Risk	€	2383	2756	590	780	780	939	1248	1248	544	602	544	483
2.3.1.2	Fuel Sensitivity	Factor	0.26	0.00	0.43	0.35	0.36	0.53	0.43	0.44	0.20	0.19	0.25	0.27
2.3.1.3	Constr. Time	Years	4.83	5.5	3	3	3	3	3	3	3	3	3	3
2.3.2	Operation													
2.3.2.1	Marginal Cost	€cents/kWh	1.2	0.4	1.5	1.7	1.8	1.7	1.9	2.0	4.4	5.0	4.8	5.0
2.3.2.2	Flexibility	Ordinal	6	6	8	8	8	8	8	8	7	7	7	7
2.3.2.3	Availability	Factor	0.90	0.90	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
3	SOCIAL													

Table A2.2 - NEEDS Database for France, Environmental & Economic Indicators for Technologies 13-26

France

Technology Number			13	14	15	16	17	18	19	20	21	22	23	24	25	26
Technology Class						**Fuel Cells**				**Biomass CHP**		**Solar**				**Wind**
Technology Name (short)			**GTCC**	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
Technology Name (long)			Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
	Criterion	Units														
1	ENVIRONMENT															
1.1	Resources															
1.1.1	Energy															
1.1.1.1	Fossil Fuels	MJ/kWh	6.79E+00	7.44E+00	8.66E+00	7.99E+00	6.05E-01	7.33E+00	7.46E+00	2.64E-01	1.12E-01	1.43E-01	1.39E-01	5.86E-02	2.32E-01	5.46E-02
1.1.1.2	Uranium	MJ/kWh	1.02E-01	2.26E-01	1.35E-01	1.33E-01	3.21E-01	1.19E-01	1.32E-01	1.38E-02	7.05E-03	4.83E-02	4.84E-02	1.98E-02	2.00E-02	9.70E-03
1.1.2	Minerals															
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	8.25E-08	1.61E-07	1.40E-07	3.19E-07	4.34E-07	2.24E-07	1.40E-07	1.48E-07	8.01E-08	2.39E-06	2.40E-06	3.84E-07	1.44E-07	3.56E-06
1.2	Climate															
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	3.91E-01	1.26E-01	5.26E-01	4.79E-01	4.00E-02	4.39E-01	4.42E-01	5.31E-02	3.28E-02	8.21E-03	8.64E-03	2.95E-03	2.29E-02	2.84E-03
1.3	Ecosystems															
1.3.1	Normal Op.															
1.3.1.1	Biodiversity	PDF*m2*a/kWh	2.18E-03	2.95E-03	2.92E-03	2.99E-03	3.81E-01	2.69E-03	2.55E-03	8.01E-01	1.00E-04	3.85E-03	3.88E-04	2.29E-04	5.22E-03	1.57E-04
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	3.83E-04	6.34E-04	4.95E-04	2.30E-03	2.71E-03	1.64E-03	5.95E-04	6.11E-04	2.82E-04	1.95E-03	1.98E-03	8.41E-04	1.21E-03	8.78E-04
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.10E-03	1.29E-03	1.49E-03	1.26E-03	3.35E-03	1.14E-03	1.22E-03	8.76E-03	9.44E-03	2.29E-04	2.28E-04	8.62E-05	5.32E-04	8.67E-05
1.3.2	Severe Acc.															
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.3.2.2	Land contam.	km2/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.4	Waste															
1.4.1	Chem waste	kg/kWh	4.49E-09	5.29E-09	6.13E-09	8.15E-09	3.18E-09	7.13E-09	8.89E-09	3.85E-10	2.22E-10	5.98E-09	3.33E-09	1.68E-09	5.72E-09	1.90E-09
1.4.2	Rad waste	m3/kWh	8.22E-11	1.82E-10	1.09E-10	1.07E-10	2.60E-10	9.59E-11	9.80E-11	1.10E-11	5.65E-12	3.71E-11	3.82E-11	1.52E-11	1.64E-11	7.32E-12
2	ECONOMY															
2.1	Customers															
2.1.1	Gen Cost	€/MWh	59.9	86.9	111.0	87.4	84.4	72.9	67.3	72.9	65.1	63.0	69.2	71.5	63.1	72.7
2.2	Society															
2.2.1	Jobs	Person-years/GWh	89	97	76	406	173	338	293	405	236	123	126	140	100	48
2.2.2	Fuel Autonomy	Ordinal	3	3	3	3	10	3	3	10	10	10	10	10	10	10
2.3	Utility															
2.3.1	Financial															
2.3.1.1	Financing Risk	€	440	615	0	0.39	0.39	2.47	0.31	21	21	40	0	1	1217	27
2.3.1.2	Fuel Sensitivity	Factor	0.54	0.39	0.36	0.41	0.38	0.44	0.48	0.52	0.43	0.00	0.00	0.00	0.00	0.00
2.3.1.3	Constr. Time	Years	3	3	1	0.83	0.83	0.83	0.83	2	2	2	0.5	0.5	3	2
2.3.2	Operation															
2.3.2.1	Marginal Cost	€cents/kWh	5.4	7.8	10.8	4.2	3.7	3.8	3.6	5.5	3.9	0.0	0.2	0.2	0.0	4.7
2.3.2.2	Flexibility	Ordinal	10	10	10	7	7	7	7	7	7	2	2	2	2	3
2.3.2.3	Availability	Factor	0.85	0.85	0.97	0.99	0.99	0.99	0.99	0.85	0.85	0.11	0.11	0.11	0.52	0.46
3	SOCIAL															

Table A2.3 - NEEDS Database for France, Social Indicators for Technologies 1-12

France

	Criterion	Units	1	2	3	4	5	6	7	8	9	10	11	12
Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
1	ENVIRONMENT													
2	ECONOMY													
3	SOCIAL													
3.1	Security													
3.1.1	Pol. continuity													
3.1.1.1	Secure Supply	Ordinal scale	4	3.5	3.5	3	3	3.5	3	3	3	3	3	3
3.1.1.2	Waste repos.	Ordinal scale	2	2	2	3	3	2	3	3	2	3	2	3
3.1.2	Adaptability	Ordinal scale	3	3	2	2	2	2	2	2	4	3	4	3
3.2	Political legit.													
3.2.1	Conflict	Ordinal scale	3	3	3	3	3	3	3	3	2	2	2	2
3.2.2	Participation	Ordinal scale	4.5	4	4	4	4	4	4	4	4	4	4	4
3.3	Risk													
3.3.1	Normal risk													
3.3.1.1	Mortality	YOLL/kWh	1.51E-08	2.19E-09	1.76E-07	2.07E-07	1.47E-07	9.49E-08	1.46E-07	6.21E-08	1.26E-07	1.49E-07	1.18E-07	1.51E-07
3.3.1.2	Morbidity	DALY/kWh	8.67E-09	1.31E-09	1.34E-07	1.54E-07	1.13E-07	7.28E-08	1.07E-07	4.69E-08	9.60E-08	1.14E-07	8.90E-08	1.14E-07
3.3.2	Sev. Accidents													
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	5.11E-06	9.40E-05	1.21E-01	1.34E-01	1.40E-01	4.90E-02	5.51E-02	5.74E-02	1.19E-01	1.35E-01	5.04E-02	5.80E-02
3.3.2.2	Max. fatalities	Fatalities/accident	26790	1858	272	272	272	51	51	51	272	272	51	51
3.3.3	Perceived risk													
3.3.3.1	Normal op.	Ordinal scale	4	4	3	4	4	3	4	4	3	4	3	4
3.3.3.2	Perceived Acc.	Ordinal scale	3.67	3.50	2.50	3.67	3.67	2.50	3.67	3.67	3.00	3.67	3.00	3.67
3.3.4	Terrorism													
3.3.4.1	Potential	Ordinal scale	6.5	6.5	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
3.3.4.2	Effects	Expected number of fatalities	10	10	2	3	3	2	3	3	2	3	2	3
3.3.4.3	Proliferation		1	1	0	0	0	0	0	0	0	0	0	0
3.4	Quality of Residential Environment													
3.4.1	Landscape	Ordinal scale	3.5	3.5	4	4	4	4	4	4	4	4	4	4
3.4.2	Noise	Ordinal scale	2	2	2	3	3	2	3	3	3	3	3	3

Table A2.4 - NEEDS Database for France, Social Indicators for Technologies 13-26

France

Technology Number			13	14	15	16	17	18	19	20	21	22	23	24	25	26
Technology Class						**Fuel Cells**				**Biomass CHP**		**Solar**				**Wind**
Technology Name (short)			**GTCC**	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
Technology Name (long)			Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
	Criterion	Units														
1	ENVIRONMENT															
2	ECONOMY															
3	SOCIAL															
3.1	Security															
3.1.1	Pol. continuity															
3.1.1.1	Secure Supply	Ordinal scale	3	3	3	3	3	3	3	2.5	2.5	2.5	2.5	2.5	3	3.5
3.1.1.2	Waste repos.	Ordinal scale	1	3	1	1	1	1	1	2	2	0	0	0	0	0
3.1.2	Adaptability	Ordinal scale	3	3	3	4	4	4	4	2	2	4	4	4	4	4
3.2	Political legit.															
3.2.1	Conflict	Ordinal scale	2	3	2	2	2	2	2	2	2	2	2	2	1	2
3.2.2	Participation	Ordinal scale	4	4	4	3.5	3.5	3.5	3.5	4	4	4	4	4	4	3.5
3.3	Risk															
3.3.1	Normal risk															
3.3.1.1	Mortality	YOLL/kWh	3.42E-08	4.09E-08	4.48E-08	4.18E-08	9.35E-08	3.73E-08	3.86E-08	1.80E-07	2.57E-07	9.92E-09	1.03E-08	5.44E-09	1.68E-08	4.78E-09
3.3.1.2	Morbidity	DALY/kWh	2.66E-08	3.18E-08	3.50E-08	3.29E-08	7.17E-08	2.92E-08	3.02E-08	1.40E-07	1.97E-07	9.82E-09	1.02E-08	4.92E-09	1.48E-08	5.11E-09
3.3.2	Sev. Accidents															
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	6.86E-02	7.40E-02	1.01E-01	8.92E-02	2.99E-02	8.11E-02	7.69E-02	1.68E-02	1.68E-02	1.00E-04	1.00E-04	1.00E-04	2.00E-04	2.77E-03
3.3.2.2	Max. fatalities	Fatalities/accident	109	109	109	109	27	109	109	10	10	5	5	5	5	10
3.3.3	Perceived risk															
3.3.3.1	Normal op.	Ordinal scale	3	4	3	2	2	2	2	3	3	1	1	1	1	1
3.3.3.2	Perceived Acc.	Ordinal scale	2.67	4.00	3.00	2.83	2.83	2.83	2.83	2.50	2.50	2.67	2.67	2.67	2.67	2.17
3.3.4	Terrorism															
3.3.4.1	Potential	Ordinal scale	6.9	6.9	5.9	5.9	2	5.9	5.9	1	1	2	2	3	1	2
3.3.4.2	Effects	Expected number of fatalities	5	6	5	5	3	5	5	1	1	2	2	3	1	2
3.3.4.3	Proliferation		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.4	Quality of Residential Environment															
3.4.1	Landscape	Ordinal scale	3	3	2	2	2	2	2	4	4	3	3	3	3	2
3.4.2	Noise	Ordinal scale	2	3	2	2	2	2	2	2	2	1	1	1	1	1

Table A2.5 - NEEDS Database for Germany, Environmental & Economic Indicators for Technologies 1-12

Germany

Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
	Criterion	**Units**												
1	ENVIRONMENT													
1.1	Resources													
1.1.1	Energy													
1.1.1.1	Fossil Fuels	MJ/kWh	6.76E-02	1.47E-02	6.99E+00	7.99E+00	8.18E+00	7.65E+00	8.73E+00	8.92E+00	6.90E+00	7.87E+00	7.88E+00	9.04E+00
1.1.1.2	Uranium	MJ/kWh	1.29E+01	7.45E-03	9.35E-02	2.00E-01	2.09E-01	5.39E-02	1.73E-01	1.80E-01	9.34E-02	1.93E-01	6.11E-02	1.77E-01
1.1.2	Minerals													
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	5.22E-08	2.42E-08	1.32E-07	2.75E-07	2.62E-07	9.76E-08	2.58E-07	2.41E-07	1.19E-07	2.13E-07	8.46E-08	1.93E-07
1.2	Climate													
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	4.25E-03	9.14E-04	6.85E-01	1.58E-01	8.43E-02	7.41E-01	1.14E-01	2.92E-02	6.76E-01	1.47E-01	7.63E-01	1.11E-01
1.3	Ecosystems													
1.3.1	Normal Op.													
1.3.1.1	Biodiversity	PDF*m2*a/kWh	2.19E-04	5.62E-05	5.14E-03	6.30E-03	6.51E-03	1.27E-03	2.14E-03	2.14E-03	5.25E-03	6.39E-03	1.59E-03	2.50E-03
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	5.28E-04	2.83E-04	2.06E-03	2.87E-03	2.66E-03	8.08E-04	1.32E-03	1.15E-03	1.71E-03	2.07E-03	2.57E-03	3.03E-03
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.68E-04	1.92E-05	5.35E-03	9.29E-03	4.57E-03	3.49E-03	7.65E-03	1.70E-03	3.88E-03	4.55E-03	2.86E-03	3.66E-03
1.3.2	Severe Acc.													
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0
1.3.2.2	Land contam.	km2/GWe-yr	1.58E-06	3.47E-05	0	0	0	0	0	0	0	0	0	0
1.4	Waste													
1.4.1	Chem waste	kg/kWh	6.90E-10	2.17E-10	1.36E-08	1.58E-08	7.27E-09	2.13E-08	2.43E-08	9.17E-09	4.96E-10	6.60E-10	2.56E-10	4.23E-10
1.4.2	Rad waste	m3/kWh	1.03E-08	3.22E-09	7.58E-11	1.62E-10	1.70E-10	4.37E-11	1.39E-10	1.46E-10	7.56E-11	1.56E-10	4.94E-11	1.43E-10
2	ECONOMY													
2.1	Customers													
2.1.1	Gen Cost	€/MWh	30.1	26.8	29.6	39.4	40.0	30.1	40.8	41.6	61.7	72.6	65.7	67.8
2.2	Society													
2.2.1	Jobs	Person-years/GWh	61	71	54	77	78	69	94	95	63	76	80	84
2.2.2	Fuel Autonomy	Ordinal	8	8	6	6	6	6	6	6	6	6	6	6
2.3	Utility													
2.3.1	Financial													
2.3.1.1	Financing Risk	€	2383	2756	590	780	780	939	1248	1248	544	602	544	483
2.3.1.2	Fuel Sensitivity	Factor	0.26	0.00	0.43	0.35	0.36	0.53	0.43	0.44	0.20	0.19	0.25	0.27
2.3.1.3	Constr. Time	Years	4.83	5.5	3	3	3	3	3	3	3	3	3	3
2.3.2	Operation													
2.3.2.1	Marginal Cost	€cents/kWh	1.2	0.4	1.5	1.7	1.8	1.7	1.9	2.0	4.4	5.0	4.8	5.0
2.3.2.2	Flexibility	Ordinal	6	6	8	8	8	8	8	8	7	7	7	7
2.3.2.3	Availability	Factor	0.9	0.90	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
3	SOCIAL													

Table A2.6 - NEEDS Database for Germany, Environmental & Economic Indicators for Technologies 13-26

Germany

															No solar thermal in DE	
Technology Number			13	14	15	16	17	18	19	20	21	22	23	24	25	26
Technology Class						**Fuel Cells**				**Biomass CHP**		**Solar**				**Wind**
Technology Name (short)			**GTCC**	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
Technology Name (long)			Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
	Criterion	Units														
1	ENVIRONMENT															
1.1	Resources															
1.1.1	Energy															
1.1.1.1	Fossil Fuels	MJ/kWh	6.38E+00	7.01E+00	8.14E+00	7.52E+00	6.05E-01	6.89E+00	7.02E+00	2.64E-01	1.12E-01	1.74E-01	1.69E-01	7.13E-02		5.46E-02
1.1.1.2	Uranium	MJ/kWh	7.18E-03	1.25E-01	1.57E-02	2.27E-02	3.21E-01	1.79E-02	2.96E-02	1.38E-02	7.05E-03	5.88E-02	5.89E-02	2.41E-02		9.70E-03
1.1.2	Minerals															
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	6.92E-08	1.47E-07	1.23E-07	3.05E-07	4.34E-07	2.11E-07	1.27E-07	1.48E-07	8.01E-08	2.91E-06	2.92E-06	4.67E-07		3.56E-06
1.2	Climate															
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	3.73E-01	1.06E-01	5.03E-01	4.57E-01	4.00E-02	4.19E-01	4.22E-01	5.31E-02	3.28E-02	9.98E-03	1.05E-02	3.59E-03		2.84E-03
1.3	Ecosystems															
1.3.1	Normal Op.															
1.3.1.1	Biodiversity	PDF*m2*a/kWh	1.20E-03	1.91E-03	1.67E-03	1.84E-03	3.81E-01	1.64E-03	1.49E-03	8.01E-01	1.00E-04	4.69E-03	4.72E-04	2.79E-04		1.57E-04
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	3.09E-04	5.54E-04	4.00E-04	2.21E-03	2.71E-03	1.56E-03	5.14E-04	6.11E-04	2.82E-04	2.38E-03	2.40E-03	1.02E-03		8.78E-04
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.15E-03	1.35E-03	1.55E-03	1.32E-03	3.35E-03	1.19E-03	1.27E-03	8.76E-03	9.44E-03	2.78E-04	2.77E-04	1.05E-04		8.67E-05
1.3.2	Severe Acc.															
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0		0
1.3.2.2	Land contam.	km2/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0		0
1.4	Waste															
1.4.1	Chem waste	kg/kWh	4.18E-09	4.96E-09	5.74E-09	7.78E-09	3.18E-09	6.80E-09	8.55E-09	3.85E-10	2.22E-10	7.28E-09	4.05E-09	2.04E-09		1.90E-09
1.4.2	Rad waste	m3/kWh	5.63E-12	1.01E-10	1.21E-11	1.74E-11	2.60E-10	1.37E-11	1.48E-11	1.10E-11	5.65E-12	4.52E-11	4.65E-11	1.85E-11		7.32E-12
2	ECONOMY															
2.1	Customers															
2.1.1	Gen Cost	€/MWh	59.9	86.9	111.0	87.4	84.4	72.9	67.3	72.9	65.1	76.6	83.7	86.6		72.7
2.2	Society															
2.2.1	Jobs	Person-years/GWh	89	97	76	406	173	338	293	405	236	123	126	140		48
2.2.2	Fuel Autonomy	Ordinal	3	3	3	3	10	3	3	10	10	10	10	10		10
2.3	Utility															
2.3.1	Financial															
2.3.1.1	Financing Risk	€	440	615	0	0.39	0.39	2.47	0.31	21	21	40	0	1		27
2.3.1.2	Fuel Sensitivity	Factor	0.54	0.39	0.36	0.41	0.38	0.44	0.48	0.52	0.43	0.00	0.00	0.00		0.00
2.3.1.3	Constr. Time	Years	3	3	1	0.83	0.83	0.83	0.83	2	2	2	0.5	0.5		2
2.3.2	Operation															
2.3.2.1	Marginal Cost	€cents/kWh	5.4	7.8	10.8	4.2	3.7	3.8	3.6	5.5	3.9	0.0	0.2	0.2		4.7
2.3.2.2	Flexibility	Ordinal	10	10	10	7	7	7	7	7	7	2	2	2		3
2.3.2.3	Availability	Factor	0.85	0.85	0.97	0.99	0.99	0.99	0.99	0.85	0.85	0.09	0.09	0.09		0.46
3	SOCIAL															

Table A2.7 - NEEDS Database for Germany, Social Indicators for Technologies 1-12

Germany

Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
	Criterion	Units												
1	ENVIRONMENT													
2	ECONOMY													
3	SOCIAL													
3.1	Security													
3.1.1	Pol. continuity													
3.1.1.1	Secure Supply	Ordinal scale	4	4	4	4	4	4	4	4	4	4	4	4
3.1.1.2	Waste repos.	Ordinal scale	4.5	4.5	1.5	3.5	3.5	1.5	3.5	3.5	1.5	3.5	1.5	3.5
3.1.2	Adaptability	Ordinal scale	3	3	2	2	2	2	2	2	3	3	3	3
3.2	Political legit.													
3.2.1	Conflict	Ordinal scale	5	5	3	3	3	3	3	3	2.5	2.5	2.5	2.5
3.2.2	Participation	Ordinal scale	5	5	4	4	4	4	4	4	4	4	4	4
3.3	Risk													
3.3.1	Normal risk													
3.3.1.1	Mortality	YOLL/kWh	1.76E-08	2.56E-09	2.11E-07	2.42E-07	1.76E-07	1.15E-07	1.71E-07	7.73E-08	1.50E-07	1.78E-07	1.44E-07	1.83E-07
3.3.1.2	Morbidity	DALY/kWh	1.05E-08	1.61E-09	1.59E-07	1.79E-07	1.33E-07	8.72E-08	1.25E-07	5.80E-08	1.13E-07	1.34E-07	1.07E-07	1.36E-07
3.3.2	Sev. Accidents													
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	1.84E-06	3.38E-05	1.21E-01	1.34E-01	1.40E-01	4.90E-02	5.51E-02	5.74E-02	1.19E-01	1.35E-01	5.04E-02	5.80E-02
3.3.2.2	Max. fatalities	Fatalities/accident	9720	670	272	272	272	51	51	51	272	272	51	51
3.3.3	Perceived risk													
3.3.3.1	Normal op.	Ordinal scale	5	5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
3.3.3.2	Perceived Acc.	Ordinal scale	3.00	3.00	2.67	3.17	3.17	2.67	3.17	3.17	2.67	3.17	2.67	3.17
3.3.4	Terrorism													
3.3.4.1	Potential	Ordinal scale	6.5	6.5	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
3.3.4.2	Effects	Expected number of fatalities	10	10	2	3	3	2	3	3	2	3	2	3
3.3.4.3	Proliferation		1	1	0	0	0	0	0	0	0	0	0	0
3.4	Quality of Residential Environment													
3.4.1	Landscape	Ordinal scale	3	3	4	4	4	4	4	4	4	4	4	4
3.4.2	Noise	Ordinal scale	2	2	3	3	3	3	3	3	3	3	3	3

Table A2.8 - NEEDS Database for Germany, Social Indicators for Technologies 13-26

Germany															No solar thermal in DE	
Technology Number			13	14	15	16	17	18	19	20	21	22	23	24	25	26
Technology Class						**Fuel Cells**				**Biomass CHP**		**Solar**				**Wind**
Technology Name (short)			**GTCC**	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
Technology Name (long)			Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
	Criterion	Units														
1	ENVIRONMENT															
2	ECONOMY															
3	SOCIAL															
3.1	Security															
3.1.1	Pol. continuity															
3.1.1.1	Secure Supply	Ordinal scale	4	3.5	4	4	4	4	4	3	3	3	3	3		4
3.1.1.2	Waste repos.	Ordinal scale	1	3.5	1	1	1	1	1	1.5	1.5	1.5	1.5	1.5		1
3.1.2	Adaptability	Ordinal scale	3	3	4	5	5	5	5	2	2	4	4	4		4
3.2	Political legit.															
3.2.1	Conflict	Ordinal scale	2	2.5	1	1	1	1	1	1	1	1	1	1		2
3.2.2	Participation	Ordinal scale	3.5	4	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5		2
3.3	Risk															
3.3.1	Normal risk															
3.3.1.1	Mortality	YOLL/kWh	6.34E-08	7.35E-08	8.22E-08	7.59E-08	1.32E-07	6.81E-08	7.02E-08	2.67E-07	3.60E-07	1.59E-08	1.62E-08	8.52E-09		6.29E-09
3.3.1.2	Morbidity	DALY/kWh	4.71E-08	5.48E-08	6.14E-08	5.72E-08	9.90E-08	5.11E-08	5.26E-08	1.99E-07	2.68E-07	1.51E-08	1.54E-08	7.58E-09		6.46E-09
3.3.2	Sev. Accidents															
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	6.86E-02	7.40E-02	1.01E-01	8.92E-02	2.99E-02	8.11E-02	7.69E-02	1.68E-02	1.68E-02	1.00E-04	1.00E-04	1.00E-04		2.77E-03
3.3.2.2	Max. fatalities	Fatalities/accident	109	109	109	109	27	109	109	10	10	5	5	5		10
3.3.3	Perceived risk															
3.3.3.1	Normal op.	Ordinal scale	2	2.5	2	2	2	2	2	3.5	3.5	1	1	1		0.5
3.3.3.2	Perceived Acc.	Ordinal scale	3.00	3.17	1.67	2.00	2.00	2.00	2.00	2.67	2.67	2.00	2.00	2.00		2.33
3.3.4	Terrorism															
3.3.4.1	Potential	Ordinal scale	6.9	6.9	5.9	5.9	2	5.9	5.9	1	1	2	2	3		2
3.3.4.2	Effects	Expected number of fatalities	5	6	5	5	3	5	5	1	1	2	2	3		2
3.3.4.3	Proliferation		0	0	0	0	0	0	0	0	0	0	0	0		0
3.4	Quality of Residential Environment															
3.4.1	Landscape	Ordinal scale	3	3.75	1.25	1.25	1.25	1.25	1.25	4	4	1.75	1.75	1.75		2.75
3.4.2	Noise	Ordinal scale	2	3	1	1	1	1	1	3	3	1	1	1		1

Table A2.9 - NEEDS Database for Italy, Environmental & Economic Indicators for Technologies 1-12

Italy

								No lignite in Italy					No lignite in Italy	
Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
	Criterion	**Units**												
1	ENVIRONMENT													
1.1	Resources													
1.1.1	Energy													
1.1.1.1	Fossil Fuels	MJ/kWh	6.99E-02	1.52E-02	7.22E+00	8.25E+00	8.45E+00				7.13E+00	8.13E+00		
1.1.1.2	Uranium	MJ/kWh	1.34E+01	7.70E-03	9.66E-02	2.07E-01	2.16E-01				9.64E-02	1.99E-01		
1.1.2	Minerals													
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	5.39E-08	2.50E-08	1.36E-07	2.84E-07	2.70E-07				1.23E-07	2.20E-07		
1.2	Climate													
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	4.39E-03	9.44E-04	7.08E-01	1.64E-01	8.70E-02				6.98E-01	1.52E-01		
1.3	Ecosystems													
1.3.1	Normal Op.													
1.3.1.1	Biodiversity	PDF*m2*a/kWh	2.26E-04	5.80E-05	5.31E-03	6.51E-03	6.72E-03				5.43E-03	6.60E-03		
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	5.45E-04	2.92E-04	2.13E-03	2.96E-03	2.75E-03				1.76E-03	2.14E-03		
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.73E-04	1.98E-05	5.52E-03	9.60E-03	4.72E-03				4.01E-03	4.71E-03		
1.3.2	Severe Acc.													
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0				0	0		
1.3.2.2	Land contam.	km2/GWe-yr	2.99E-06	6.60E-05	0	0	0				0	0		
1.4	Waste													
1.4.1	Chem waste	kg/kWh	7.13E-10	2.24E-10	1.41E-08	1.64E-08	7.51E-09				5.13E-10	6.82E-10		
1.4.2	Rad waste	m3/kWh	1.06E-08	3.32E-09	7.83E-11	1.67E-10	1.75E-10				7.81E-11	1.62E-10		
2	ECONOMY													
2.1	Customers													
2.1.1	Gen Cost	€/MWh	30.5	26.9	30.0	39.9	40.5				62.1	73.0		
2.2	Society													
2.2.1	Jobs	Person-years/GWh	61	71	54	77	78				63	76		
2.2.2	Fuel Autonomy	Ordinal	0	0	6	6	6				6	6		
2.3	Utility													
2.3.1	Financial													
2.3.1.1	Financing Risk	€	2383	2756	590	780	780				544	602		
2.3.1.2	Fuel Sensitivity	Factor	0.26	0.00	0.44	0.36	0.37				0.21	0.20		
2.3.1.3	Constr. Time	Years	4.83	5.5	3	3	3				3	3		
2.3.2	Operation													
2.3.2.1	Marginal Cost	€cents/kWh	1.2	0.5	1.6	1.7	1.8				4.4	5.1		
2.3.2.2	Flexibility	Ordinal	6	6	8	8	8				7	7		
2.3.2.3	Availability	Factor	0.90	0.90	0.85	0.85	0.85				0.85	0.85		
3	SOCIAL													

Table A2.10 - NEEDS Database for Italy, Environmental & Economic Indicators for Technologies 13-26

Italy

	Technology Number		13	14	15	16	17	18	19
	Technology Class					Fuel Cells			
	Technology Name (short)		GTCC	GTCC CCS	IC CHP	MCFC NG	MCFC wood gas	MCFC NG	SOFC NG
	Technology Name (long)		Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas
	Criterion	Units							
1	ENVIRONMENT								
1.1	Resources								
1.1.1	Energy								
1.1.1.1	Fossil Fuels	MJ/kWh	7.16E+00	7.85E+00	8.84E+00	8.16E+00	6.07E-01	7.48E+00	7.62E+00
1.1.1.2	Uranium	MJ/kWh	1.07E-01	2.35E-01	1.37E-01	1.35E-01	3.22E-01	1.21E-01	1.34E-01
1.1.2	Minerals								
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	8.85E-08	1.70E-07	1.44E-07	3.22E-07	4.36E-07	2.27E-07	1.43E-07
1.2	Climate								
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	4.11E-01	1.37E-01	5.34E-01	4.86E-01	4.30E-02	4.46E-01	4.49E-01
1.3	Ecosystems								
1.3.1	Normal Op.								
1.3.1.1	Biodiversity	PDF*m2*a/kWh	2.40E-03	3.21E-03	3.10E-03	3.15E-03	2.55E-01	2.85E-03	2.71E-03
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	4.03E-04	6.62E-04	5.03E-04	2.31E-03	2.72E-03	1.65E-03	6.02E-04
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.23E-03	1.44E-03	1.61E-03	1.37E-03	3.52E-03	1.24E-03	1.32E-03
1.3.2	Severe Acc.								
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0	0	0
1.3.2.2	Land contam.	km2/GWe-yr	0	0	0	0	0	0	0
1.4	Waste								
1.4.1	Chem waste	kg/kWh	4.74E-09	5.57E-09	6.25E-09	8.26E-09	3.19E-09	7.24E-09	9.00E-09
1.4.2	Rad waste	m3/kWh	8.62E-11	1.90E-10	1.11E-10	1.08E-10	2.60E-10	9.71E-11	9.92E-11
2	ECONOMY								
2.1	Customers								
2.1.1	Gen Cost	€/MWh	61.0	88.1	111.0	87.4	84.4	72.9	67.3
2.2	Society								
2.2.1	Jobs	Person-years/GWh	89	97	76	406	173	338	293
2.2.2	Fuel Autonomy	Ordinal	3	3	3	3	10	3	3
2.3	Utility								
2.3.1	Financial								
2.3.1.1	Financing Risk	€	440	615	0	0.39	0.39	2.47	0.31
2.3.1.2	Fuel Sensitivity	Factor	0.54	0.40	0.36	0.41	0.38	0.44	0.48
2.3.1.3	Constr. Time	Years	3	3	1	0.83	0.83	0.83	0.83
2.3.2	Operation								
2.3.2.1	Marginal Cost	€cents/kWh	5.5	7.9	10.8	4.2	3.7	3.8	3.6
2.3.2.2	Flexibility	Ordinal	10	10	10	7	7	7	7
2.3.2.3	Availability	Factor	0.85	0.85	0.97	0.99	0.99	0.99	0.99
3	SOCIAL								

	Technology Number		20	21	22	23	24	25	26
	Technology Class		Biomass CHP		Solar				Wind
	Technology Name (short)		CHP poplar	CHP straw	PV-Si plant	PV-Si building	PV-CdTe building	Solar thermal	Wind-offshore
	Technology Name (long)		Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
	Criterion	Units							
1	ENVIRONMENT								
1.1	Resources								
1.1.1	Energy								
1.1.1.1	Fossil Fuels	MJ/kWh	2.68E-01	1.12E-01	1.37E-01	1.33E-01	5.59E-02	2.22E-01	6.24E-02
1.1.1.2	Uranium	MJ/kWh	1.49E-02	7.05E-03	4.61E-02	4.61E-02	1.89E-02	1.91E-02	1.11E-02
1.1.2	Minerals								
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	1.51E-07	8.01E-08	2.28E-06	2.29E-06	3.66E-07	1.38E-07	4.07E-06
1.2	Climate								
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	5.93E-02	3.28E-02	7.83E-03	8.24E-03	2.81E-03	2.18E-02	3.25E-03
1.3	Ecosystems								
1.3.1	Normal Op.								
1.3.1.1	Biodiversity	PDF*m2*a/kWh	5.34E-01	1.00E-04	3.68E-03	3.70E-04	2.19E-04	4.98E-03	1.79E-04
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	6.42E-04	2.82E-04	1.86E-03	1.88E-03	8.02E-04	1.16E-03	1.00E-03
1.3.1.3	Air pollution	PDF*m2*a/kWh	9.12E-03	9.44E-03	2.18E-04	2.17E-04	8.22E-05	5.08E-04	9.91E-05
1.3.2	Severe Acc.								
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0	0	0
1.3.2.2	Land contam.	km2/GWe-yr	0	0	0	0	0	0	0
1.4	Waste								
1.4.1	Chem waste	kg/kWh	4.01E-10	2.22E-10	5.71E-09	3.17E-09	1.60E-09	5.46E-09	2.17E-09
1.4.2	Rad waste	m3/kWh	1.19E-11	5.65E-12	3.54E-11	3.64E-11	1.45E-11	1.57E-11	8.37E-12
2	ECONOMY								
2.1	Customers								
2.1.1	Gen Cost	€/MWh	73.8	65.7	60.1	66.0	68.3	60.2	76.4
2.2	Society								
2.2.1	Jobs	Person-years/GWh	405	236	123	126	140	100	48
2.2.2	Fuel Autonomy	Ordinal	10	10	10	10	10	10	10
2.3	Utility								
2.3.1	Financial								
2.3.1.1	Financing Risk	€	21	21	40	0	1	1217	27
2.3.1.2	Fuel Sensitivity	Factor	0.53	0.44	0.00	0.00	0.00	0.00	0.00
2.3.1.3	Constr. Time	Years	2	2	2	0.5	0.5	3	2
2.3.2	Operation								
2.3.2.1	Marginal Cost	€cents/kWh	5.6	4.0	0.0	0.2	0.2	0.0	4.7
2.3.2.2	Flexibility	Ordinal	7	7	2	2	2	2	3
2.3.2.3	Availability	Factor	0.85	0.85	0.12	0.12	0.12	0.54	0.40
3	SOCIAL								

Table A2.11 - NEEDS Database for Italy, Social Indicators for Technologies 1-12

Italy

								No lignite in Italy					No lignite in Italy	
Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
	Criterion	Units												
1	ENVIRONMENT													
2	ECONOMY													
3	SOCIAL													
3.1	Security													
3.1.1	Pol. continuity													
3.1.1.1	Secure Supply	Ordinal scale	3	3.5	3.5	3.5	3.5				4	4		
3.1.1.2	Waste repos.	Ordinal scale	5	4.5	3	4	4				2	4		
3.1.2	Adaptability	Ordinal scale	3	4	2.5	2.5	2.5				3	3		
3.2	Political legit.													
3.2.1	Conflict	Ordinal scale	4.5	4.5	3.5	3.5	3.5				2.5	2.5		
3.2.2	Participation	Ordinal scale	5	5	4	4.5	4.5				4	4.5		
3.3	Risk													
3.3.1	Normal risk													
3.3.1.1	Mortality	YOLL/kWh	1.46E-08	2.12E-09	1.94E-07	2.12E-07	1.64E-07				1.35E-07	1.60E-07		
3.3.1.2	Morbidity	DALY/kWh	8.33E-09	1.28E-09	1.48E-07	1.61E-07	1.26E-07				1.03E-07	1.22E-07		
3.3.2	Sev. Accidents													
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	1.07E-05	2.02E-04	1.25E-01	1.38E-01	1.44E-01				1.23E-01	1.40E-01		
3.3.2.2	Max. fatalities	Fatalities/accident	51987	3621	272	272	272				272	272		
3.3.3	Perceived risk													
3.3.3.1	Normal op.	Ordinal scale	5	5	3.5	3.5	3.5				3.5	3.5		
3.3.3.2	Perceived Acc.	Ordinal scale	4.67	4.67	3.17	3.67	3.67				3.17	3.67		
3.3.4	Terrorism													
3.3.4.1	Potential	Ordinal scale	6.5	6.5	4.9	4.9	4.9				4.9	4.9		
3.3.4.2	Effects	Expected number of fatalities	10	10	2	3	3				2	3		
3.3.4.3	Proliferation		1	1	0	0	0				0	0		
3.4	Quality of Residential Environment													
3.4.1	Landscape	Ordinal scale	4	4	3.75	3.75	3.75				3.75	3.75		
3.4.2	Noise	Ordinal scale	2	2	3	3	3				3	3		

Table A2.12 - NEEDS Database for Italy, Social Indicators for Technologies 13-26

Italy

Technology Number			13	14	15	16	17	18	19	20	21	22	23	24	25	26
Technology Class						**Fuel Cells**				**Biomass CHP**		**Solar**				**Wind**
Technology Name (short)			**GTCC**	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
Technology Name (long)			Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentratin g solar thermal power plant	Wind
	Criterion	**Units**														
1	ENVIRONMENT															
2	ECONOMY															
3	SOCIAL															
3.1	Security															
3.1.1	Pol. continuity															
3.1.1.1	Secure Supply	Ordinal scale	3	3	3	3	3	3	3	3	3	3	3	3	3	3.5
3.1.1.2	Waste repos.	Ordinal scale	1	4	1	1	1	1	1	3	3	2.5	2.5	2.5	2	2
3.1.2	Adaptability	Ordinal scale	3	3	3.5	4.5	4.5	4.5	4.5	2.5	2.5	4.5	4.5	4.5	4	4
3.2	Political legit.															
3.2.1	Conflict	Ordinal scale	3	3.5	1.5	1	1	1	1	1	1	1	1	1	1	1.5
3.2.2	Participation	Ordinal scale	3.5	4.5	2.5	1.5	1.5	1.5	1.5	3	3	3	3	3	3.5	4
3.3	Risk															
3.3.1	Normal risk															
3.3.1.1	Mortality	YOLL/kWh	3.80E-08	4.48E-08	4.79E-08	4.45E-08	9.33E-08	3.98E-08	4.11E-08	1.84E-07	2.41E-07	8.77E-09	9.03E-09	4.80E-09	1.53E-08	5.08E-09
3.3.1.2	Morbidity	DALY/kWh	2.95E-08	3.48E-08	3.74E-08	3.51E-08	7.21E-08	3.12E-08	3.22E-08	1.43E-07	1.85E-07	9.03E-09	9.27E-09	4.50E-09	1.42E-08	5.72E-09
3.3.2	Sev. Accidents															
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	7.09E-02	7.64E-02	1.01E-01	8.92E-02	2.99E-02	8.11E-02	7.69E-02	1.68E-02	1.68E-02	1.00E-04	1.00E-04	1.00E-04	2.07E-04	2.77E-03
3.3.2.2	Max. fatalities	Fatalities/accident	109	109	109	109	27	109	109	10	10	5	5	5	5	10
3.3.3	Perceived risk															
3.3.3.1	Normal op.	Ordinal scale	3	4	1	1	1	1	1	3.5	3.5	1	1	1	1	1
3.3.3.2	Perceived Acc.	Ordinal scale	2.67	3.67	3.00	3.00	3.00	3.00	3.00	3.17	3.17	2.17	2.17	2.17	2.00	2.67
3.3.4	Terrorism															
3.3.4.1	Potential	Ordinal scale	6.9	6.9	5.9	5.9	2	5.9	5.9	1	1	2	2	3	1	2
3.3.4.2	Effects	Expected number of fatalities	5	6	5	5	3	5	5	1	1	2	2	3	1	2
3.3.4.3	Proliferation		0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.4	Quality of Residential Environment															
3.4.1	Landscape	Ordinal scale	2.75	3.25	1.75	1.25	1.25	1.25	1.25	3.75	3.75	3	3	3	3	2
3.4.2	Noise	Ordinal scale	2	2	3	2	2	2	2	3	3	1	1	1	1.5	1

Table A2.13 - NEEDS Database for Switzerland, Environmental & Economic Indicators for Technologies 1-12

Switzerland

								No lignite in Switzerland					No lignite in Switzerland	
Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
	Criterion	**Units**												
1	ENVIRONMENT													
1.1	Resources													
1.1.1	Energy													
1.1.1.1	Fossil Fuels	MJ/kWh	6.76E-02	1.47E-02	6.99E+00	7.99E+00	8.18E+00				6.90E+00	7.87E+00		
1.1.1.2	Uranium	MJ/kWh	1.29E+01	7.45E-03	9.35E-02	2.00E-01	2.09E-01				9.34E-02	1.93E-01		
1.1.2	Minerals													
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	5.22E-08	2.42E-08	1.32E-07	2.75E-07	2.62E-07				1.19E-07	2.13E-07		
1.2	Climate													
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	4.25E-03	9.14E-04	6.85E-01	1.58E-01	8.43E-02				6.76E-01	1.47E-01		
1.3	Ecosystems													
1.3.1	Normal Op.													
1.3.1.1	Biodiversity	PDF*m2*a/kWh	2.19E-04	5.62E-05	5.14E-03	6.30E-03	6.51E-03				5.25E-03	6.39E-03		
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	5.28E-04	2.83E-04	2.06E-03	2.87E-03	2.66E-03				1.71E-03	2.07E-03		
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.68E-04	1.92E-05	5.35E-03	9.29E-03	4.57E-03				3.88E-03	4.55E-03		
1.3.2	Severe Acc.													
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0				0	0		
1.3.2.2	Land contam.	km2/GWe-yr	3.09E-06	6.81E-05	0	0	0				0	0		
1.4	Waste													
1.4.1	Chem waste	kg/kWh	6.90E-10	2.17E-10	1.36E-08	1.58E-08	7.27E-09				4.96E-10	6.60E-10		
1.4.2	Rad waste	m3/kWh	1.03E-08	3.22E-09	7.58E-11	1.62E-10	1.70E-10				7.56E-11	1.56E-10		
2	ECONOMY													
2.1	Customers													
2.1.1	Gen Cost	€/MWh	30.1	26.8	29.6	39.4	40.0				61.7	72.6		
2.2	Society													
2.2.1	Jobs	Person-years/GWh	61	71	54	77	78				63	76		
2.2.2	Fuel Autonomy	Ordinal	0	0	0	0	0				0	0		
2.3	Utility													
2.3.1	Financial													
2.3.1.1	Financing Risk	€	2383	2756	590	780	780				544	602		
2.3.1.2	Fuel Sensitivity	Factor	0.26	0.00	0.43	0.35	0.36				0.20	0.19		
2.3.1.3	Constr. Time	Years	4.83	5.5	3	3	3				3	3		
2.3.2	Operation													
2.3.2.1	Marginal Cost	€cents/kWh	1.2	0.4	1.5	1.7	1.8				4.4	5.0		
2.3.2.2	Flexibility	Ordinal	6	6	8	8	8				7	7		
2.3.2.3	Availability	Factor	0.9	0.90	0.85	0.85	0.85				0.85	0.85		
3	SOCIAL													

Table A2.14 - NEEDS Database for Switzerland, Environmental & Economic Indicators for Technologies 13-26

Switzerland

															No solar thermal in CH	No offshore wind in CH
Technology Number			13	14	15	16	17	18	19	20	21	22	23	24	25	26
Technology Class						**Fuel Cells**				**Biomass CHP**		**Solar**				**Wind**
Technology Name (short)			**GTCC**	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
Technology Name (long)			Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
	Criterion	**Units**														
1	ENVIRONMENT															
1.1	Resources															
1.1.1	Energy															
1.1.1.1	Fossil Fuels	MJ/kWh	6.65E+00	7.30E+00	8.48E+00	7.83E+00	6.05E-01	7.19E+00	7.31E+00	2.64E-01	1.12E-01	1.53E-01	1.48E-01	6.25E-02		
1.1.1.2	Uranium	MJ/kWh	5.40E-02	1.75E-01	7.51E-02	7.74E-02	3.21E-01	6.82E-02	8.05E-02	1.38E-02	7.05E-03	5.16E-02	5.17E-02	2.12E-02		
1.1.2	Minerals															
1.1.2.1	Metal Ores	kg(Sb-eq.)/kWh	7.72E-08	1.55E-07	1.33E-07	3.13E-07	4.34E-07	2.19E-07	1.35E-07	1.48E-07	8.01E-08	2.55E-06	2.56E-06	4.10E-07		
1.2	Climate															
1.2.1	CO2 equiv	kg(CO2-eq.)/kWh	3.85E-01	1.19E-01	5.18E-01	4.72E-01	4.00E-02	4.32E-01	4.35E-01	5.31E-02	3.28E-02	8.76E-03	9.22E-03	3.15E-03		
1.3	Ecosystems															
1.3.1	Normal Op.															
1.3.1.1	Biodiversity	PDF*m2*a/kWh	1.75E-03	2.50E-03	2.38E-03	2.49E-03	3.81E-01	2.24E-03	2.09E-03	8.01E-01	1.00E-04	4.11E-03	4.14E-04	2.45E-04		
1.3.1.2	Ecotoxicity	PDF*m2*a/kWh	3.48E-04	5.96E-04	4.50E-04	2.26E-03	2.71E-03	1.60E-03	5.57E-04	6.11E-04	2.82E-04	2.08E-03	2.11E-03	8.97E-04		
1.3.1.3	Air pollution	PDF*m2*a/kWh	1.17E-03	1.37E-03	1.58E-03	1.35E-03	3.35E-03	1.22E-03	1.30E-03	8.76E-03	9.44E-03	2.44E-04	2.43E-04	9.20E-05		
1.3.2	Severe Acc.															
1.3.2.1	Hydrocarbons	t/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0		
1.3.2.2	Land contam.	km2/GWe-yr	0	0	0	0	0	0	0	0	0	0	0	0		
1.4	Waste															
1.4.1	Chem waste	kg/kWh	4.38E-09	5.17E-09	5.99E-09	8.02E-09	3.18E-09	7.02E-09	8.77E-09	3.85E-10	2.22E-10	6.39E-09	3.55E-09	1.79E-09		
1.4.2	Rad waste	m3/kWh	4.36E-11	1.41E-10	6.03E-11	6.17E-11	2.60E-10	5.45E-11	5.61E-11	1.10E-11	5.65E-12	3.96E-11	4.08E-11	1.62E-11		
2	ECONOMY															
2.1	Customers															
2.1.1	Gen Cost	€/MWh	59.9	86.9	111.0	87.4	84.4	72.9	67.3	72.9	65.1	67.2	73.7	76.2		
2.2	Society															
2.2.1	Jobs	Person-years/GWh	89	97	76	406	173	338	293	405	236	123	126	140		
2.2.2	Fuel Autonomy	Ordinal	0	0	0	0	10	0	0	10	10	10	10	10		
2.3	Utility															
2.3.1	Financial															
2.3.1.1	Financing Risk	€	440	615	0	0.39	0.39	2.47	0.31	21	21	40	0	1		
2.3.1.2	Fuel Sensitivity	Factor	0.54	0.39	0.36	0.41	0.38	0.44	0.48	0.52	0.43	0.00	0.00	0.00		
2.3.1.3	Constr. Time	Years	3	3	1	0.83	0.83	0.83	0.83	2	2	2	0.5	0.5		
2.3.2	Operation															
2.3.2.1	Marginal Cost	€cents/kWh	5.4	7.8	10.8	4.2	3.7	3.8	3.6	5.5	3.9	0.0	0.2	0.2		
2.3.2.2	Flexibility	Ordinal	10	10	10	7	7	7	7	7	7	2	2	2		
2.3.2.3	Availability	Factor	0.85	0.85	0.97	0.99	0.99	0.99	0.99	0.85	0.85	0.11	0.11	0.11		
3	SOCIAL															

Table A2.15 - NEEDS Database for Switzerland, Social Indicators for Technologies 1-12

Switzerland

								No lignite in Switzerland					No lignite in Switzerland	
Technology Number			1	2	3	4	5	6	7	8	9	10	11	12
Technology Class			**Nuclear Plants**		**Adv. Fossil**									
Technology Name (short)			**EPR**	**SFR**	**PC**	**PC-post CCS**	**PC-oxyfuel CCS**	**PL**	**PL-post CCS**	**PL-oxyfuel CCS**	**IGCC coal**	**IGCC coal CCS**	**IGCC lig**	**IGCC lig CCS**
Technology Name (long)			European Pressurized Reactor	Sodium Fast Reactor (Gen IV Fast Breeder Reactor	Pulverized Coal (PC) steam plant	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Coal (PC) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Pulverized Lignite (PL) steam plant	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), post combustion	Pulverized Lignite (PL) plant with Carbon Capture & Storage (CCS), oxyfuel combustion	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)	Integrated Gasification Combined Cycle (IGCC)	Integrated Gasification Combined Cycle (IGCC) with Carbon Capture & Storage (CCS)
	Criterion	Units												
1	ENVIRONMENT													
2	ECONOMY													
3	SOCIAL													
3.1	Security													
3.1.1	Pol. continuity													
3.1.1.1	Secure Supply	Ordinal scale	2.5	2	2.5	2	2				2.5	2		
3.1.1.2	Waste repos.	Ordinal scale	4	4	3	3.5	3.5				3	3.5		
3.1.2	Adaptability	Ordinal scale	3	3	3	3	3				3	3		
3.2	Political legit.													
3.2.1	Conflict	Ordinal scale	5	5	2.5	2	2				2.5	2		
3.2.2	Participation	Ordinal scale	5	5	4	4	4				4	4		
3.3	Risk													
3.3.1	Normal risk													
3.3.1.1	Mortality	YOLL/kWh	1.94E-08	2.73E-09	2.74E-07	2.92E-07	2.28E-07				1.96E-07	2.32E-07		
3.3.1.2	Morbidity	DALY/kWh	1.16E-08	1.71E-09	2.02E-07	2.13E-07	1.68E-07				1.44E-07	1.70E-07		
3.3.2	Sev. Accidents													
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	8.56E-06	1.59E-04	1.21E-01	1.34E-01	1.40E-01				1.19E-01	1.35E-01		
3.3.2.2	Max. fatalities	Fatalities/accident	44090	3060	272	272	272				272	272		
3.3.3	Perceived risk													
3.3.3.1	Normal op.	Ordinal scale	4	4	3	3	3				3	3		
3.3.3.2	Perceived Acc.	Ordinal scale	4.67	4.67	3.67	3.33	3.33				3.67	3.33		
3.3.4	Terrorism													
3.3.4.1	Potential	Ordinal scale	6.5	6.5	4.9	4.9	4.9				4.9	4.9		
3.3.4.2	Effects	Expected number	10	10	2	3	3				2	3		
3.3.4.3	Proliferation		1	1	0	0	0				0	0		
3.4	Quality of Residential Environment													
3.4.1	Landscape	Ordinal scale	3.25	3.25	2.75	2.5	2.5				2.75	2.5		
3.4.2	Noise	Ordinal scale	2	2	4	3.5	3.5				4	3.5		

Table A2.16 - NEEDS Database for Switzerland, Social Indicators for Technologies 13-26

Switzerland

															No solar thermal in CH	No offshore wind in CH
Technology Number			13	14	15	16	17	18	19	20	21	22	23	24	25	26
Technology Class						**Fuel Cells**				**Biomass CHP**		**Solar**				**Wind**
Technology Name (short)			**GTCC**	**GTCC CCS**	**IC CHP**	**MCFC NG**	**MCFC wood gas**	**MCFC NG**	**SOFC NG**	**CHP poplar**	**CHP straw**	**PV-Si plant**	**PV-Si building**	**PV-CdTe building**	**Solar thermal**	**Wind-offshore**
Technology Name (long)			Combined Cycle	Combined Cycle with Carbon Capture & Storage (CCS), post combustion	Combined Cycle Heat and Power	Molten Carbonate Fuel Cells, natural gas	Molten Carbonate Fuel Cells, wood gas	Molten Carbonate Fuel Cells, natural gas	Solid Oxide Fuel Cells (tubular, natural gas	Steam turbine cogeneration, short rotation forestry poplar	Steam turbine cogeneration, agricultural waste wheat straw	PV, Mono-crystalline Si, Plant Size	PV, Mono-crystalline Si, Building Integrated	CdTe, Building Integrated	Concentrating solar thermal power plant	Wind
	Criterion	Units														
1	ENVIRONMENT															
2	ECONOMY															
3	SOCIAL															
3.1	Security															
3.1.1	Pol. continuity															
3.1.1.1	Secure Supply	Ordinal scale	3	3	4	3	3	3	3	3	3	3	3	3		
3.1.1.2	Waste repos.	Ordinal scale	2	3.5	1	1	1	1	1	3	3	1	1	1		
3.1.2	Adaptability	Ordinal scale	3	2.5	3	5	5	5	5	3	3	4	4	4		
3.2	Political legit.															
3.2.1	Conflict	Ordinal scale	3	3	1.5	1	1	1	1	2	2	2	2	2		
3.2.2	Participation	Ordinal scale	3.5	4	1	1	1	1	1	2	2	2	2	2		
3.3	Risk															
3.3.1	Normal risk															
3.3.1.1	Mortality	YOLL/kWh	7.44E-08	8.65E-08	9.77E-08	8.86E-08	1.62E-07	7.97E-08	8.29E-08	3.45E-07	4.71E-07	1.62E-08	1.65E-08	8.37E-09		
3.3.1.2	Morbidity	DALY/kWh	5.42E-08	6.32E-08	7.14E-08	6.52E-08	1.19E-07	5.85E-08	6.07E-08	2.52E-07	3.43E-07	1.45E-08	1.48E-08	7.12E-09		
3.3.2	Sev. Accidents															
3.3.2.1	Exp. mortality	Fatalities/GWe-yr	6.86E-02	7.40E-02	1.01E-01	8.92E-02	2.99E-02	8.11E-02	7.69E-02	1.68E-02	1.68E-02	1.00E-04	1.00E-04	1.00E-04		
3.3.2.2	Max. fatalities	Fatalities/accident	109	109	109	109	27	109	109	10	10	5	5	5		
3.3.3	Perceived risk															
3.3.3.1	Normal op.	Ordinal scale	2	3	1	1	1	1	1	3	3	1	1	1		
3.3.3.2	Perceived Acc.	Ordinal scale	2.67	3.33	1.83	1.83	1.83	1.83	1.83	3.67	3.67	2.17	2.17	2.17		
3.3.4	Terrorism															
3.3.4.1	Potential	Ordinal scale	6.9	6.9	5.9	5.9	2	5.9	5.9	1	1	2	2	3		
3.3.4.2	Effects	Expected number	5	6	5	5	3	5	5	1	1	2	2	3		
3.3.4.3	Proliferation		0	0	0	0	0	0	0	0	0	0	0	0		
3.4	Quality of Residential Environment															
3.4.1	Landscape	Ordinal scale	2.5	2.5	1	1	1	1	1	2.75	2.75	2	2	2		
3.4.2	Noise	Ordinal scale	2	2.5	1	1	1	1	1	4	4	1	1	1		

Figure A3.1 – Total Consumption of Fossil Resources

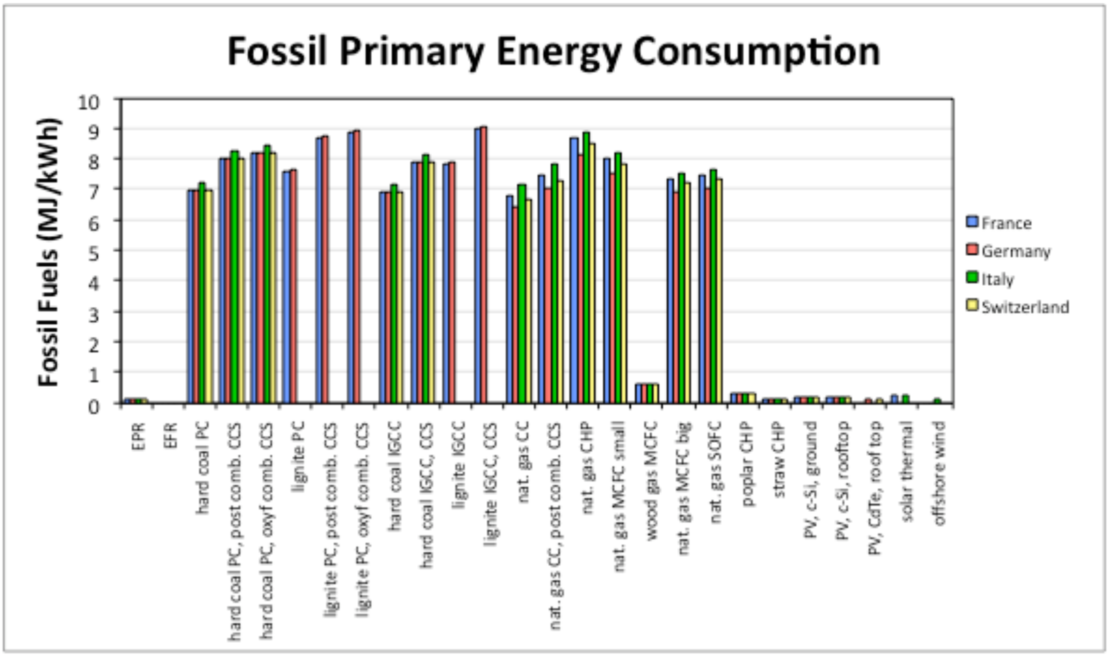


Figure A3.2 – Total Consumption of Uranium

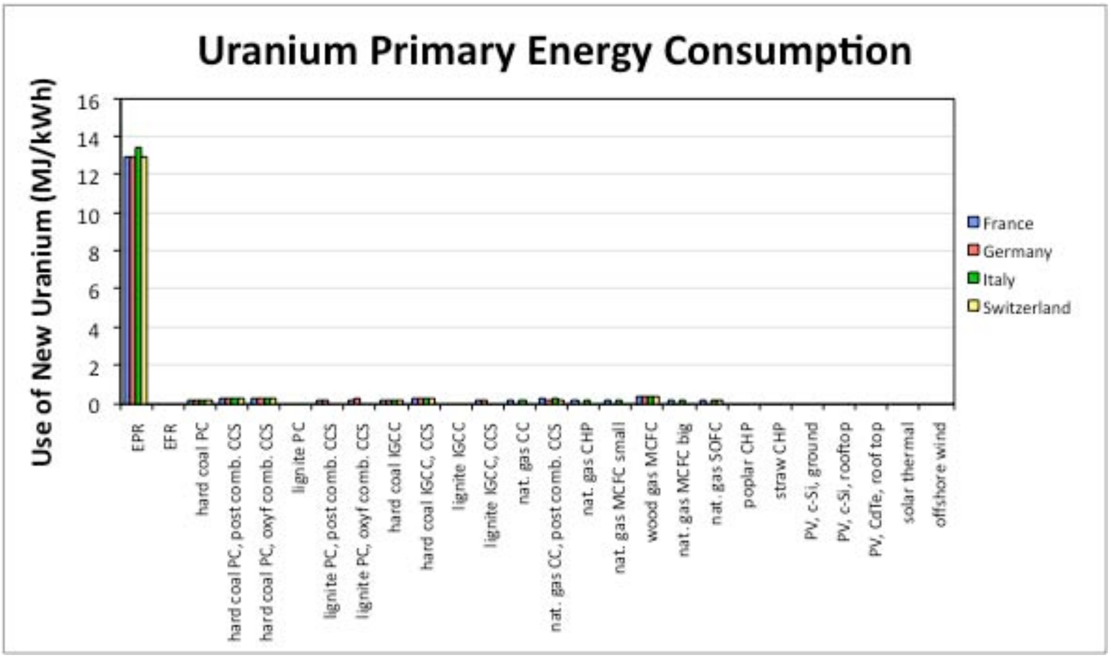


Figure A3.3 – Weighted Total Consumption of Metallic Ores

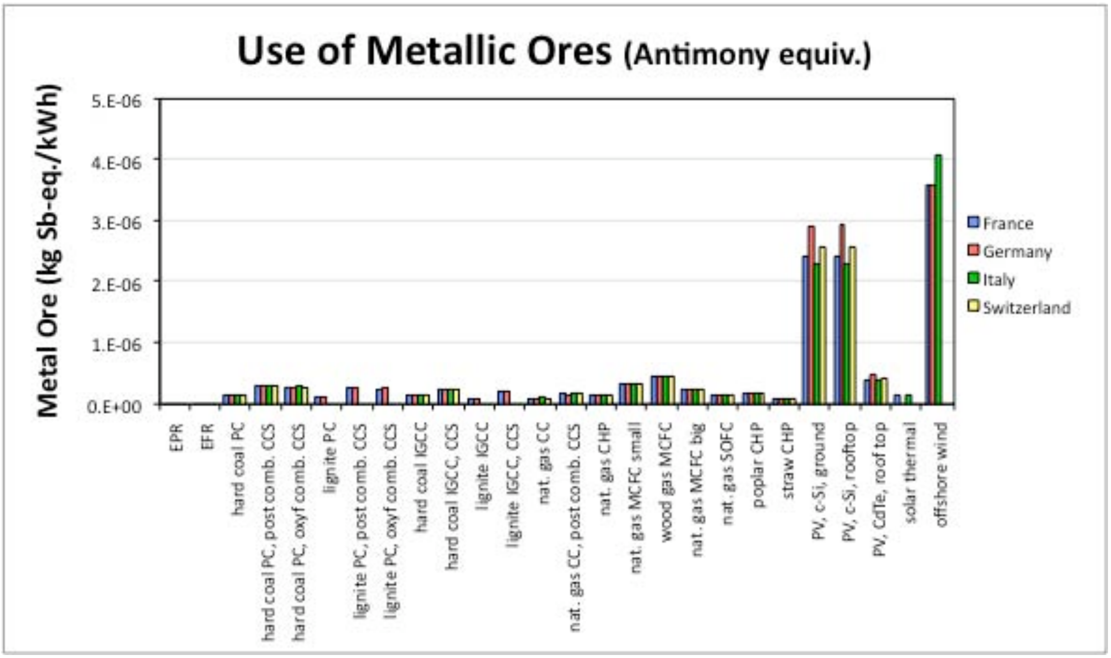


Figure A3.4 – Global Warming Potential

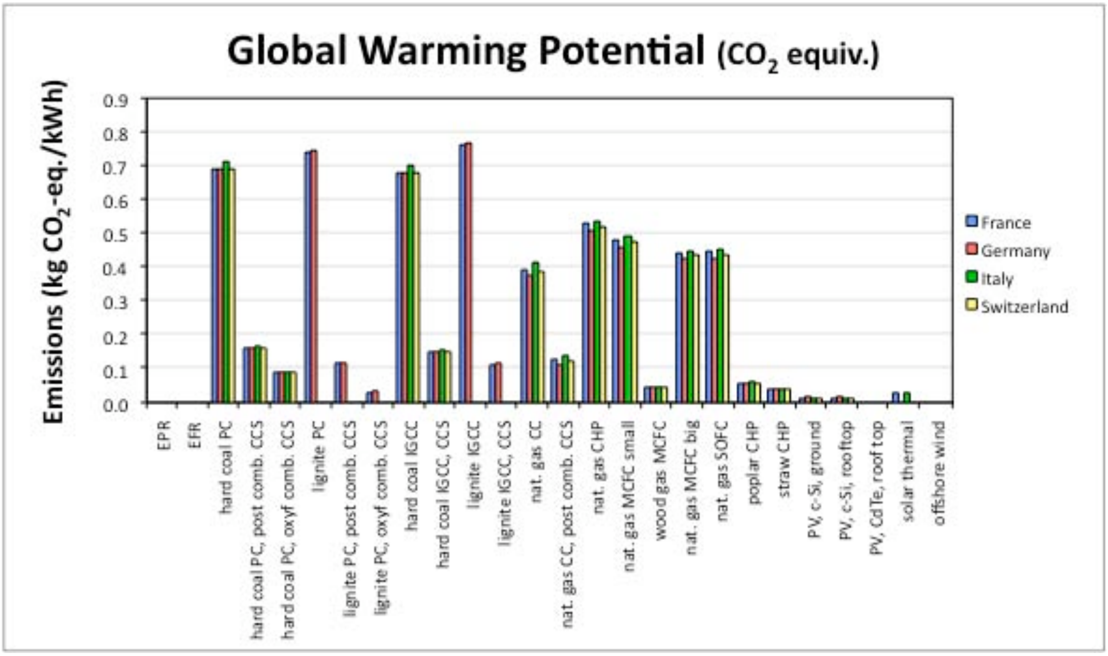


Figure A3.5 – Impacts of Land Use on Ecosystems

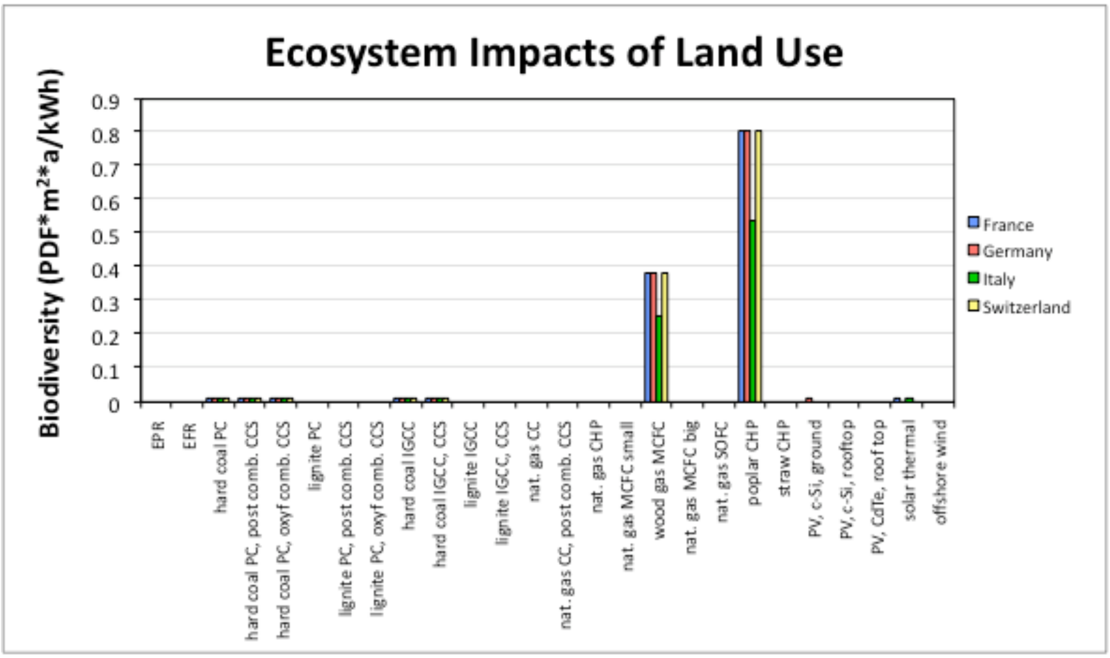


Figure A3.6 – Impacts of Toxic Substances on Ecosystems

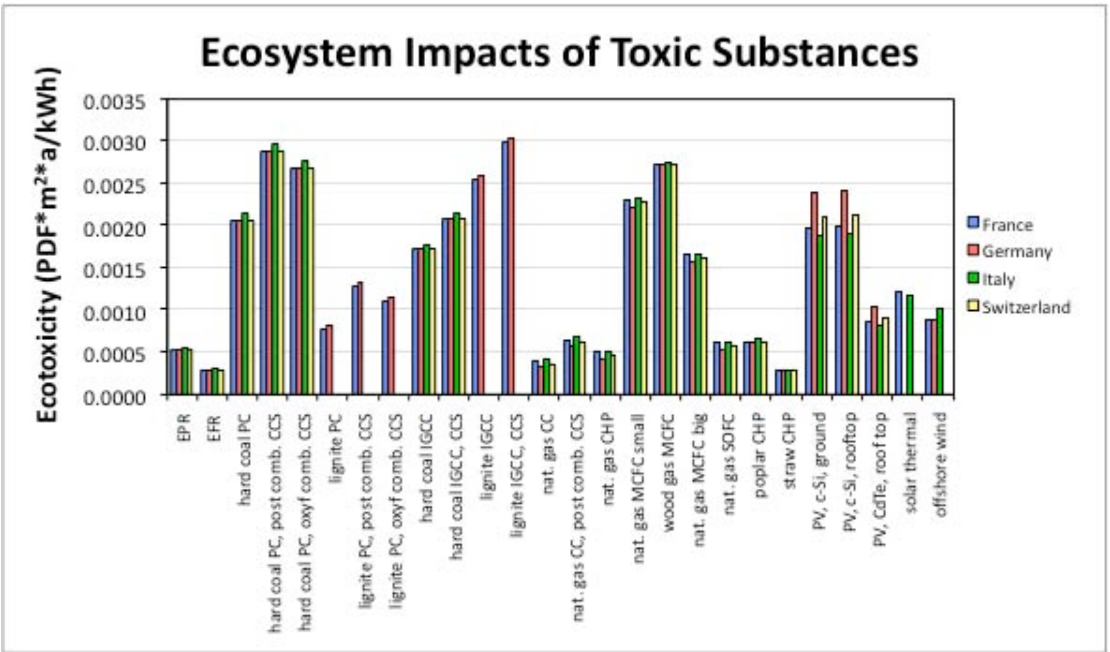


Figure A3.7 – Impacts of Air Pollution on Ecosystems

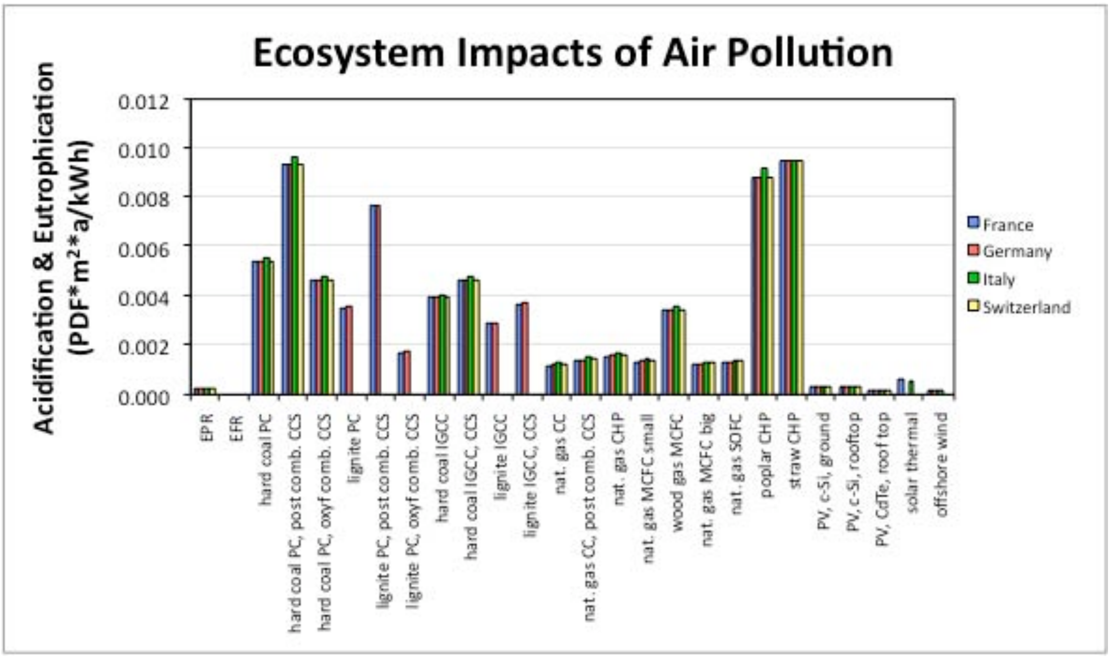
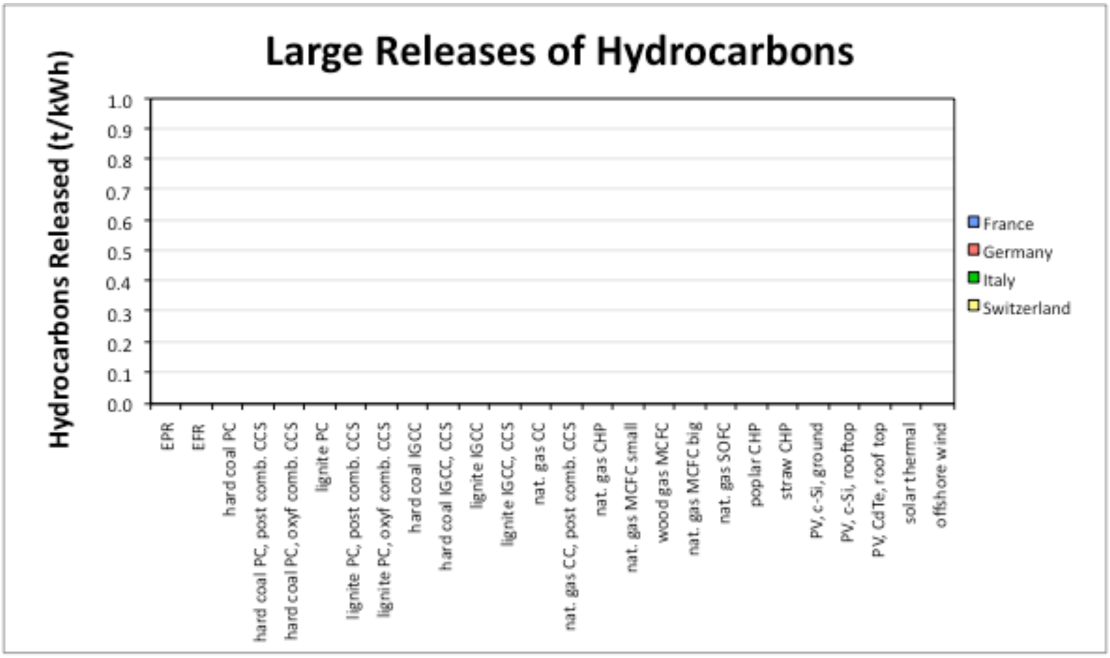


Figure A3.8 – Large Releases of Hydrocarbons



Note: Because no oil burning generation technologies were included, there is no potential for large oil spills in any of the energy chains.

Figure A3.9 – Nuclear Land Contamination

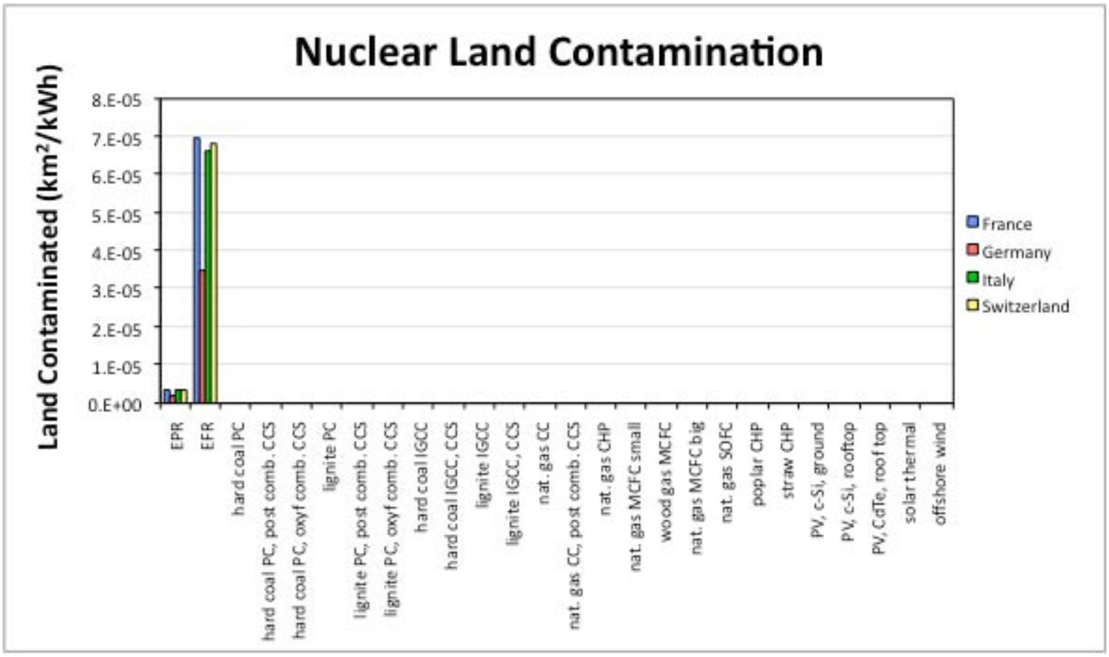


Figure A3.10 – Total Weight of Special Chemical Wastes Stored in Underground Repositories

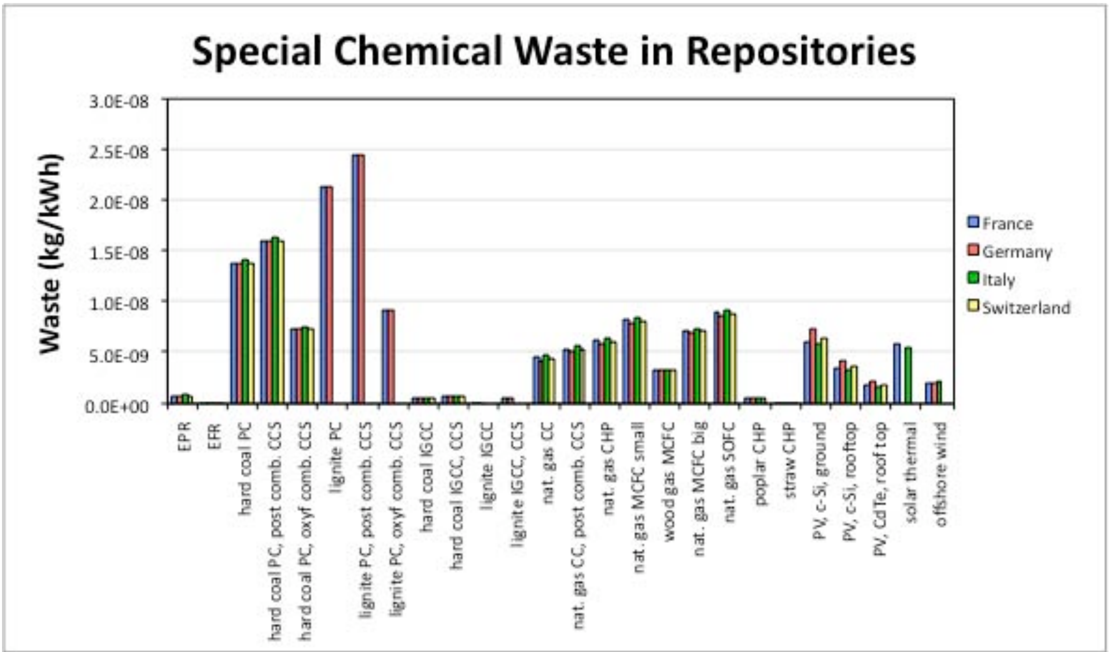


Figure A3.11 – Total Amount of Medium and High Level Radioactive Wastes to be Stored in Geological Repositories

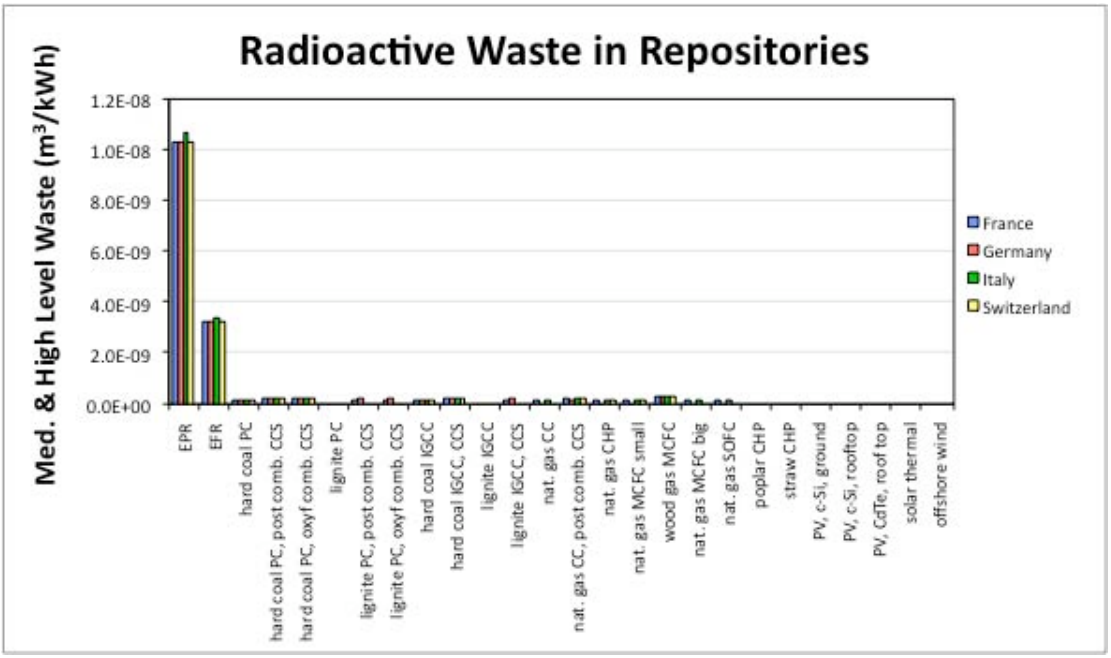


Figure A3.12 – Average Generation Cost

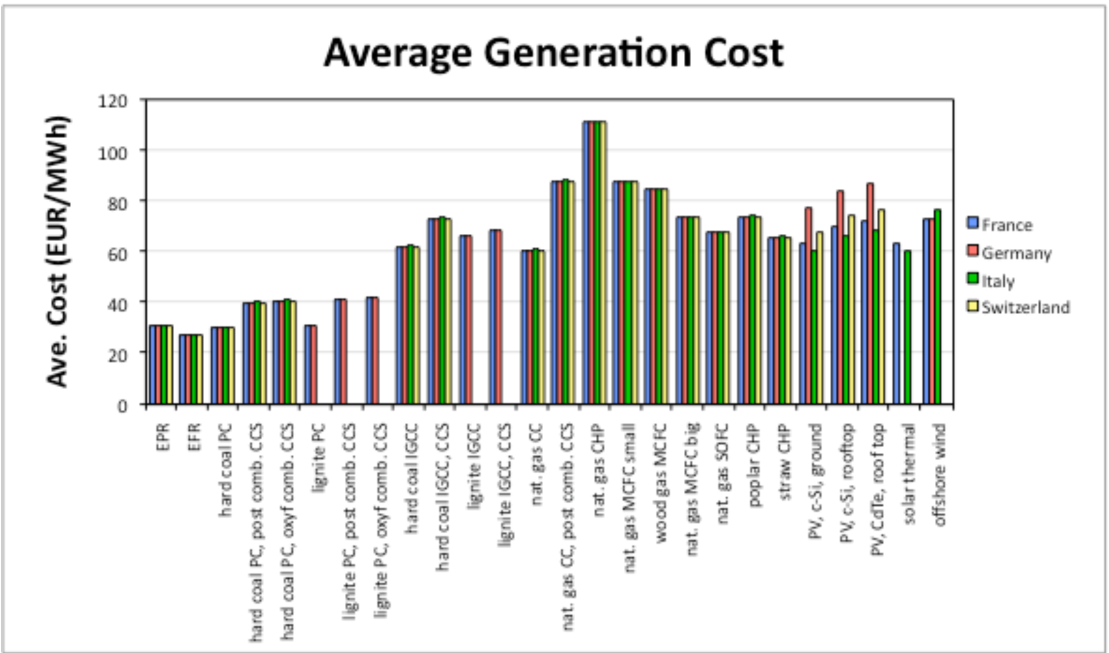


Figure A3.13 – Direct Labor

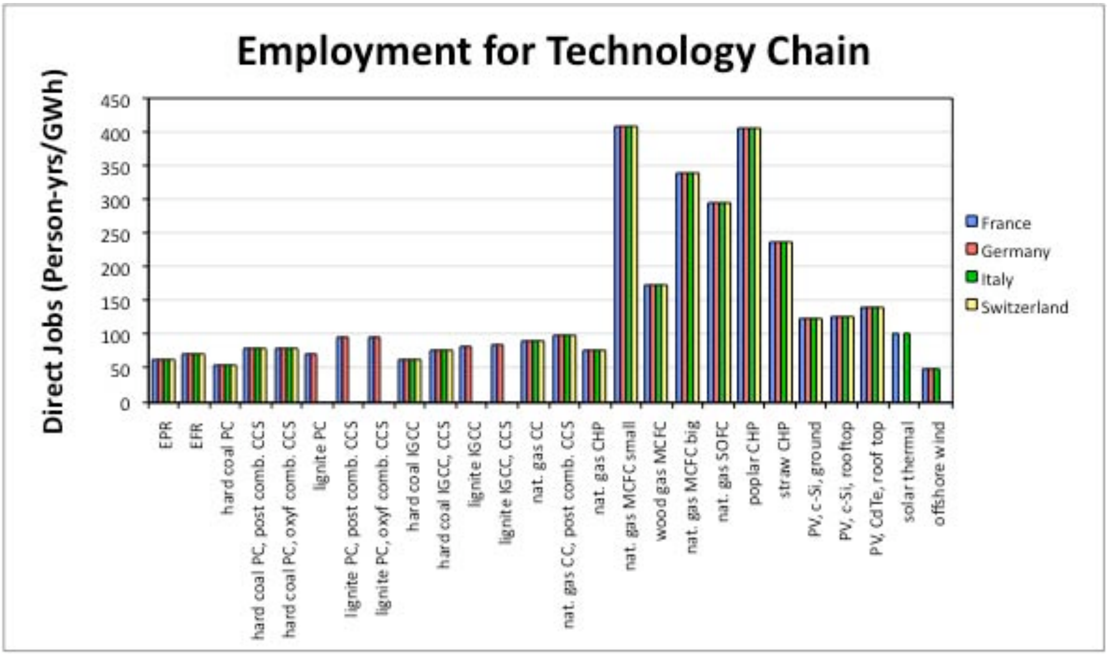


Figure A3.14 – Medium to Long Term Independence from Foreign Energy Sources

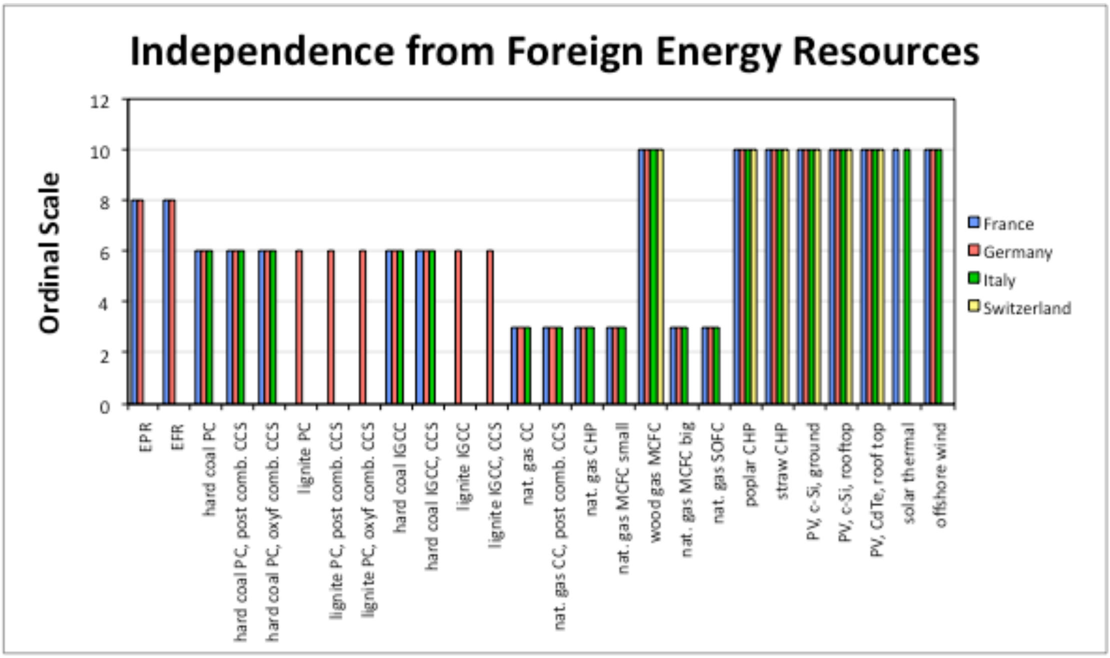


Figure A3.15 – Total Capital Cost

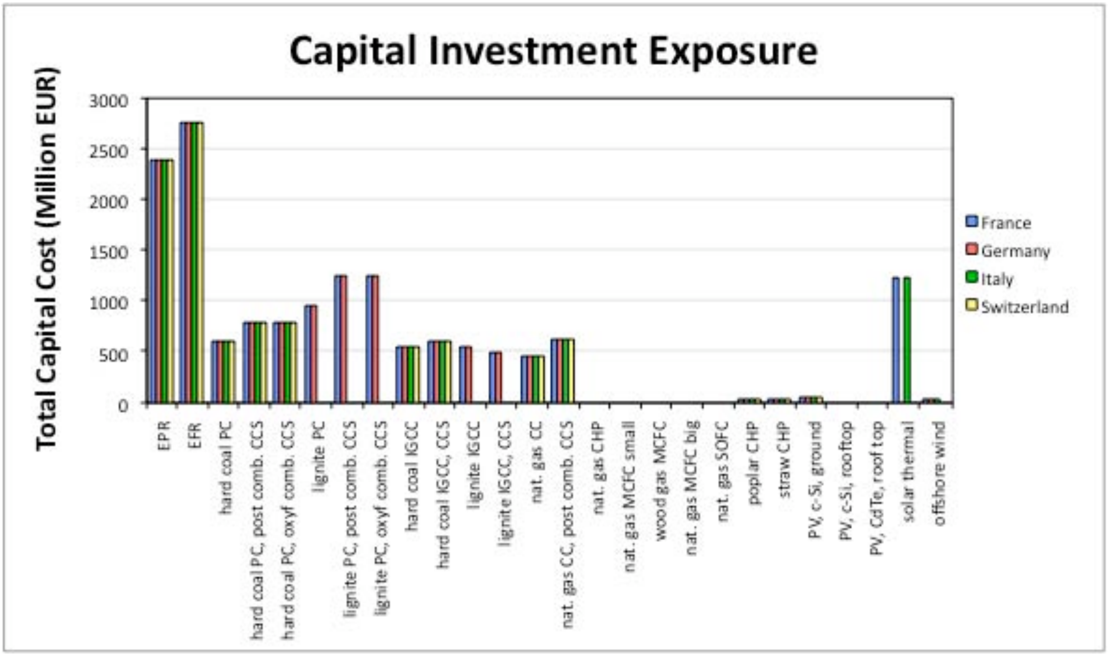


Figure A3.16 – Ratio of Fuel Cost to Generation Cost

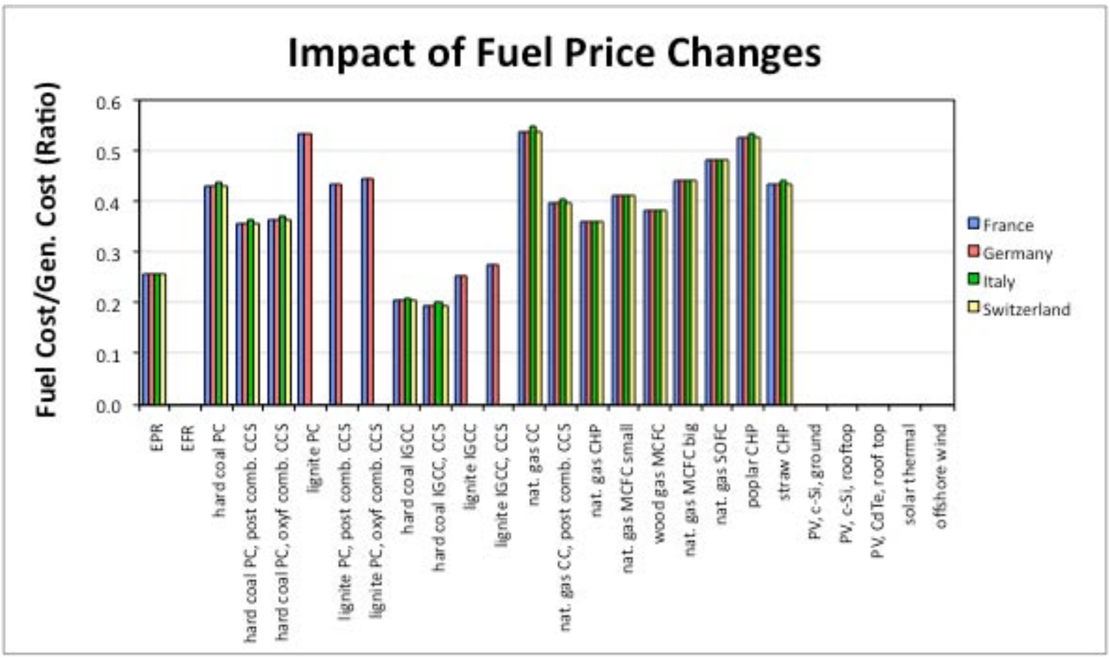


Figure A3.17 – Construction Time

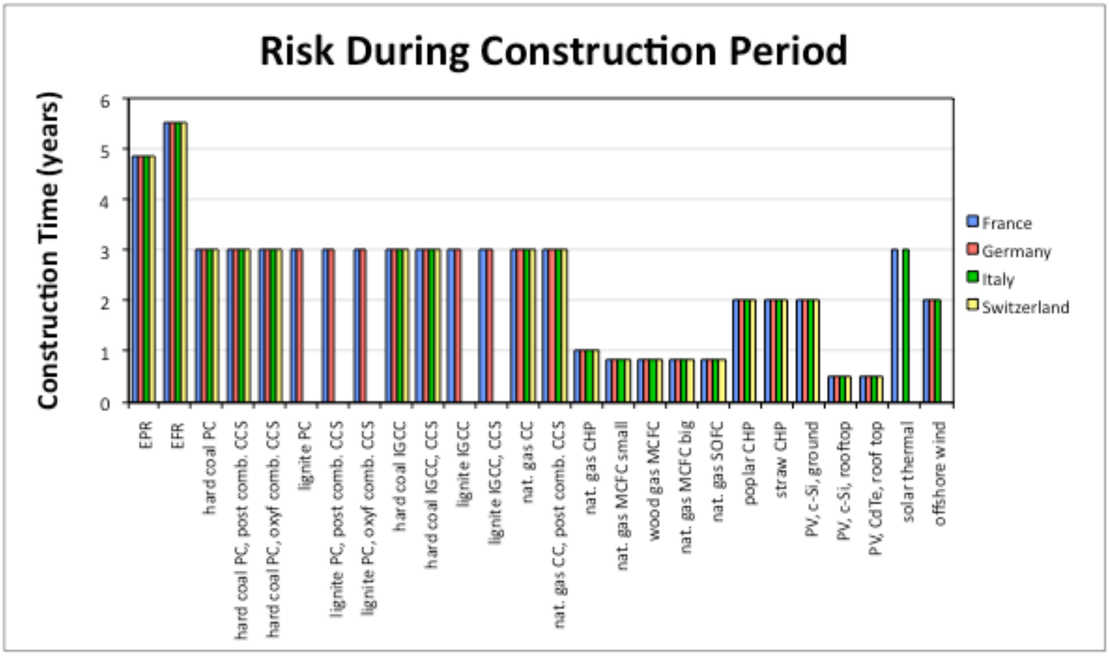


Figure A3.18 – Average Variable Cost of Generation

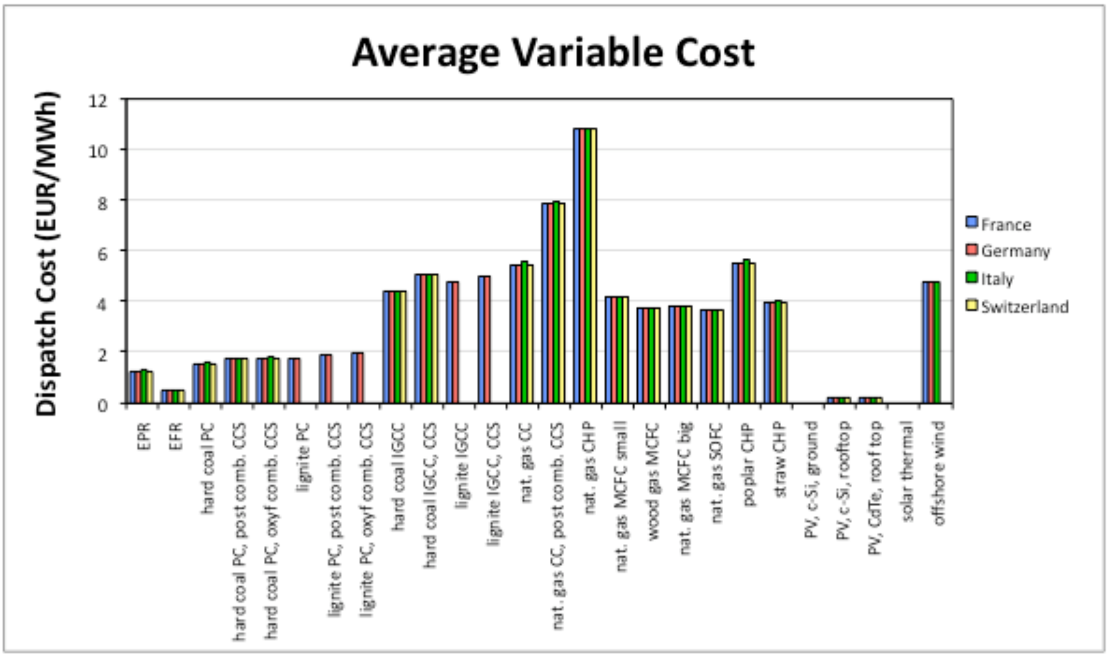


Figure A3.19 – Flexibility of Dispatch

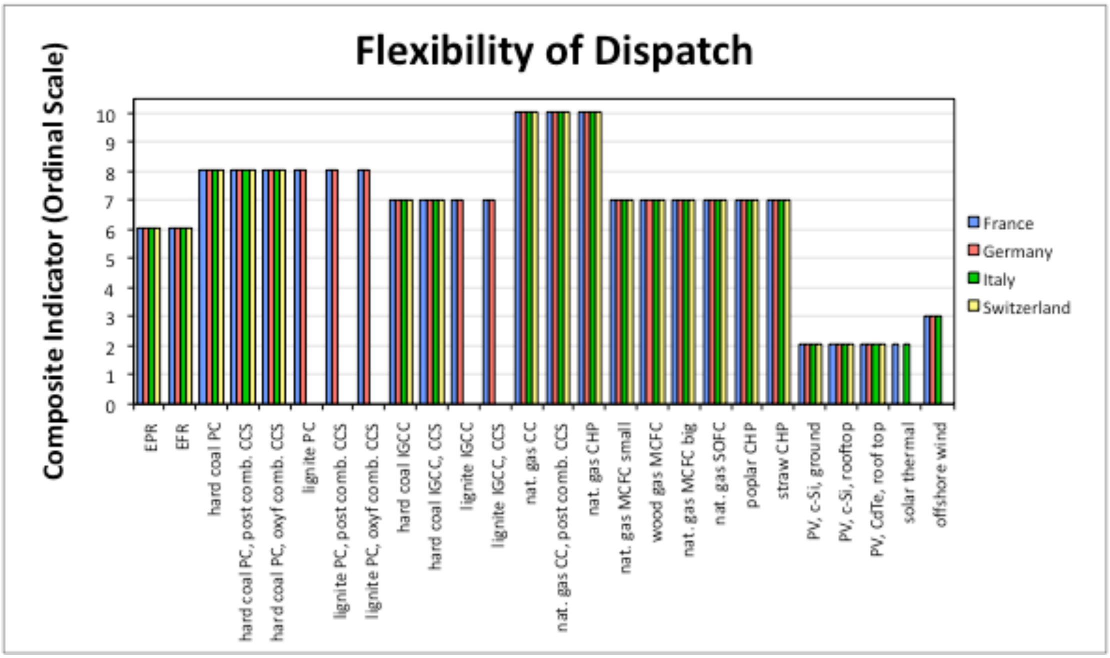


Figure A3.20 – Equivalent Availability Factor

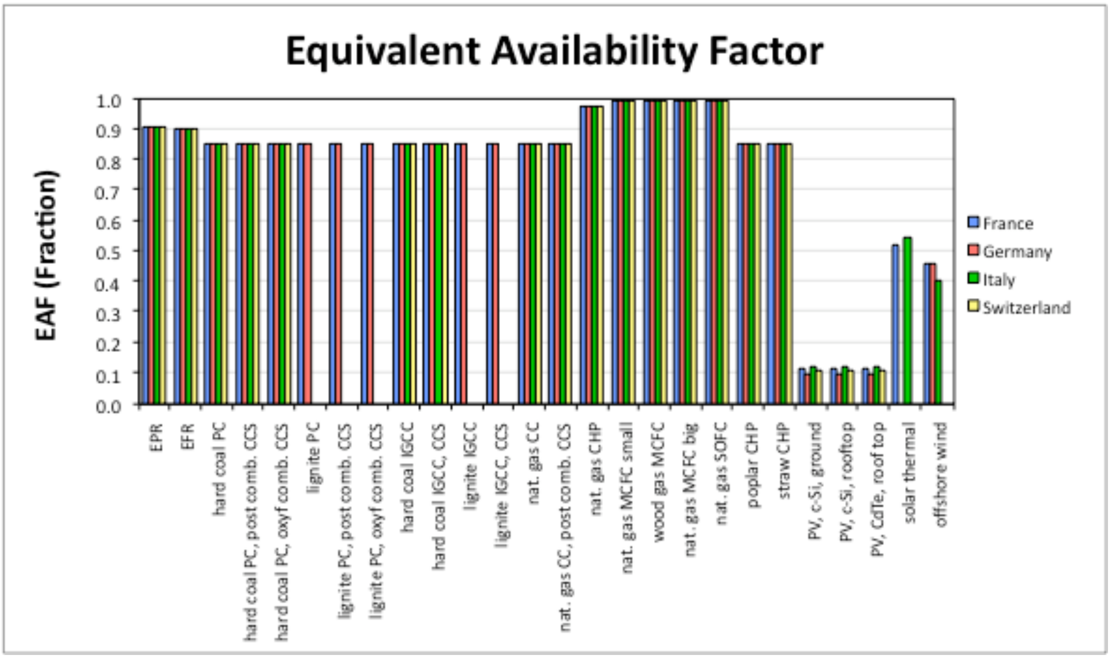


Figure A3.21 – Market Concentration in the Primary Energy Supply

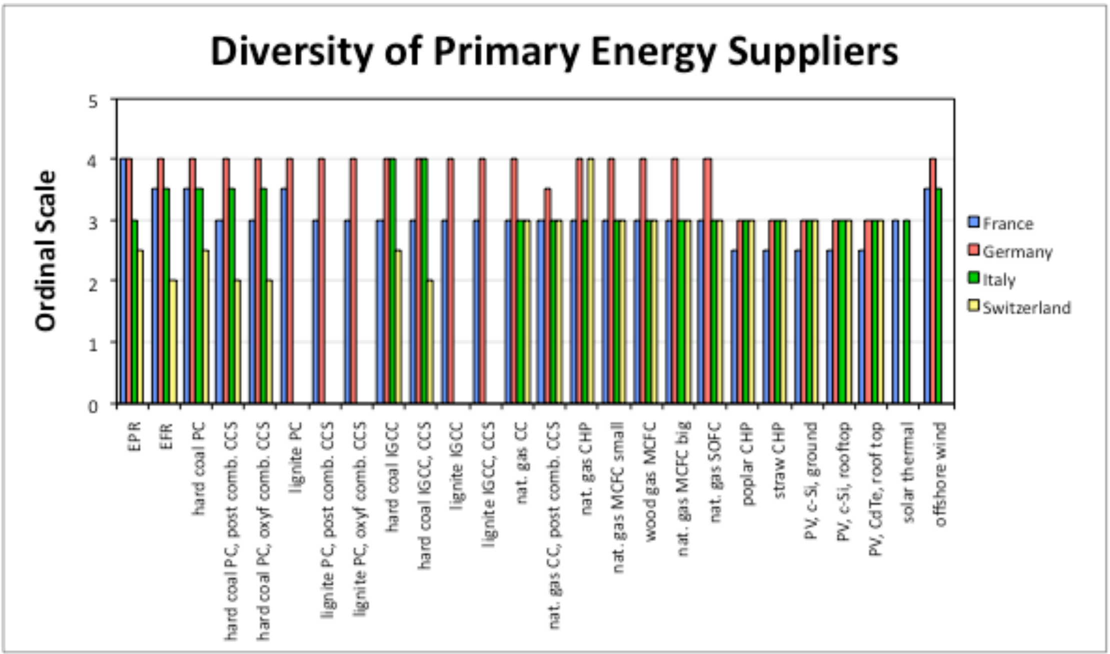


Figure A3.22 – Probability that Waste Storage Management will not be Available

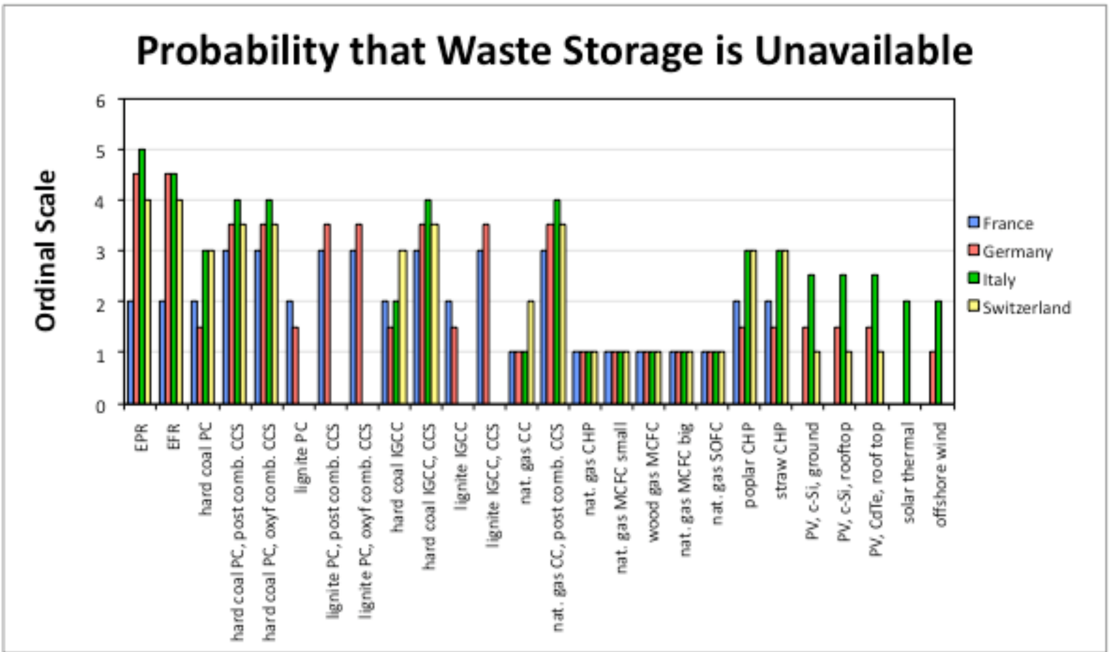


Figure A3.23 – Flexibility to Incorporate Technological Change

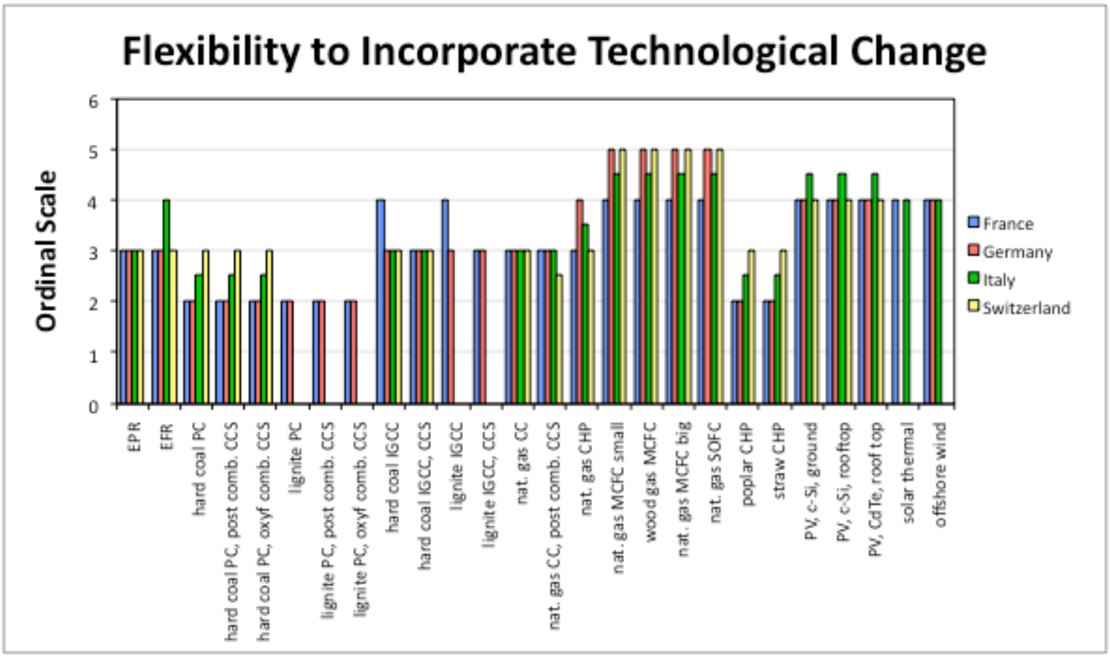


Figure A3.24 – Potential of Energy System Induced Conflicts

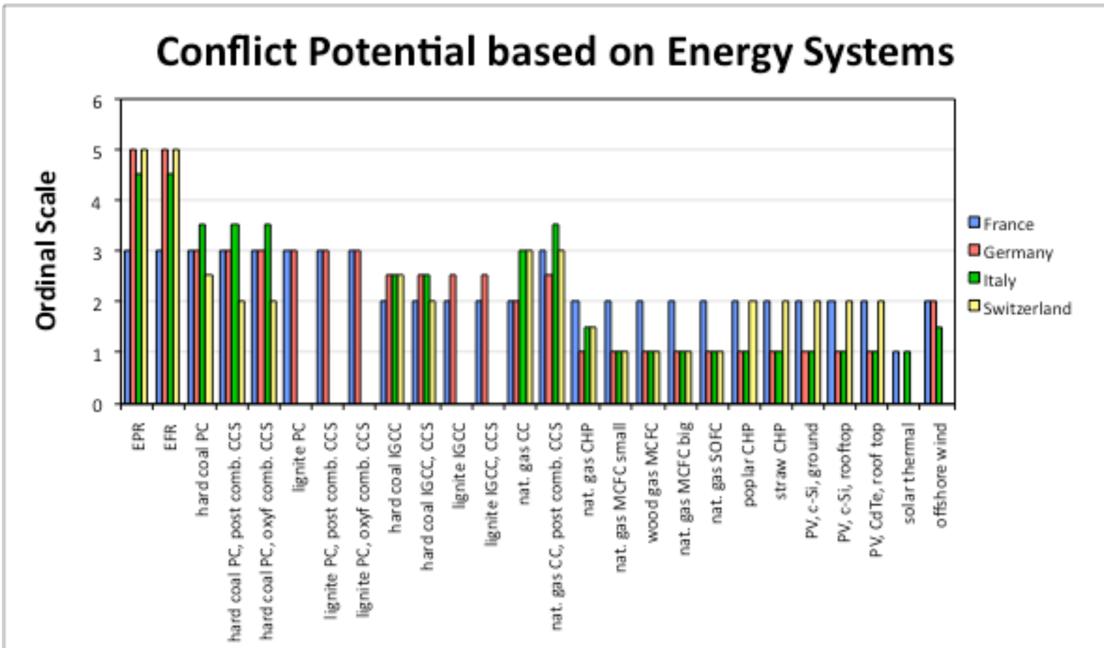


Figure A3.25 – Necessity of Participative Decision-making Processes

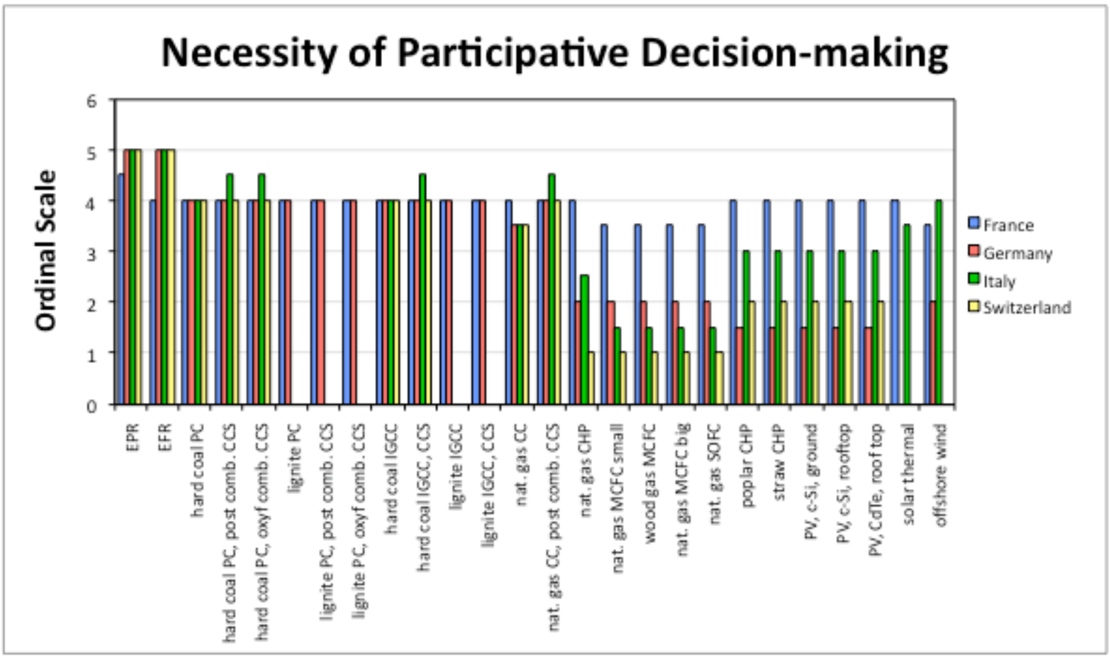


Figure A3.26 – Mortality due to Normal Operation

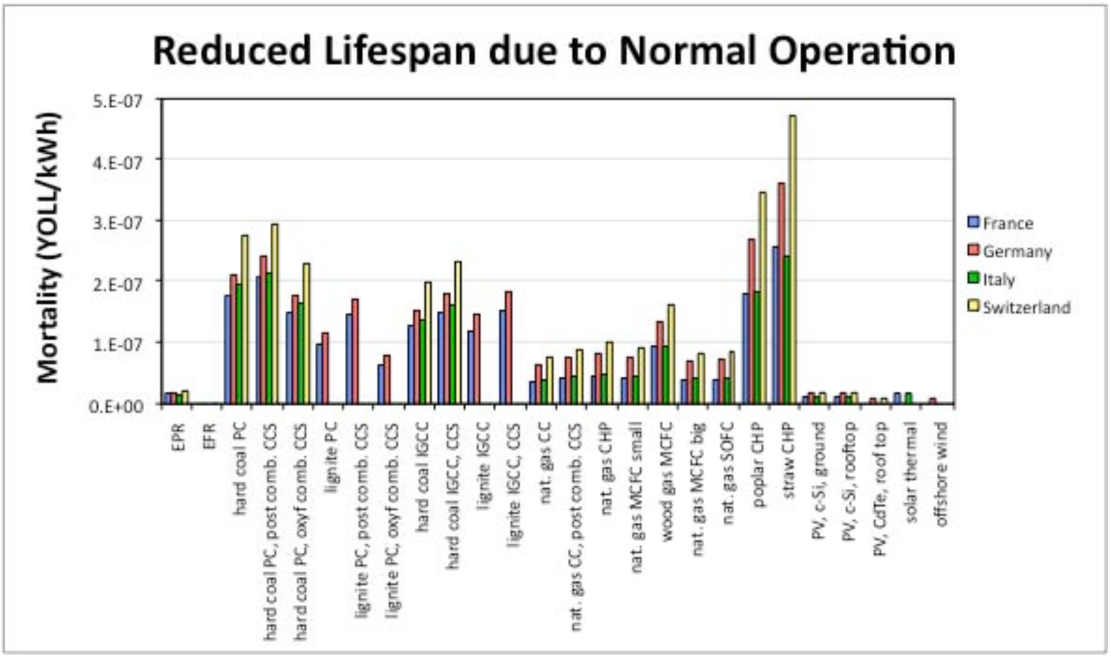


Figure A3.27 – Morbidity due to Normal Operation

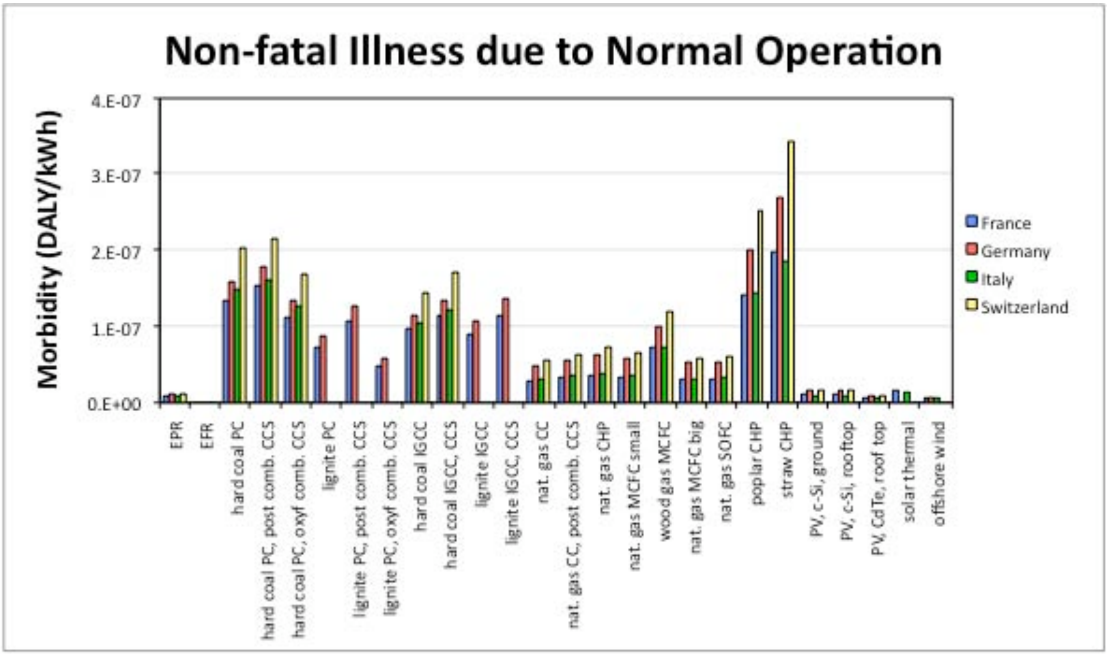


Figure A3.28 – Expected Mortality due to Severe Accidents

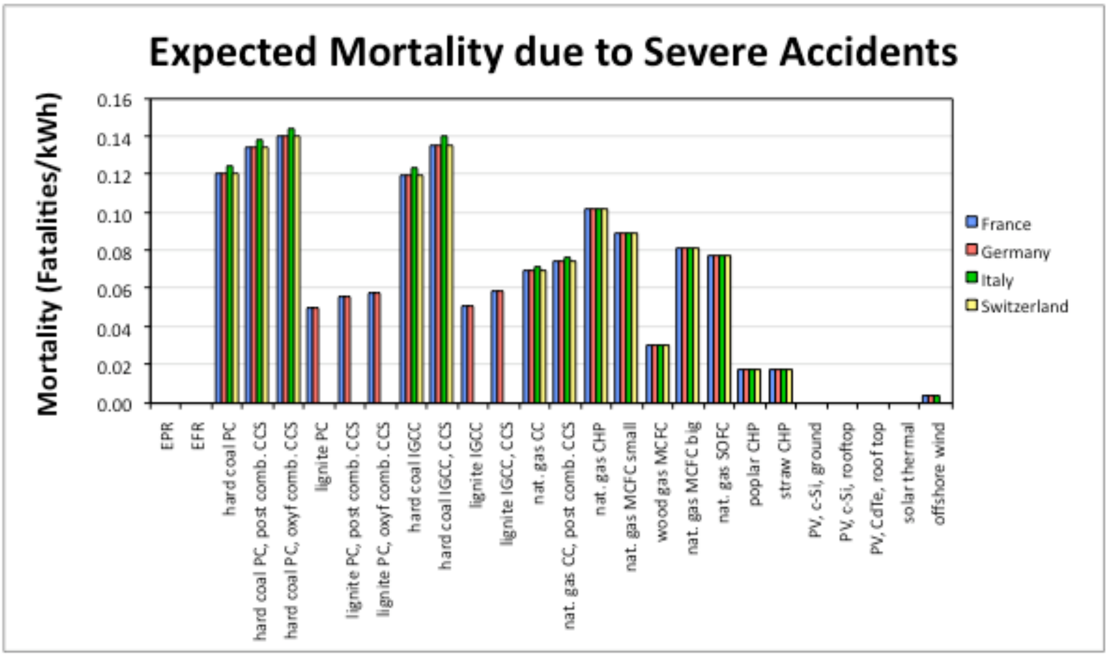


Figure A3.29 – Maximum Credible Number of Fatalities per Accident

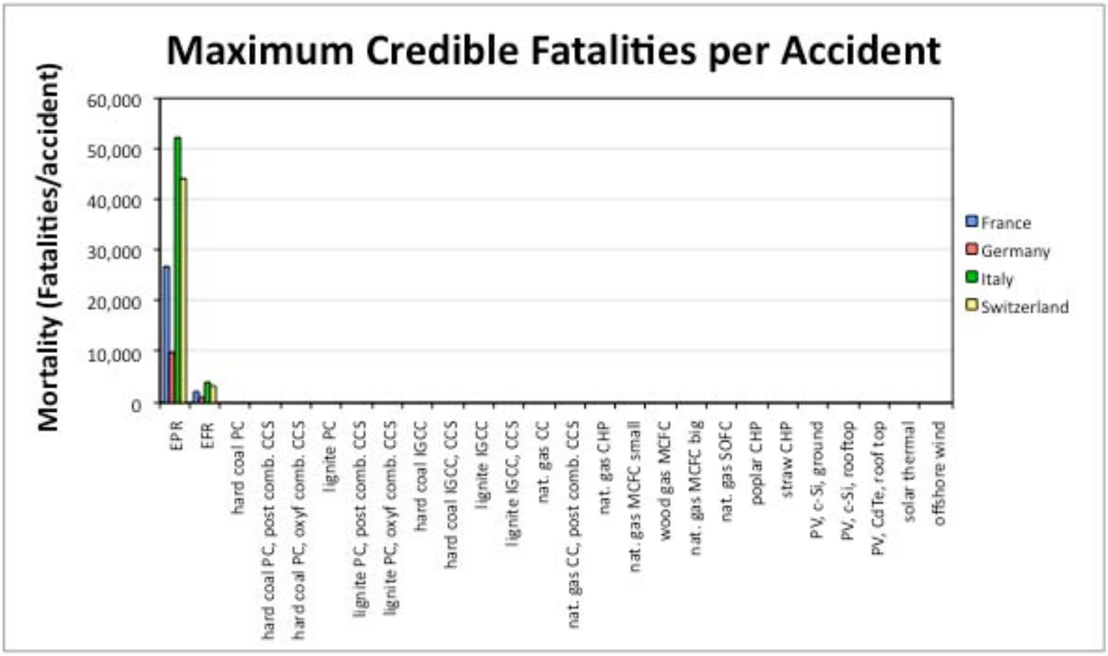


Figure A3.30 – Perceived Risk of Normal Operation

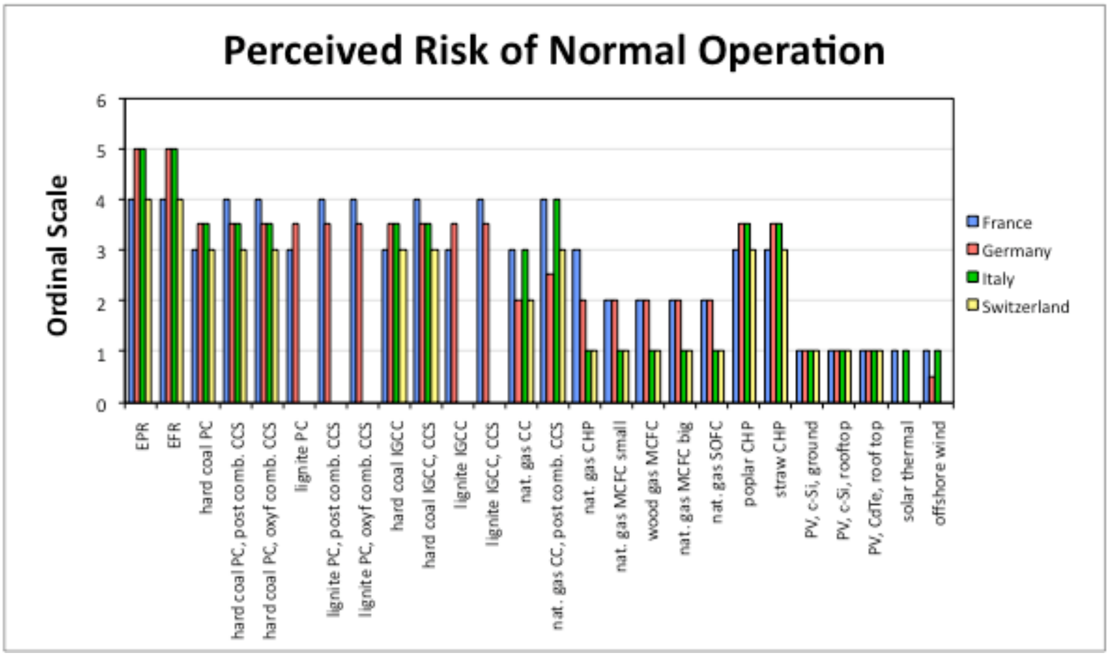


Figure A3.31 – Perceived Characteristics of Accident Risks

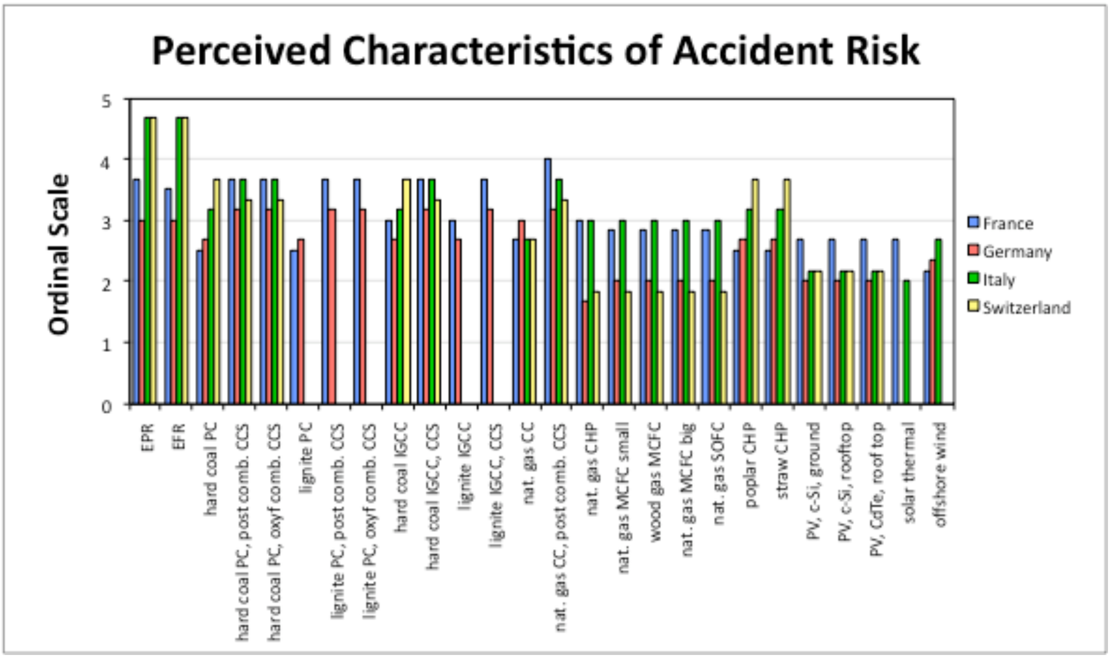


Figure A3.32 – Potential of a Successful Terrorist Attach

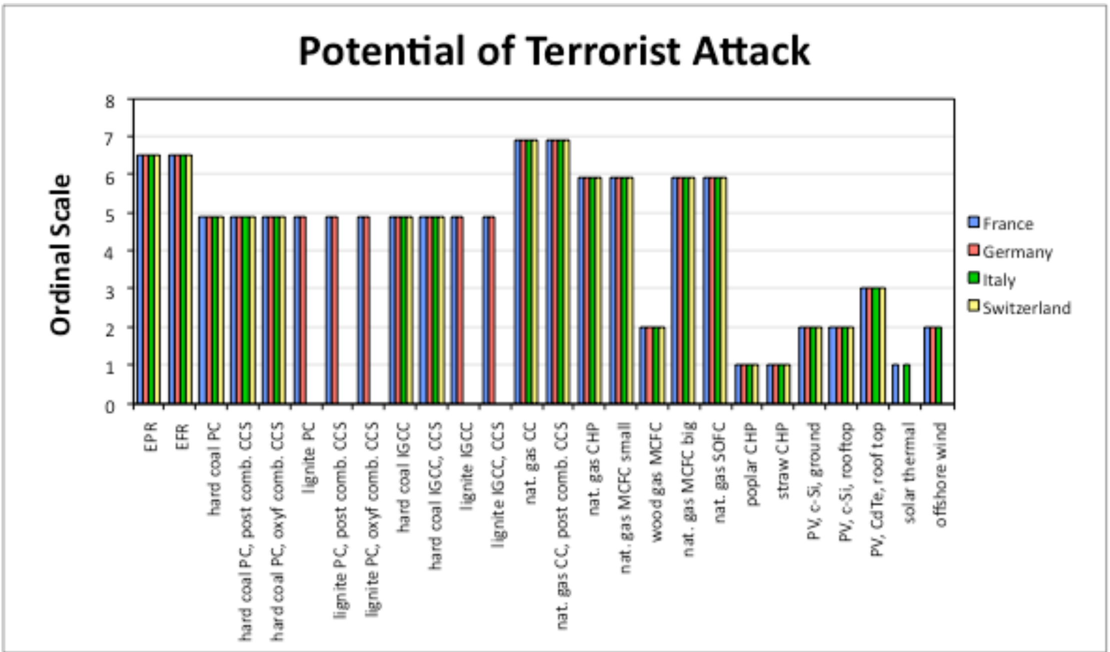


Figure A3.33 – Likely Potential Effects of a Successful Terrorist Attach

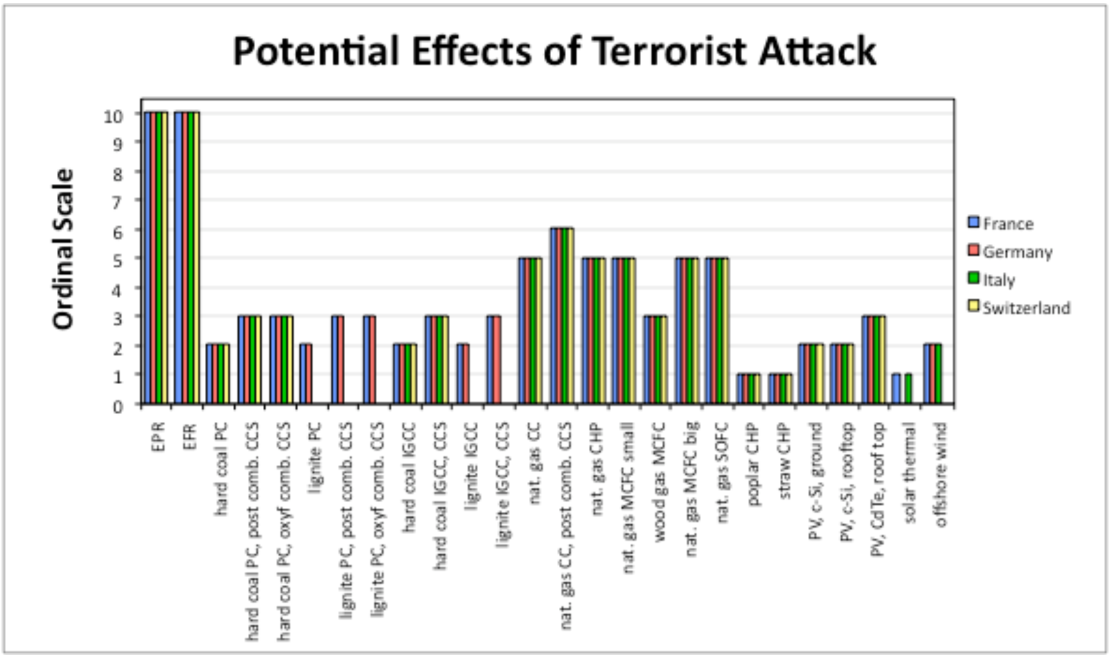


Figure A3.34 – Potential for Misuse of Technologies and Substances within the Nuclear Energy Chain

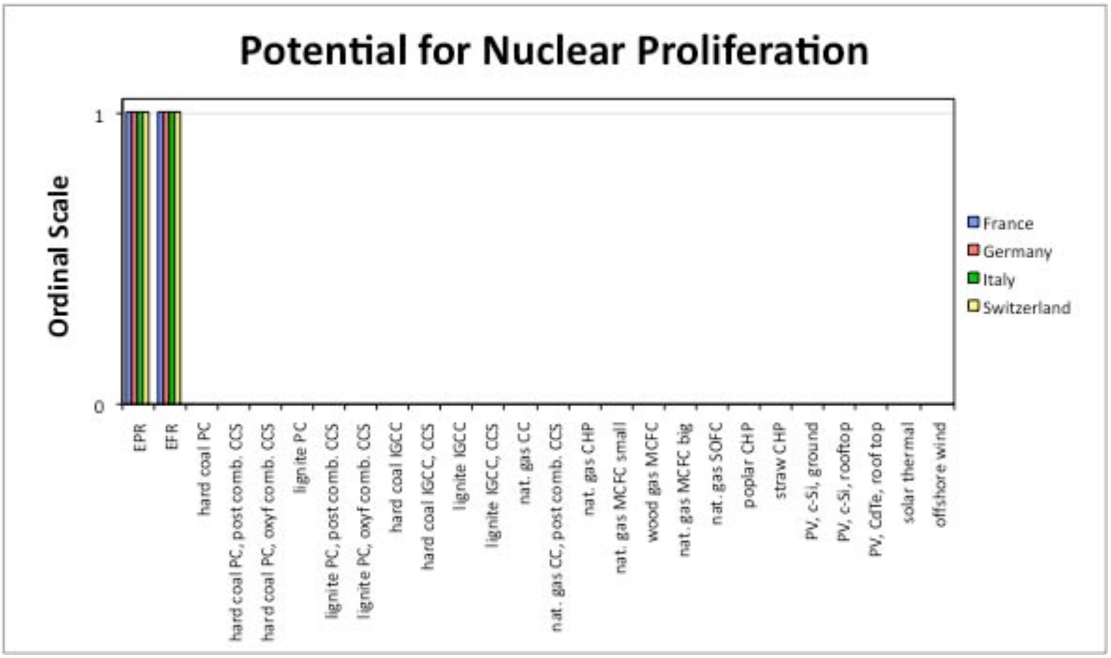


Figure A3.35 – Functional and Aesthetic Impact of Energy Infrastructure on Landscape

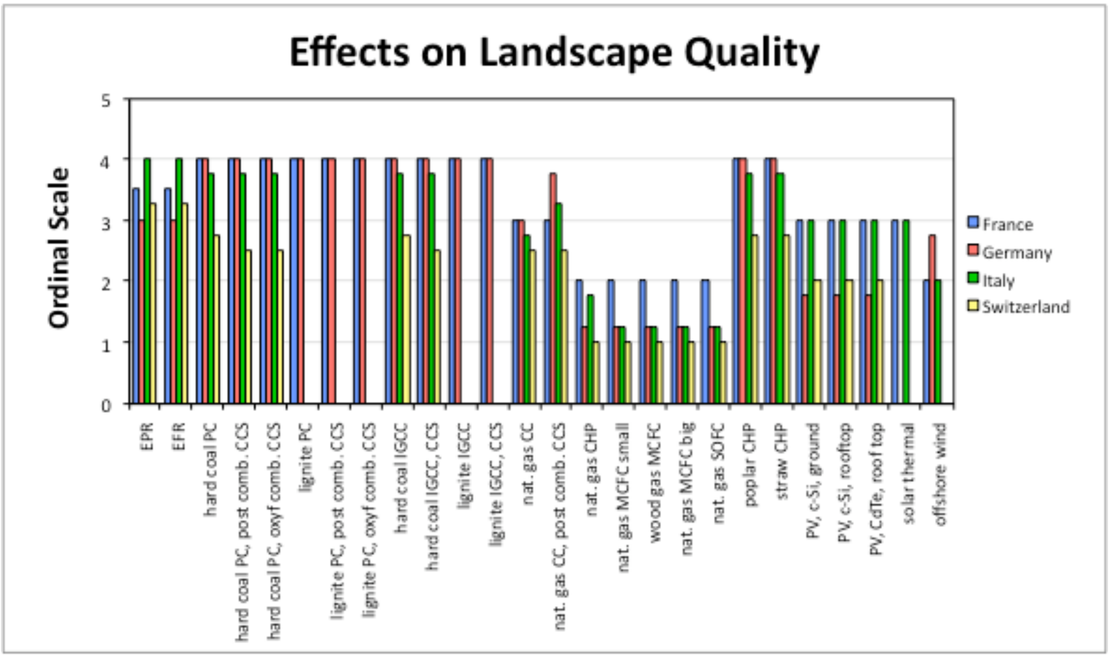


Figure A3.36 – Extent to which residents feel highly affected by noise