7 Environmental Impacts of the MED-CSP Scenario

The environmental problems linked to the use of fossil and nuclear energy sources are well acknowledged today: global climate change, acidification of ecosystems, risks from nuclear accidents, long term accumulation of radioactive waste, and effects on the public health from air pollution /ExternE 1999/. Our energy system is based on digging materials out of the subsoil and dissolving them after their use in the atmosphere and in the surface environment, where they tend to accumulate, creating serious environmental impacts. As renewable energy technologies rely on natural energy and material flow cycles, they can reduce the environmental impact of energy supply. Although for most of them the energy conversion process is emission free, environmental impacts result from the provision of raw materials and the manufacturing and disposal of components. The following environmental characterisation is based on a life cycle perspective, taking into account emissions from all the up- and downstream processes related to energy conversion **(**Figure 7-1).

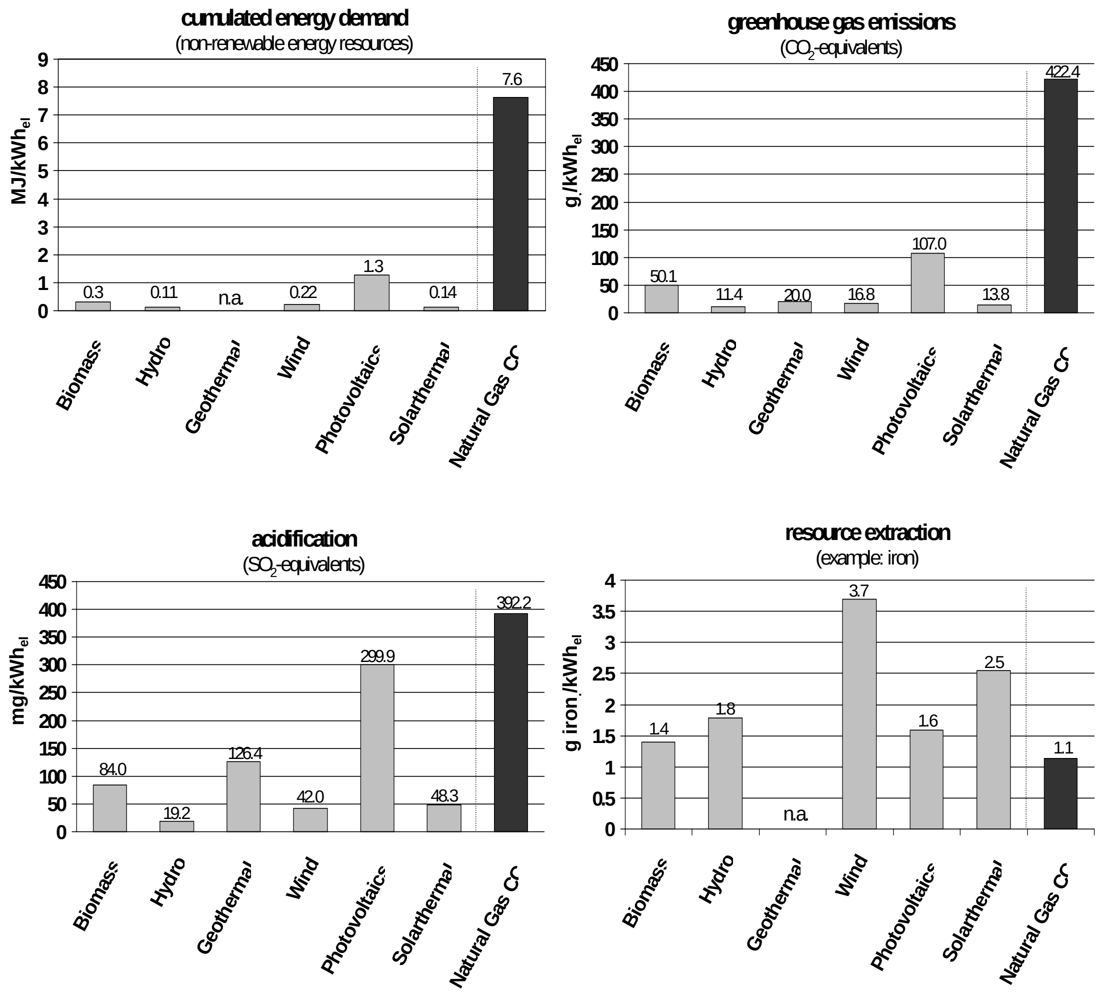

Figure 7-1: Environmental characteristics (cumulated energy demand, greenhouse gas emissions, acidification, resource extraction) of RES-technologies for electricity generation (Biomass: forest residuals, 20 MW steam turbine; Hydro: 3 MW run-of-river plant; Geothermal: 900 kW organic rankine cycle (ORC) cogeneration plant; Wind: 1.5 MW on-shore; PV: 3 kW p-Si roof application, Central Europe; Solar thermal: parabolic trough 80 MW (Southern Europe); Natural Gas CC: natural gas combined cycle, 58 % efficiency)

It is obvious that both the consumption of non-renewable energy resources and the emissions of greenhouse gases is more than an order of magnitude higher than that of renewables even for a highly efficient gas fired combined cycle power plant – and the difference is even larger compared to less efficient coal fired steam cycle power plants. This fact underlines the important role of renewable energies for climate protection. Electricity generation from hydropower, wind and solar thermal power plants ranks particularly high on these two categories. For geothermal energy, the combined production of heat and electricity is required to achieve similar values. Harvesting, transport and processing of biomass requires substantial combustion of fossil fuels, so that biomass ranks slightly worse than the non-combustion processes. Despite significant improvements in recent years, the manufacturing of photovoltaic cells still requires a quite high material and energy input, leading to relatively high life cycle emissions, which in the case of SO_2 are even in the same order of magnitude as those from the gas fired power plants.

Basically, the environmental impacts of renewable energy technologies are dominated by emissions from energy conversion in upstream processes such as component manufacturing or transportation. The data thus primarily characterise the resource efficiency of the underlying economy rather than the performance of a specific energy conversion technology. Changes in the national energy mix will therefore have a direct impact on the life cycle emissions. The evaluation of emerging technologies should thus be based on conditions that are representative for the time of their market entry, rather than associating them with the environmental load from technologies that they are expected to replace. Figure 7-2 illustrates the large potential for the reduction of life cycle CO_2-emissions from a PV-roof application due to key technological developments (use of solar-grade silicon, increase in recycling rates, electricity generation with a high share of renewable energies).

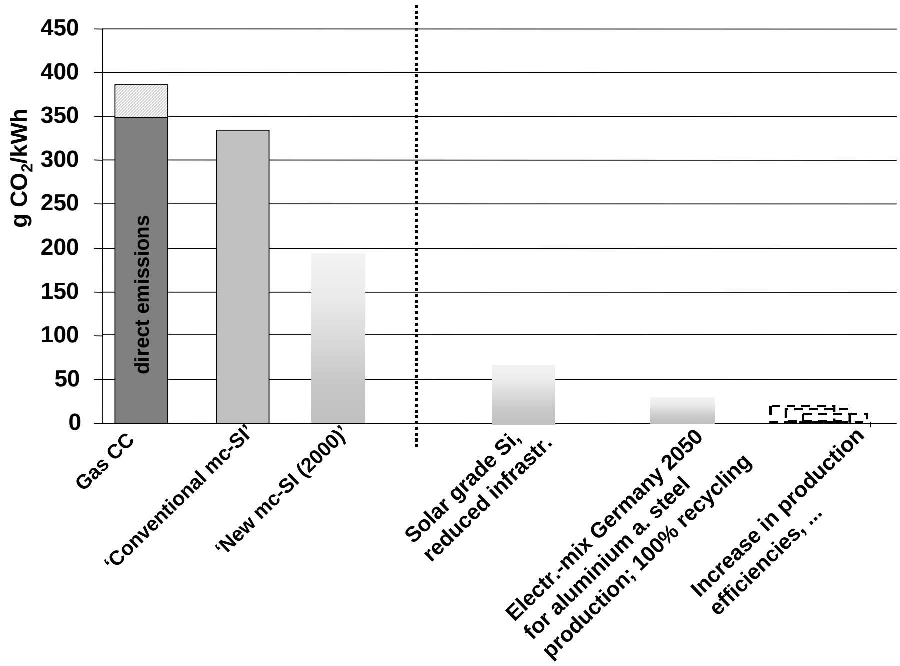

Figure 7-2: Life cycle emissions of CO_2 from a 3 kW p-Si roof application as a function of technological development and change in the energy mix of an economy

Certainly, environmental impacts from energy generating processes leading to public health effects, losses of crops and material damage pose a significant economic burden on society which is not reflected in current energy prices. Hence, the claim for adjusting those external costs asks for a supplement to the energy price that accounts for environmental damage costs from power plant emissions. Although the quantification of environmental impacts and the subsequent monetary valuation is extremely complex and a matter of great uncertainties, the European Commission, based on a thorough research effort, decided to allow Member States to grant operating aid of up to 5 cent/kWh to new plants producing renewable energy on the basis of external costs avoided. This measure for internalising environmental damage costs underlines the environmental advantages of renewable energy technologies and helps to increase their competitiveness /EWEA 2002/.

Our present energy system is still revealing numerous sustainability deficits, in particular with respect to its impacts on ecosystems. It is based on energy carriers with limited availability. It burdens our atmosphere, our soil, and water with pollutants and greenhouse gases, and moreover, leaks in oil pipelines, oil-tanker accidents, area-devastating coalmining, an unresolved question of how to dispose of nuclear waste, and the possibilities of reactor accidents. The list of environmental problems in the field of energy is long.

A more intensive use of renewable energy promises to be the remedy. The fuels for the corresponding energy conversion technologies are the natural flows of energy surrounding us in the form of radiated solar energy and the wind, the energy from flowing waters and the energy from waves, the energy contained in biomass and geothermal energy. By using these flows of energy abundant in nature, the consumption of fossil and nuclear energy on our planet can be avoided.

Renewable energy is largely compatible with our climate and resources. However, the installations needed to convert these flows of energy must first be constructed, operated, and finally be dismantled at the end of their useful service life. Raw materials and energy are necessary for these purposes. What are the effects on the environment compared to using conventional energy? Two key parameters can clarify this question: the energy payback time, i.e. the time needed by an energy system to generate the same amount of energy required for its construction, operation, and disposal; and the cumulated greenhouse gas emissions.

For fossil fired or nuclear plants, the energy payback time for the construction of the plant is around 2 to 3 months. Yet in terms of their overall operation, these plants never amortise because more energy always is consumed in the form of fuel than is produced in the form of useful energy. Water, wind, and solar-thermal power plants need between 3 and 13 months for amortisation of their construction energy, i.e. considerably less than their useful service life. Once this amortisation time has elapsed, each hour of operation then provides valuable energy which is “ecologically gratis”!

The production of solar cells is energy intensive. Today’s systems based on crystalline silicon have energy amortisation times of several years in Germany and shortly one year in the Southern Mediterranean region, however, their useful service life is a multiple of this time period. Further progress in the production and technology of solar cells should reduce this value to between one and two years within the next decade. Therefore, a multiple of the energy originally expended in constructing these systems using renewable energy is produced within their operational lifetime – quite the opposite to both fossil-fired plants and nuclear power stations. This low consumption of resources is also reflected in the associated emissions of green-house gases. These emissions from constructing the plants, whereby the present- day energy supply structure was taken as the baseline, for most renewable energy technologies is between 10 and 25 g/kWh of useful energy. In the case of photovoltaic systems, reductions are possible in the medium term to about 50 g/kWh.

If the future energy supply were to include higher proportions of renewable energy, then the emissions of greenhouse gases resulting from constructing the plants would fall even more, since more low-emission energy would then be used and technical progress would optimise the efficient and ecological production. Thus, on the ecology balance sheet, renewable energy can be designated as being an environmentally very compatible energy technique, even when considering the plant construction.

For an ecologically optimised expansion of renewable energy, it is furthermore necessary to consider other environmental aspects as well. Besides the environmental effects associated with the construction, operation, and disposal of the installation, there are other problem areas characteristic for each individual technology which can lead to conflicts with the goal of nature conservation.

All detrimental effects to the environment resulting from the use of renewable energy must be analysed with great care so that new problems do not arise while attempting to establish a long-term sustainable energy system. Exactness in planning, embedding in the local conditions, compatibility of the utilised technologies, consideration for ecology-based criteria, and a sound mix of different kinds of renewable energy carriers, must assure a maximum of environmental compatibility when providing energy. The German Federal Ministry for the Environment is thus funding several socio-economic studies which analyse in detail the ecological benefits as well as potential weaknesses of renewable energy technologies. Based on the results of these studies, strategies for an ecologically optimised expansion of renewable energies in Germany are derived.

The measures of environmental compatibility specified for renewable energy must of course also be applied for the types of energy still being used today. Otherwise the danger exists of a one-sided and therefore biased assessment, which can lead to a situation in which small local impacts from using renewable energy are classified as alarming, while considerably more serious effects on our entire habitat from using fossil and nuclear energy are overlooked.

7.1 Environmental Impacts of Renewable Energy Technologies

The environmental impact of renewable energy technologies are summarized in Table 7-1 and described in more detail in the following.

Wind Energy

Wind power plants are usually installed at windy and exposed sites. Planning the installation must therefore, as a matter of fact, consider all the needs of nature protection as well as compatibility with bird flight routes and similar aspects. Compliance is assured by legislative requirements and the designation of high-priority and suitable areas. Furthermore, in the case of offshore wind parks, the compatibility with the marine fauna must be assured. Even the disputed spoiling of the appearance of the country-side, in particular in the highly structured central mountain regions, can be subjected in part to objective observations if, for instance, areas of particularly high visual sensitivity are represented by appropriate GIS-supported methods. A balance between climate protection and the appearance of a local wind power plant can therefore be found.

Wind turbines occupy only a small fraction of the land area required for their erection, the rest can be used for other purposes or left in its natural state. For this reason, wind power development is ideally suited to farming areas. In other settings, however, wind power development can create serious land-use conflicts. In forested areas it may mean clearing trees and cutting roads, a prospect that is sure to generate controversy, and near populated areas, wind projects often run into stiff opposition from people who regard them as unsightly and noisy, or who fear their presence may reduce property values.

In California, bird deaths from electrocution or collisions with spinning rotors have emerged as a problem at the Altamont Pass wind "farm," where more than 30 threatened golden eagles and 75 other raptors such as red-tailed hawks died or were injured during a three-year period. Studies under way to determine the cause of these deaths and find preventive measures may have an important impact on the public image and rate of growth of the wind industry. In appropriate areas, and with imagination, careful planning, and early contacts between the wind industry, environmental groups, and affected communities, siting and environmental problems should not be insurmountable /EWEA 2002/, /BMU 2004-1/, /BMU 2004-2/, /Brower 1992/.

Solar Energy

Since solar power systems generate no air pollution during operation, the primary environmental, health, and safety issues involve how they are manufactured, installed, and ultimately disposed of. Energy is required to manufacture and install solar components, and any fossil fuels used for this purpose will generate emissions. Thus, an important question is how much fossil energy input is required for solar systems compared to the fossil energy consumed by comparable conventional energy systems. Although this varies depending upon the technology and climate, the energy balance is generally favourable to solar systems in applications where they are cost effective, and it is improving with each successive generation of technology.

Materials used in some solar systems can create health and safety hazards for workers and anyone else coming into contact with them. In particular, the manufacturing of photovoltaic cells often requires hazardous materials such as arsenic and cadmium. Even relatively inert silicon, a major material used in solar cells, can be hazardous to workers if it is breathed in as dust. Workers involved in manufacturing photovoltaic modules and components must consequently be protected from exposure to these materials. Photovoltaic systems can take advantage of unused space on the roofs of homes and buildings and in urban and industrial lots. And, in solar building designs, the structure itself acts as the collector, so there is no need for any additional space at all.

The large amount of land required for utility-scale solar power plants-approximately one square kilometre for every 20-60 megawatts (MW) is often considered an additional problem. However, looking at the life cycle use of land including raw material exploitation, operation, infrastructure and disposal, solar technologies come out as the most area efficient electricity generating technologies (Figure 7-3). Generating electricity from coal actually requires as much or more land per unit of energy delivered if the land used in strip mining is taken into account. The collectors of large scale photovoltaic systems as well as the mirrors from concentrating solar thermal power systems can be used as shading device as described in Chapter 2. Thus they would gain waste desert land for human activities rather than “consuming” land for energy use.

Table 7-1: Potential Environmental Impacts of Power Technologies

Fossil Fuel Technologies

- Effects of atmospheric pollution on human health
- Accidents affecting workers and/or the public
- Effects of atmospheric pollution on:
    - materials and buildings
    - crops and forests
    - freshwater and fisheries
    - unmanaged ecosystems
- Impacts of global warming
- Impacts of noise
- Impacts of coal and lignite mining on ground and surface waters
- Impacts of coal mining on building and construction
- Resettlement necessary through lignite extraction
- Accidental oil spills effect marine life
- Emissions from exploration and extraction from oil and gas wells

Nuclear Technologies

- Radiological health impacts by routine and accidental releases to the environment
- Radiological health impacts on workers due to routine work and accidental exposure
- Increased natural background radiation due to major accident releases

Wind Power

- Accidents affecting workers and/or the public
- Effects on visual amenity
- Impact on marine life and shipping routes in case of offshore plants
- Danger of collisions in case of offshore parks
- Effects of noise emissions on amenity
- Atmospheric emissions during manufacturing, construction and servicing

Hydropower

- Occupational health effects
- Employment benefits and local economic effects
- Impacts of transmission lines on bird populations
- Damage to private goods (forestry, agriculture, water supply, ferry traffic)
- Damages to environmental goods and cultural objects

Solar Photovoltaic Power

- Accidents affecting workers and/or the public
- Effects on visual amenity
- Atmospheric emissions during manufacturing, construction and servicing
- Hazardous materials from production and disposal of equipment

Solar Thermal Power

- Atmospheric pollution from combustion (in hybrid operation) and during production and construction of equipment
- Visual impact on amenity, noise of cooling towers
- Smell from synthetic oil heat transfer fluid
- Synthetic oil heat transfer fluid considered hazardous material
- Pollution of soil and water from spilling HTF oil
- Impact of concentrated beam radiation on persons, birds and insects
- Impact of large plants on regional albedo
- Land use

Geothermal Power

- Thermal and chemical atmospheric, water and soil pollution by well blow-outs and leakage and during drilling
- Noise from drilling and from cooling towers
- Solid waste disposal
- Visual impact on amenity from pipelines and cooling towers
- Sinking of land surface

Biomass Power

- Atmospheric pollution by combustion and collection of biomass
- Smell and visual impact on amenity
- Land use of energy crops
- Impact of fertilizers on soil and water
- Water demand
- Potential overuse of fuel wood and land resources

Solar-thermal power plants (like most conventional power plants) also require cooling water, which may be costly or scarce in desert areas. However, again like in conventional plants, alternatively dry cooling towers with air fan can be applied for cooling. Another solution is to use a co-generation system for thermal sea water desalination as cooling device. In this case the plant would even generate poTable 7-water instead of consuming water, provided that salty water is available. Of course on the coasts, direct cooling with sea water is also feasible.

Solar thermal parabolic trough plants in California report some leakages of the synthetic heat transfer fluid oil contained in the collector field to transport the heat from the collectors to the steam cycle plant. There is also a smell of the HTF reported to prevail in the installations. However, those problems were obviously manageable in the 20 years of operation experienced up to now. Leakages have been controlled by new interconnection elements (ball joints) and contaminated soil can be recovered by bacteriological decontamination. Research and development of the past years has lead to various new systems that don’t need the synthetic oil any more, but directly use water and steam as heat transfer fluid.

Geothermal Energy

Geothermal energy is heat contained below the earth's surface. The only type of geothermal energy that has been widely developed is hydrothermal energy, which consists of trapped hot water or steam. However, new technologies are being developed to exploit hot dry rock (accessed by drilling deep into rock), geo-pressured resources (pressurized brine mixed with methane), and magma.

The various geothermal resource types differ in many respects, but they raise a common set of environmental issues. Air and water pollution are two leading concerns, along with the safe disposal of hazardous waste and land subsidence. Since these resources would be exploited in a highly centralized fashion, reducing their environmental impacts to an accepTable 7-level should be relatively easy. But it will always be difficult to site plants in scenic or otherwise environmentally sensitive areas.

The method used to convert geothermal steam or hot water to electricity directly affects the amount of waste generated. Closed-loop systems are almost totally benign, since gases or fluids removed from the well are not exposed to the atmosphere and are usually injected back into the ground after giving up their heat. Although this technology is more expensive than conventional open-loop systems, in some cases it may reduce scrubber and solid waste disposal costs enough to provide a significant economic advantage.

Open-loop systems, on the other hand, can generate large amounts of solid wastes as well as noxious fumes. Metals, minerals, and gases leach out into the geothermal steam or hot water as it passes through the rocks. The large amounts of chemicals released when geothermal fields are tapped for commercial production can be hazardous or objectionable to people living and working nearby.

At The Geysers, the largest geothermal development, steam vented at the surface contains hydrogen sulphide (H2S)-accounting for the area's "rotten egg" smell-as well as ammonia, methane, and carbon dioxide. At hydrothermal plants carbon dioxide is expected to make up about 10 percent of the gases trapped in geo-pressured brines. For each kilowatt-hour of electricity generated, however, the amount of carbon dioxide emitted is still only about 5 percent of the amount emitted by a coal- or oil-fired power plant.

Scrubbers reduce air emissions but produce a watery sludge high in sulphur and vanadium, a heavy metal that can be toxic in high concentrations. Additional sludge is generated when hydrothermal steam is condensed, causing the dissolved solids to precipitate out. This sludge is generally high in silica compounds, chlorides, arsenic, mercury, nickel, and other toxic heavy metals. One costly method of waste disposal involves drying it as thoroughly as possible and shipping it to licensed hazardous waste sites.

Usually the best disposal method is to inject liquid wastes or re-dissolved solids back into a porous stratum of a geothermal well. This technique is especially important at geo-pressured power plants because of the sheer volume of wastes they produce each day. Wastes must be injected well below fresh water aquifers to make certain that there is no communication between the usable water and waste-water strata. Leaks in the well casing at shallow depths must also be prevented.

In addition to providing safe waste disposal, injection may also help prevent land subsidence. At Wairakei, New Zealand, where wastes and condensates were not injected for many years, one area has sunk 7.5 meters since 1958. Land subsidence has not been detected at other hydrothermal plants in long-term operation.

Most geothermal power plants will require a large amount of water for cooling or other purposes. In places where water is in short supply, this need could raise conflicts with other users for water resources.

The development of hydrothermal energy faces a special problem. Many hydrothermal reservoirs are located in or near wilderness areas of great natural beauty. Proposed developments in such areas have aroused intense opposition.

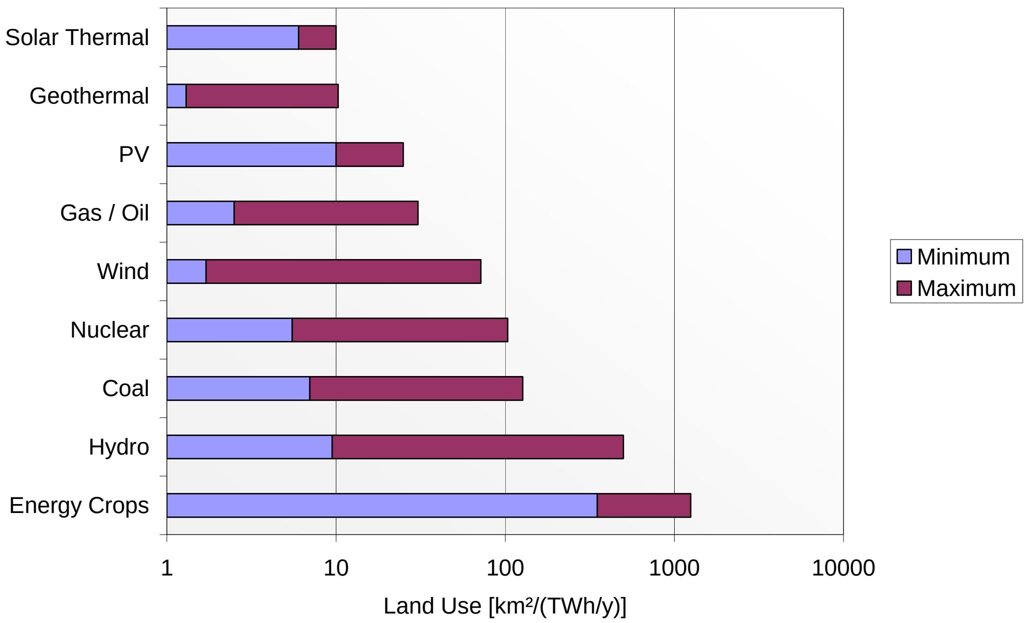

Figure 7-3: Maximum and minimum values found in the literature for life cycle land requirements of different power technologies per TWh/y /WEC 2004/, /HGF 2001/, /SECO 2003/, Ecoinvent 2000/. Due to different sources and methodologies, the results shown in the graph are not necessarily comparable to each other.

Biomass

The use of biomass must be carefully analysed with particular regard to the required surface areas. Today and in the near future primarily residuals and waste material are used as bio-energy carriers. In the long-term, the cultivation of biomass for energy purposes will compete with the ecologically desirable reduced intensification of agriculture.

Emissions from conventional biomass-fuelled power plants are generally similar to emissions from coal-fired power plants, with the noTable 7-difference that biomass facilities produce very little sulphur dioxide or toxic metals (cadmium, mercury, and others). The most serious problem is their particulate emissions, which must be controlled with special devices. More advanced technologies, such as the whole-tree burner (which has three successive combustion stages) and the gasifier/combustion turbine combination, should generate much lower emissions, perhaps comparable to those of power plants fuelled by natural gas.

Facilities that burn raw municipal waste present a unique pollution-control problem. This waste often contains toxic metals, chlorinated compounds, and plastics, which generate harmful emissions. Since this problem is much less severe in facilities burning refuse-derived fuel pelletized or shredded paper and other waste with most inorganic material removed-most waste-to-energy plants built in the future are likely to use this fuel. Co-firing refuse derived fuel in coal-fired power plants may provide an inexpensive way to reduce coal emissions without having to build new power plants /NREL 2004/.

A major benefit of substituting biomass for fossil fuels is that, if done in a sustainable fashion, it would greatly reduce emissions of greenhouses gases. The amount of carbon dioxide released when biomass is burned is very nearly the same as the amount required to replenish the plants grown to produce the biomass. Thus, in a sustainable fuel cycle, there would be no net emissions of carbon dioxide, although some fossil-fuel inputs may be required for planting, harvesting, transporting, and processing biomass. Yet, if efficient cultivation and conversion processes are used, the resulting emissions should be small (around 20 percent of the emissions created by fossil fuels alone). And if the energy needed to produce and process biomass came from renewable sources in the first place, the net contribution to global warming would be zero.

Similarly, if biomass wastes such as crop residues or municipal solid wastes are used for energy, there should be few or no net greenhouse gas emissions. There would even be a slight greenhouse benefit in some cases, since, when landfill wastes are not burned, the potent greenhouse gas methane may be released by anaerobic decay.

One surprising side effect of growing trees and other plants for energy is that it could benefit soil quality and farm economies. Energy crops could provide a steady supplemental income for farmers in off-seasons or allow them to work unused land without requiring much additional equipment. Moreover, energy crops could be used to stabilize cropland or rangeland prone to erosion and flooding. Trees would be grown for several years before being harvested, and their roots and leaf litter could help stabilize the soil. The planting of coppicing, or self-regenerating, varieties would minimize the need for disruptive tilling and planting. Perennial grasses harvested like hay could play a similar role; soil losses with a crop such as switchgrass, for example, would be negligible compared to annual crops such as corn.

If improperly managed, however, energy farming could have harmful environmental impacts. Although energy crops could be grown with less pesticide and fertilizer than conventional food crops, large-scale energy farming could nevertheless lead to increases in chemical use simply because more land would be under cultivation. It could also affect biodiversity through the destruction of species habitats, especially if forests are more intensively managed. If agricultural or forestry wastes and residues were used for fuel, then soils could be depleted of organic content and nutrients unless care was taken to leave enough wastes behind. These concerns point up the need for regulation and monitoring of energy crop development and waste use.

Energy farms may present a perfect opportunity to promote low-impact sustainable agriculture, or, as it is sometimes called, organic farming. A relatively new federal effort for food crops emphasizes crop rotation, integrated pest management, and sound soil husbandry to increase profits and improve long-term productivity. These methods could be adapted to energy farming. Nitrogen-fixing crops could be used to provide natural fertilizer, while crop diversity and use of pest parasites and predators could reduce pesticide use. Though such practices may not produce as high a yield as more intensive methods, this penalty could be offset by reduced energy and chemical costs. This would fit quite well into the concept of integrated multi-purpose solar plants as described in Chapter 2 and in the special report on this topic by /Bassam 2004/.

Increasing the amount of forest wood harvested for energy could have both positive and negative effects. On one hand, it could provide an incentive for the forest-products industry to manage its resources more efficiently, and thus improve forest health. But it could also provide an excuse, under the "green" mantle, to exploit forests in an unsustainable fashion. Unfortunately, commercial forests have not always been soundly managed, and many people view with alarm the prospect of increased wood cutting. Their concerns can be met by tighter government controls on forestry practices and by following the principles of "excellent" forestry. If such principles are applied, it should be possible to extract energy from forests indefinitely.

Hydropower

The use of hydroelectric power can create severe ecological problems. In the case of run-of-river power stations, the migration of the fish can be impeded by an interruption in the natural flow of the water. The construction of weirs, discharge channels, and dammed-up waters, together with reduced flow rates, turbulence, and dragging power of the waters, can cause changes in the water structure, transportation of sediments, and the ecological balance of the waters and the surroundings.

Furthermore, dam-type hydroelectric power stations can lead to conflicts of use with farming and to flooding of large open spaces. At the same time, however, these are also protect against high water and provide drinking water.

The conflicts in goals between protecting the climate and protecting the waters can be reduced by construction measures. For example, upstream migration routes for fish, re-routing, and sluice flows can improve the passage through the rivers.

For example, minimum amounts of water being discharged from power stations can prevent the build-up of sludge and damage to the mother bed. Environmental impact assessment required for authorization place high requirements on the ecological quality of the plant. At untouched stretches it is a matter of consequence to deny the construction of hydroelectric power stations for the conservation of the environmental treasures usually found there.

The impact of very large dams can very serious. The reservoirs created by such projects frequently inundate large areas of forest, farmland, wildlife habitats, scenic areas, and even towns. In addition, the dams can cause radical changes in river ecosystems both upstream and downstream.

Small hydropower plants using reservoirs can cause similar types of damage, though obviously on a smaller scale. Some of the impacts on fish can be mitigated by installing "ladders" or other devices to allow fish to migrate over dams, and by maintaining minimum river-flow rates; screens can also be installed to keep fish away from turbine blades.

7.2 Environmental Impacts resulting from the MED-CSP Scenario

The MED-CSP scenario was developed according to the following principles:

- Environmental and economic sustainability.
- Balanced mix of renewable and conventional energy technologies to cope with technical, economical and environmental requisites defined by “crash barriers”.
- Cooperation and learning from best practice in Northern and Southern countries.

The goal was to quantify a power supply system in the analysed EU-MENA countries with considerably reduced greenhouse gas emissions and other pollutants without creating other serious environmental, societal or economic problems. The key concerns resulting from the scenario CG/HE were land use, emissions of greenhouse gases and other pollutants, and direct environmental impacts. They are summarised in the following.

Land Use

The specific land requirement of hydropower ranges between 10 km²/(TWh/y) for micro-hydropower and over 400 km²/(TWh/y) for very large schemes like the Aswan dam (Table 7-2). The average value resulted in 165 km²/(TWh/y) for the total analysed region. Geothermal power requires little land (1 to 10 km²/(TWh/y)), and the areas affected are in the subsoil at thousands of meters depth. In our scenario, biomass is produced mainly by agricultural and municipal residues (no extra land use) and from wood, resulting in an average land use of only 2 km²/(TWh/y). Energy crops – with a very high land use – were not considered in the MENA countries, as they would compete with food and water supply. For wind power, the average land use was 46 km²/(TWh/y). The specific values differ considerably according to the different performance indicators in each country.

Concentrating solar thermal power schemes have a specific land use of 6-10 km²/TWh. However, land could be gained from waste land, if multi-purpose CSP plants are applied. This would mean winning additional land rather than land “consumption”. Photovoltaic energy has no additional land use if installed on roofs, and a slightly higher land use than CSP if installed in large installations. An average land use of 7 km²/(TWh/y) was assumed. It may seem paradox that solar and geothermal power generation has the best land use efficiency among all power technologies, even when not considering the potential land gain effect.

The total mix of renewable energies in 2050 within the scenario CG/HE has an average land use of 22.5 km²/(TWh/y), which is in the same order as the average value of natural gas fired combined cycle power stations, which represent the best available fossil fuelled power technology. Disposal of sequestrated CO2 is not considered within this figure. The land use of oil or coal fired steam cycles is between 50 and 100 km²/TWh. Considering the long time during which areas are affected by nuclear waste disposal and uranium mining, nuclear plants also have a high land consumption in the order of 100 km²/(TWh/y). This figure does not account for nuclear accidents like the one in Tschernobyl. The change to renewable energies will therefore lead to a more efficient land use for power generation.

Solar thermal power plants will also be used for sea water desalination. A concentrating solar thermal collector array required for desalinating 1 billion m³/y would cover a total land area of approximately 10 km x 10 km, corresponding to about 10 m³ desalinated water per m² of collector area. In case of linear Fresnel or multi-tower technology, the collectors could act like blinds, blocking the intense direct solar radiation and creating a cool space underneath with sufficient light for horticulture or other purposes. About 10 % of the desalted water would be sufficient for irrigating the desert land beneath the collectors with a water column of 1 m/a. In the year 2050, our scenario arrives at 2900 TWh/y of electricity (including solar power generation and desalination) and 160 billion m³/y of desalted water. For this a collector field of 120 x 120 km² would be necessary, which is equivalent to not more than 0.15 % (0.0015) of the Sahara desert.

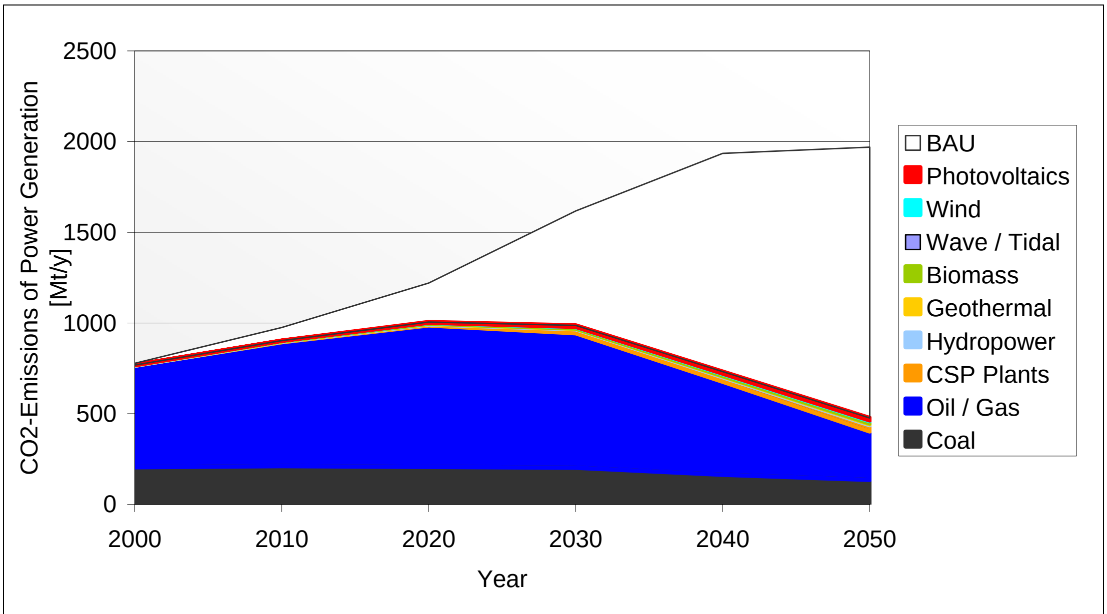

Figure 7-4: CO2-emissions of electricity generation in million tons per year for all countries for the scenario CG/HE and emissions that would occur in a business as usual case (BAU)

Emission of Greenhouse Gases and other Pollutants

The emissions of renewable energy technologies are mainly occurring during the production of the plant's components, because most plants are produced within today's industrial production schemes that use mostly fossil energies. Thus, the emission occurs from fossil power plants that are at present used to provide energy for the production of plant components. The life cycle emissions are valid for a power park with average CO2 emissions of 700 g/kWh. During operation, only biomass and geothermal plants produce emissions. The emission of greenhouse gases (CO2 equivalent) of renewable energy technologies are by orders of magnitude lower than those of fossil fuelled technologies. Coal plants usually have emissions of 900 – 1100 kgCO2/MWh, oil plants around 600 - 700 kgCO2/MWh. Even coal plants with CO2 sequestration would still emit more CO2 than solar or wind power plants, as about 20 % of their emissions would still reach the atmosphere. Moreover, it is not yet clear for how long CO2 reservoirs of sequestration would remain isolated from the atmosphere. Other emissions that mainly occur during combustion like nitrates NOx and sulphates SOx as well as phosphoric acids are also avoided. They can lead to acidification and over-nutrition (eutrophication) of soils and water bodies. Emissions of CSP plants in hybrid operation will gradually be reduced with time applying increased solar thermal storage capacities.

For the future fuel-based power generation in Europe, an increasing share of CO2 sequestration was considered as discussed in chapter 5.2.

At present, the total carbon emissions of electricity generation of all countries analyzed in the study amount to approximately 770 million tons per year. Instead of growing to 2000 million tons per year that would be expected for the year 2050 in a business as usual case our scenario achieves a reduction of emissions to 475 million tons within that same time span (Figure 7-4). The scenario avoids a total of 28 billion tons of carbon dioxide until 2050, which is equivalent to the present total annual CO_2-emissions world wide.

The scenario reaches a per capita emission of 0.58 tons/cap/y in the power sector in 2050 (Figure 7-5). This is acceptable in terms of the recommended total emission of 1-1.5 tons/cap (ref. WP 1).

Other Environmental Impacts

Any power technology has an impact on the environment, which must be evaluated very carefully in order to avoid harmful results. Wind plants may have a negative impact on bird habitats and, through visual effects and noise, on recreational and municipal areas. Offshore wind parks may additionally affect marine habitats in their vicinity. Geothermal hot dry rock technology will establish a water cycle from the depths, which will contain a lot of minerals harmful to the surface environment. Therefore, it must be secured that the water cycle used for extracting the heat from the ground is always returned and not infiltrated into surface or groundwater bodies. The disposal of biomass residues is in fact a positive contribution to the environment. Using wood for energy purposes is more critical considering the present over-exploitation of fuel wood in most arid regions. Plants must be carefully designed and distributed to not overexploit the natural resources. It must also be considered that traditional fuel wood would compete with fuel wood for electricity. All in all the environmental impacts of most renewable energy technologies is manageable if there is a careful prior analysis and design.

The environmental impact of hydropower is well known and documented world wide. Especially in arid regions, large dams may affect severely the natural habitat of many species, as they usually dwell in the narrow and shaded canyons of the river beds which are set underwater by the dam. Therefore in most cases large hydro dams must be considered as questionable in terms of environmental compatibility.

The effects of large scale sea water desalination plants must also thoroughly be evaluated in order to avoid damages by the salty brine and by chemical additives used against scaling and fouling. Due to the large demand of desalination that can be foreseen, intensive research and development for environmentally compatible desalination technologies is of high priority in order to avoid the overload of the local environment of those plants.

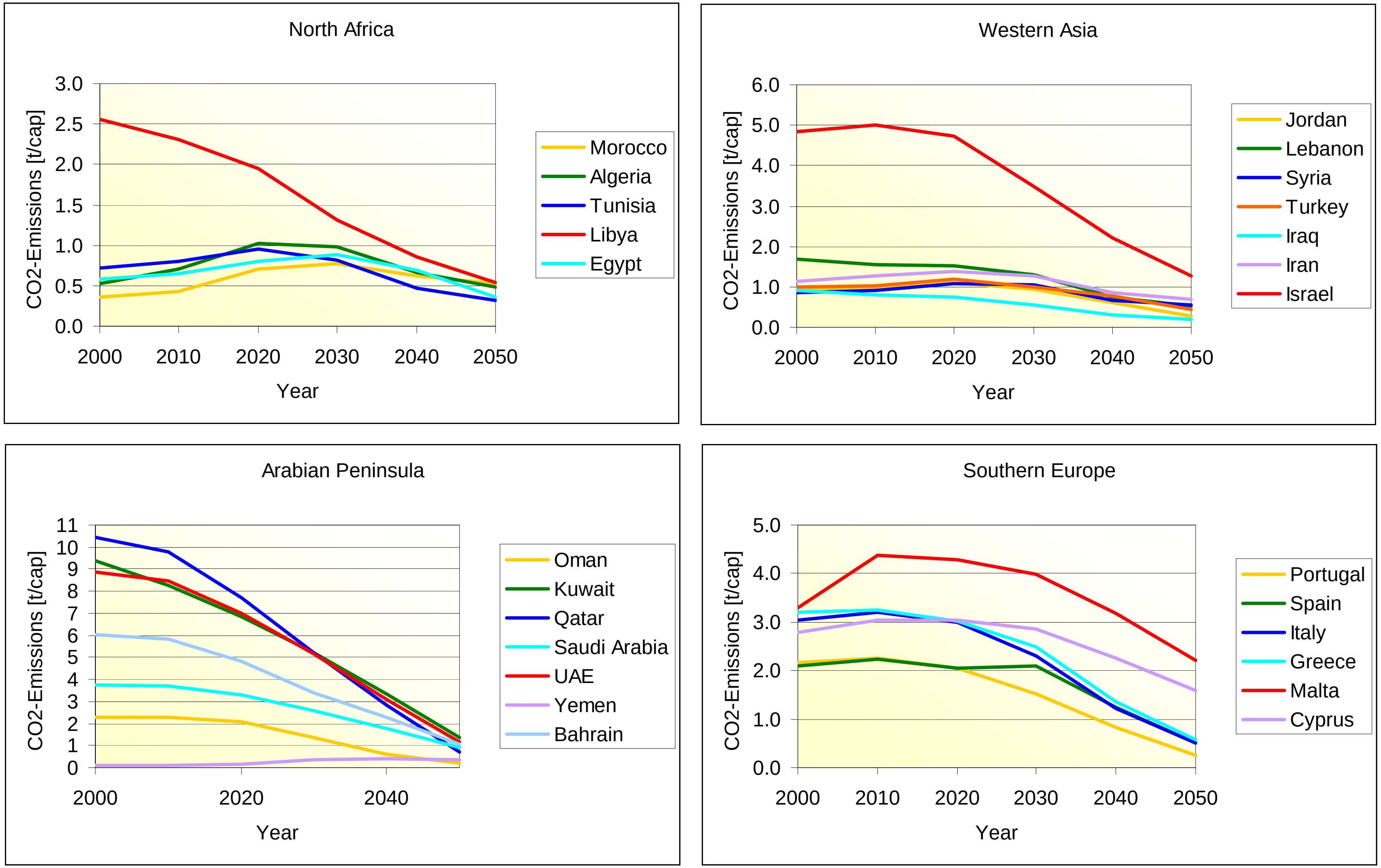

Figure 7-5: Annual per Capita CO2 Emissions of Power Generation (Scenario CG/HE)

	Hydro	Geo	CSP	Bio	Wind	PV	Total	Country	Area Used
	km²	km²	km²	km²	km²	km²	km²	km²	%
Bahrain	0	0	21	0	2	2	25	707	3.5%
Cyprus	20	0	5	0	15	1	42	9251	0.5%
Iran	1890	11	2093	29	340	112	4476	1648000	0.3%
Iraq	11828	0	1137	3	279	48	13295	438317	3.0%
Israel	351	0	174	0	21	28	574	21946	2.6%
Jordan	4	0	240	0	67	31	343	97740	0.4%
Kuwait	0	0	78	0	0	18	96	17818	0.5%
Lebanon	140	0	72	0	9	11	231	10452	2.2%
Oman	0	0	133	0	244	29	405	212457	0.2%
Qatar	0	0	17	0	0	7	24	11437	0.2%
Saudi Arabia	0	71	810	6	559	97	1543	2240000	0.1%
Syria	650	0	699	2	335	60	1747	185180	0.9%
UAE	0	0	60	1	0	21	82	77700	0.1%
Yemen	0	128	1530	2	101	180	1941	536869	0.4%
Algeria	78	5	989	8	978	97	2155	2381741	0.1%
Egypt	13696	26	2370	0	2240	252	18584	1002000	1.9%
Libya	0	0	131	2	392	27	553	1775500	0.0%
Morocco	544	10	900	12	692	119	2277	458730	0.5%
Tunisia	82	3	260	2	419	35	801	163610	0.5%
Greece	608	5	21	14	481	28	1157	131957	0.9%
Italy	5245	14	30	30	2367	70	7757	301302	2.6%
Malta	0	0	2	0	5	1	8	316	2.4%
Portugal	1370	7	60	11	406	21	1875	92389	2.0%
Spain	3594	9	150	43	1827	35	5658	504782	1.1%
Turkey	6880	120	750	41	1353	200	9343	779452	1.2%
Total km²	46978	410	12733	208	13133	1529	74991	13099653	0.6%
Electricity TWh/y	288	205	2122	195	285	218	3314		
Relative km²/(TWh/y)	162.9	2.0	6.0	1.9	46.1	7.0	22.5		

Table 7-2: Areas required for renewable electricity generation in 2050 for the scenario CG/HE. The two columns at right show the total area of each country and the percentage of this area used for power generation by renewable energy sources in 2050. Hydropower surface demand varies strongly between countries. Photovoltaic surface demand considers only 50 % of the total because many plants will be installed on roofs. Wind power and CSP surface demand is calculated as if exclusively used for power generation. Biomass surface demand is only considered for fuel wood energy