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Organisation name for this paper: DLR, CIEMAT
Paper coordinator: Peter Viebahn (DLR)
Authors: Peter Viebahn, Stefan Kronshage, Franz Trieb (DLR), Yolanda Lechon (CIEMAT)

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Contents

Abbreviations

AA	Atmospheric Air
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CRS	Central Receiver Systems
CSP	Concentrating Solar Power
ct	Euro-Cent
DNI	Direct Normal Irradiance
DSG	Direct Steam Generation
EGC	Electricity Generation Costs
EUMENA	Europe, Middle East, North Africa
GT	Gas Turbine
GW_{el}	Gigawatt (electrical)
GWh_{el}	Gigawatt-hours (electrical)
HTF	Heat Transfer Fluid
kW_{el}	Kilowatt (electrical)
kWh_{el}	Kilowatt-Hour (electrical)
MS	Molten Salt
$MW_{el / th}$	Megawatts (electrical / thermal)
PCM	Phase Change Material
R&D	Research and Development
RS Ia / Ib / IIa	NEEDS Research Streams Ia / Ib / IIa
SEGS	Solar Electricity Generating System
ST	Steam Turbine
STP	Solar Thermal Power
TO	Thermo oil
TWh_{el}	Terawatt-Hour (electrical)
y	Year

1 Introduction

Solar thermal power generation systems capture energy from solar radiation, transform it into heat, and generate electricity from the heat using steam turbines, gas turbines, Stirling engines, or pressure staged turbines (Figure 1.1):

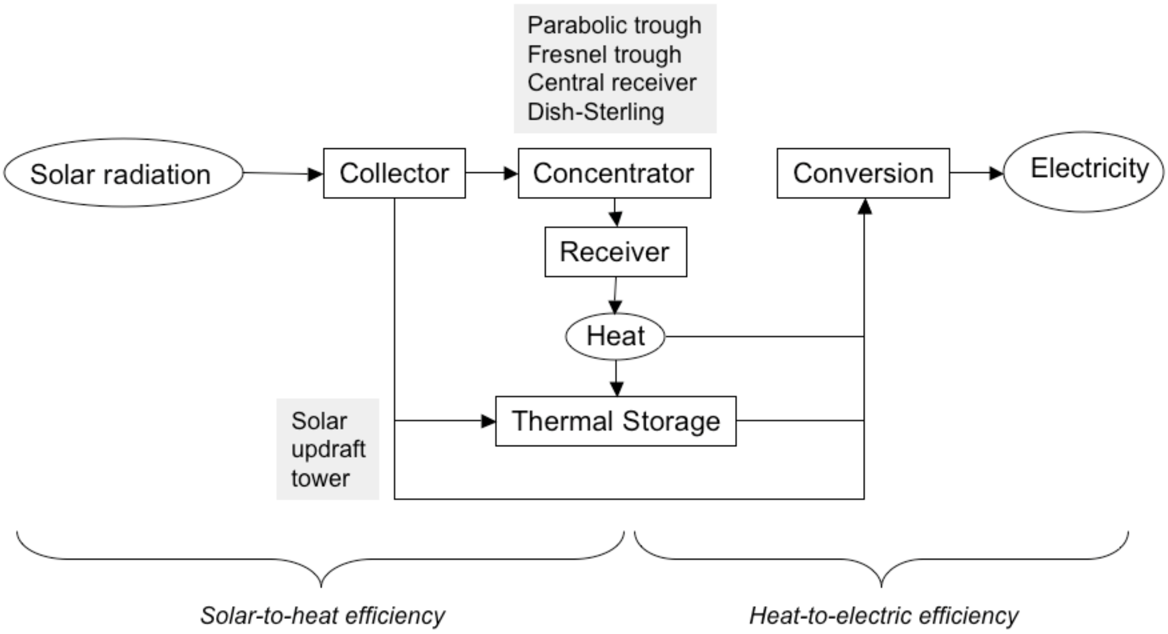

Figure 1.1: Schematic illustration of the component parts of solar thermal power plants

The four main types of solar thermal power plants developed and tested so far are:

- Parabolic trough and Fresnel trough technology
- Central receiver system (also called power tower or solar tower)
- Dish-Stirling system
- Solar updraft tower plant

Parabolic and Fresnel trough, central receiver, and dish-engine systems concentrate the sunlight to gain higher temperatures in the power cycle. The primary resource for concentrating solar power (CSP) technology is the direct solar irradiance perpendicular to a surface that is continuously tracking the sun (direct normal irradiance, DNI). CSP systems have their highest potential in the "sun belt" of the earth, which is between the 20th and 40th degree of latitude south and north.

Solar updraft towers do not concentrate the sunlight. They use the direct fraction of the sunlight as well as the diffuse fraction. As a consequence, the working temperature is much lower than those of concentrating systems, and thus the efficiency.

The electricity is produced by different ways:

- Troughs and central receivers usually use a steam turbine to convert the heat into electricity. As heat transfer fluids oil, molten salt, air, or water can be used. Central receivers can achieve very high operating temperatures of more than 1,000 °C enabling them to produce hot air for gas turbines operation combined with downstream steam turbine operation resulting in high conversion efficiencies.

- Dish-Stirling systems can use an engine at the focus of each dish or transport heat from an array of dishes to a single central power-generating block.
- Solar updraft towers work with a central updraft tube to generate a solar induced convective flow which drives pressure staged turbines.

The total solar-to-electricity efficiencies are calculated by combining the conversion of solar energy to heat within the collector (solar-to-heat efficiency) with the conversion of heat to electricity in the power block (heat-to-electricity efficiency).

Thermodynamic power cycles can be operated with fossil and renewable fuels like oil, gas, coal, and biomass as well as with solar energy. This hybrid operation has the potential to increase the value of CSP technology by increasing its power availability and decreasing its cost by making more effective use of the power block.

All CSP concepts have the perspective to expand their time of solar operation to base load using thermal energy storage and larger collector fields. Solar heat collected during the daytime can be stored in storage systems based on concrete, molten salt, ceramics, or phase change materials. At night, it can be extracted from the storage to run the power block continuously. This is a very important feature for the coupling with desalination processes, as they usually prefer steady-state operation and are not very easily operated with fluctuating energy input.

Furthermore, high-temperature concentrated solar energy can be used for co-generation of electricity and process heat. In this case, the primary energy input is used with efficiencies of up to 85%. Possible applications cover the combined production of industrial heat, district cooling and sea water desalination. (DLR 2007)

This study is organised as follows. After this introduction chapter 2 gives a short overview on the different technology options and reports the current development regarding especially the Spanish and the U.S. market. Chapter 3 describes solar thermal technology development pathways depending on three scenarios, a "pessimistic", an "optimistic-realistic", and a "very optimistic" development. Based on the possible installed solar thermal capacities determined for each of these scenarios the learning curve approach is applied to solar thermal power plants. For each of the scenarios future electricity generation costs are derived.

While the former analyses are based on solar thermal technology in general a more detailed view on the technologies is required for the life cycle inventory calculations. Therefore in chapter 4 future technology configurations are specified and implemented into the general NEEDS project LCI database. They are based on the most actual data on the technologies currently being built in Spain.

Finally chapter 5 presents the overall LCI results split into an inventory analysis of the individual technologies and an interpretation of the NEEDS key emissions' list analysed for the three development scenarios. The results which are derived for the individual technologies and differentiated for two locations (Spain in case A and Algeria in case B) are composed to one final figure for each pollutant by assuming different shares between the technologies as well as between the originating locations for the future solar thermal electricity supply in Europe. The results are based on the “440 ppm” energy systems scenario given by RS IIa.

2 Solar thermal power plants today

2.1 Technology options

2.1.1 Parabolic and Fresnel trough technology

Parabolic trough systems (Figure 2.1) consist of trough solar collector arrays and a conventional power block with steam turbine and generator. A heat transfer fluid, currently synthetic thermo oil, is pumped through the collector array and heated up to 400 °C. This oil is used to produce steam in heat exchangers before being circulated back to the array. The steam is used in a conventional steam turbine-based power plant.

In southern California nine "solar electricity generation systems" (SEGS) power plants were built between 1984 and 1989 with a total capacity of 354 MW_{el}. They were continuously improved and are in commercial operation until today. Only the first 14 MW pilot plant was decommissioned after 20 years of operation. The SEGS systems are co-fired with natural gas to provide continuous operation when the sun does not shine. During the early 1980s, some other small parabolic trough demonstration plants were constructed in the United States, Japan, Spain, and Australia.

Figure 2.1: Parabolic trough system of type SEGS

In general, parabolic trough systems using thermo oil can be considered as most mature CSP technology due to the experience in California. New opportunities could restart this commercial success and the year 2006 is regarded as an important milestone for the diffusion of this technology. For the first time in almost two decades a new 1 MW_{el} power station started its operation in the U.S. (Arizona) (REA 2006). As of June 2007 with Nevada Solar One the third largest CSP plant worldwide started operation generating 64 MW_{el} in Boulder City (Acciona 2008). Both projects were enabled by improved conditions for CSP plants in the South West guaranteed by the new U.S. Energy Bill. (Sarasin 2006). Currently several new CPS power plants with loads between 177 and 553 MW_el are announced to be built in the U.S. Their realisation depends on the endangered 30% investment tax credit. (Hoexter 2008)

Spain is currently the most attractive market for realising CSP projects because an incentive of around 22 ct/kWh_{el} is offered for solar thermal electricity within the Renewable Energy Act (Royal Decree 436/2004, see RD 2004). The law intends to support CSP plants with a capacity of up to 500 MW_{el}. Currently the first two power stations with a capacity of 50 MW_{el} each are being built on the plateau of Guadix in the province of Granada by SENER (Andasol 1 and Andasol 2, see SolarMillenium 2008). They are equipped with a 7.5 hours thermal storage and are projected to operate 3,820 full load hours. The construction of one more plant, Andasol 3 (using steam instead of thermo oil), is announced for 2010. With more than 1,000 MW_{el} of CSP plants currently designed in Spain the limit is overrun by more than 100% (Pitz-Paal 2006, Sarasin 2006).

Further developments of the original system are aiming at the replacement of the synthetic heat transfer oil with direct steam or with molten salt. *Direct steam generation* (DSG) allows the collection of energy at higher temperatures as well as the elimination of one heat-exchange step which increases the overall efficiency of the plant. Furthermore it avoids the need to replace the heat transfer fluid as it is necessary in case of thermo oil and it avoids the use of energy intensive manufactured and toxic oil. Both improve the plant's economic and ecological balance. The first DSG plant commercially being built will be the 50 MW_{el} project Andasol 3 in Spain.

The utilisation of *molten salts as primary fluid* shows similar advantages like the increase of the solar field operating temperature and therefore a better efficiency, and the elimination of the heat exchanger in case of using a molten salt storage system. On the other hand, the solar field and the heat transfer fluid require continuous heat tracing to avoid refreezing of the salt. Currently there are only few studies concerned with this innovation (Kearney et al. 2004, Price et al. 2007).

The *Fresnel trough* simplifies the concentration system by using a plain surface of nearly flat mirror facets, which track the sun with only a single axis and approximate the classic parabolic mirror. The efficiency is smaller than with a classic parabolic mirror. The idea is that the lower costs over-compensate the energy losses in the final economic assessment.

A lot of projects using Fresnel systems are being promoted worldwide amounting for a total capacity of 513 MW_{el} (World Bank 2005). A 1 MW_{th} add-on for steam heating to a coal fired power plant has already been tested in New South Wales, Australia, with Compact Linear Fresnel Reflector technology. This plant is to be extended to up to 38 MW_{el} (RISE 2007). The largest direct application of Fresnel collectors is currently being projected within the "Jordan/Aqaba Solar Water Project", where a hybrid Fresnel collector (co-fired with natural gas) is planned for purpose of tri-generation: In the final stage it will produce 8.5 MW_{el} electrical energy, 40 MW_{th} thermal energy, and 140 GWh/a cooling, operating with 8,470 full load hours. (Kern 2006)

2.1.2 Central receiver systems

Central receiver (CR) systems consist of a field of heliostats (almost plane mirrors), a tower, and a receiver at the top of the tower. The field of heliostats all move independently to one another and beam the solar radiation to one single point, the receiver. Heliostat fields can either surround the tower or be spread out on the shadow side of the tower. Two generic approaches to heliostat design have been used: a plane structure and a "stretched membrane" approach. Major investigations during the past 20 years have focused on four heat transfer fluid systems: water/steam, molten salt, atmospheric air, and pressurised air. (Romero et al. 2002)

Central receivers have the advantage that the energy conversion takes place at a single fixed point, which reduces the need for energy transport. By the high concentration factor operation temperatures of more than 1,000 °C can be reached. This rises the conversion efficiency and allows for advanced energy conversion systems (combined cycle instead of steam cycle). Figure 2.2 shows the 11 MW PS 10 tower power system operated near Sevilla.

One of the newest developments is the "beam-down" concept proposed and tested partly by the Weizmann Institute of Science in Israel. Rather than converting the concentrated solar energy at the top of the tower, a hyperbolically shaped secondary mirror directs the converging radiation vertically downward to a focal point at the bottom of the tower.

Figure 2.2: 10 MW PS10 central receiver plant in Spain (source: SolarPaces 2007)

The largest central receiver solar system formerly realised was the 10 MW_{el} "Solar Two" plant in southern California. In February, 2007 the 11 MW solar thermal power plant PS10 started its operation in Southern Spain as the first central receiver which has been built for the last years (Solúcar 2005 and SolarPaces 2007). Currently being built in Spain is the 15 MW_{el} power tower SolarTres equipped with a 16 hours thermal storage (Sener 2007). Worldwide projects with a total capacity of 566 MW_{el} are planned, therein the 2 x 20 MW_{el} power tower PS20 as a successor of PS10 and a 400 MW_{el} power tower announced by BrightSource Energy for California (Pitz-Paal 2006, Sarasin 2006, Hoexter 2008).

2.1.3 Dish-engine systems

Paraboloidal dish concentrators focus solar radiation onto a point focus receiver. Like parabolic trough systems they require continuous adjustment of its position to maintain the focus. Dish-based solar thermal power systems can be divided into two groups: those that generate electricity with engines at the focus of each dish and those that transport heat from an array of dishes to a single central power-generating block. Stirling engines are well suited for construction at the size needed for operation on single-dish systems, and they function with good efficiency. Dish-stirling units of 25 kW_{el} have achieved overall efficiency of close to

30%. This represents the maximum net solar-to-electricity conversion efficiency achieved by any non-laboratory solar energy conversion technology. (Luzzi and Lovegrove 2004)

Within this study parabolic dish systems will not be considered further because they are relatively small power generation units (5 to 50 kW_{el}), making stand-alone or other decentralised applications their most likely market (EUREC 2004). Figure 2.3 shows a dish-engine system of type EuroDish.

Figure 2.3: Dish-engine system (source: Schlaich Bergermann Solar)

2.1.4 Solar Updraft Tower Plant

A solar updraft tower plant (sometimes also called solar chimney) is a solar thermal power plant working with a combination of a non-concentrating solar collector for heating air and a central updraft tube to generate a solar induced convective flow. This air flow drives pressure staged turbines to generate electricity (Schlaich et al. 2005). The collector consists of a circular translucent roof open at the periphery and the natural ground below. Air is heated by solar radiation under this collector. In the middle of the collector there is a vertical tower with large inlets at its base. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter.

Continuous 24 hour operation can be achieved by placing tight water-filled tubes or bags under the roof. The water heats up during day-time and releases its heat at night. Thus solar radiation causes a constant updraft in the tower (although this storage system has never been installed or tested up to now). The energy contained in the updraft is converted into mechanical energy by pressure-staged turbines at the base of the tower, and into electrical energy by conventional generators.

An experimental plant with a power of 50 kW_{el} was established in Manzanares (Spain) in 1981/82. For Australia, a 200 MW_{el} solar updraft tower, shown in Figure 2.4, was planned but cancelled in summer 2006 (Enviromission 2007, Solarmission 2007). Currently a 40 MW updraft tower project is announced in Spain (Campo3 2006). Due to the uncertain perspectives of this technology, the absence of a reference project, and therefore the lack of cost and material data the solar updraft tower is not considered furthermore in this study.

Figure 2.4: Solar updraft tower originally planned in Australia (source: Schlaich Bergermann Solar)

2.1.5 Summary

Table 2.1 summarises the options described so far and lists typical technical data of solar thermal power plants.

Table 2.1: Technical characteristics of solar thermal power plants (Luzzi and Lovegrove 2004, Pitz-Paal et al. 2005, Sarasin 2006)

Technology	Typical operating temperature	Concen-tration ratio	Track-ing	Net effic. a)	Type of operation	Installed capacity	Annual output 2006	Currently projected
	°C			%		MW_{el}	GWh_{el}	MW_{el}
Parabolic + Fresnel trough	260 - 400	80-200	One-axis	9-14	commercial	354	988	1,100(Spain)[c] 2,675(worldwide) Fresnel 513
Central receiver	500 - 800	500-1,000	Two-axes	13-18	commercial	10,250	-	46 (Spain) 566 (worldwide)
Parabolic dish	500 - 1200	800-8,000	Two-axes	15-24	demo	-	-	800 (U.S.)

a) Defined as electricity generated / solar energy intercepted

b) 1987, broken down after end of project as scheduled

c) 12 - 15% fossil back up allowed to maintain the thermal storage temperature during non-generation periods (RD 2004)

2.2 Present reference technologies

Technical parameters

Table 2.2 summarises the technical data of the state-of-the-art reference technologies. For both the parabolic trough and the central receiver the data is based on the power plants currently under construction in Spain (Andasol 1 and SolarTres, respectively) (Ciemat 2006). Although PS10 is already in operation SolarTres was chosen as central receiver reference project because no data was available for PS10.

Table 2.2: Reference technologies, representing the state-of-the-art of solar thermal power plants. Modelled for a direct normal irradiation (DNI) of 2,000 kWh/(m^2,a), life-time 30 years

Type	Load	HTF	Hybrid	Thermal storage	Collec-tor area	Annual efficiency	Full load	Electric-ity out-

									hours	put
	MW_{el}		% co-firing	type	h	m^2/kW_{el}, st. hour	% Collector	% Net	h	GWh/a
Parabolic Trough	50	TO	18	MS[1)]	7.5	1.36	43.2	14.7 (p)	3,820	191
Central Receiver	15	MS	18	MS[2)]	16	1.1	45.6	15.5 (d)	6,230	93

[1)]: mixture of 60% $NaNO_3$ / 40% KNO_3

[2)]: mixture of 15% $NaNO_3$ / 43% KNO_3 / 42% $Ca(NO_3)_2$

TO: Thermo oil, MO: molten salt, st hour = storage hour

p = proven, d = to be demonstrated

Cost parameters

The cost data of concentrating solar thermal technologies reported in Table 2.3 are based on the new plants currently being built in Spain, too (Ciemat 2006). It should be noted that the cost data for the solar trough and the solar tower include a 7.5 hours and a 16 hours molten salt storage, respectively. This means a double and a triple solar field compared with a solar thermal power plant without a storage system, also expressed as “solarmultiple” 2 and 3, respectively (see chapter 3.5.1 for more information on this).

For reporting to RS2a technical specification the cost data for the solar trough is selected showing the most realistic values from our point of view.

Table 2.3: Cost data of reference technologies

Parameter		**Solar trough**	**Solar tower**
Specific investment costs	€/kW_{el}	5,300	10,140
Guarding costs	Mio. €	0	0
Specific demolition costs (greenfield)	€/kW_{el}	53	101
Fixed costs of operation	€/kW_{el},y	380	526
Other variable costs	€/MWh_{el}	0	0

3 Solar thermal technology development pathways

3.1 Solar thermal hot spots

Table 3.1 reports the most important strong and weak points representing solar thermal technologies.

Table 3.1: Solar thermal hot spots

Weak points / barriers	Strong points / diffusion factors
High costs	Relatively high energy density
Limited potentials in Europe	Delivery of balancing power
	No back-up energy sources necessary
	Huge amount of areas available out of Europe
	Solar steam, desalted water, and chill as by-products

Weak points and barriers

- Solar thermal power plants currently cause high electricity generation costs which have to be decreased by technological innovations, volume production, and scaling up to bigger units.
- Although there is a huge solar irradiation supply only locations with irradiations of more than 2,000 kWh/m^2,y are suited to a reasonable economic solar thermal performance. This means that Europe (except Mediterranean part) can only benefit from this potential by use of high voltage direct current lines connecting South Europe and Nord Africa with Central Europe which raise the electricity costs by 1.5 to 1 ct/kWh$_{el}$.

Strong points and diffusion factors

- An advantage of solar thermal systems is their relatively high energy density. With 200 - 300 GWh$_{el}$ electricity produced per km^2 land use they require the lowest land use per unit electricity produced among all renewables. (DLR 2005)
- Solar thermal power plants can store the primary energy in concrete, molten salt, phase change material, or ceramic storage systems and produce electricity by feeding steam turbines with the stored heat over night. This means that balancing power[1] can be delivered and therefore solar thermal power plants could be used as a back-up system even for intermittent photovoltaics and wind energy.
- Solar thermal power plants need big areas but there are huge areas available especially in the desert regions of the earth. For example, to meet Europe’s electricity demand (about 3,500 TWh/a) only by solar thermal electricity, an area of only 120 x 120 km in a North African desert would be necessary (that means 0.14% of the Sahara’s area).[2]

1 Balancing power is used to balance electricity demand and supply.

2 In reality, only a certain amount of the demand would be met by CSP. DLR's Trans-CSP study assumes 17% only, for example (DLR 2006).

- Solar thermal power plants can be operated as co-generation plants by using its steam not only for electricity generation but also for steam delivery, cooling, and desalting water.

3.2 Main drivers influencing future technology development

Climate Protection

Climate protection is one of the major drivers for solar thermal technologies, but since it is a general driver for renewable energies it is only mentioned at this place. The following drivers are more STP specific ones.

Objective of security of supply

In the technical perspective, the objective of security of supply is a pushing factor for solar thermal technologies. With the option of thermal storage or hybrid co-firing STP is able to deliver balancing power. STP thus is a stabilizing factor for the energy supply system. In South European countries which are highly dependent on fossil fuel imports like e.g. Spain or Portugal, STP generation is a high potential source for diversifying energy sources and increasing the share of domestic energy supply.

Enforced direct market support for renewable energies (feed-in-laws)

The establishment of preferential market conditions for renewable energies in several countries world-wide (e.g. feed-in laws in Germany, Spain, Portugal, and Algeria) and obvious resulting success stories like the wind energy expansion in Germany and Spain turn out as an important driver for solar thermal power plants. In Spain and Algeria STP technologies were firstly explicitly included into the support scheme. As a result, the first large-scale parabolic trough plants (3 x 50 MW_{el}) after the power plants in Southern California are being set-up in Spain.

Preferring non-intermittent electricity suppliers

Energy sources with low intermittency mean an economic advantage. STP will be able to offer balancing power at a competitive price level. By incorporating thermal storages and co-firing options, it internalizes the costs of compensating the intermittency of the solar energy resource – at still a competitive price level.

Advanced side applications and side products

STP technologies have the capability of co-generation. The joint production of electricity and heat for operating adsorption cooling facilities and heat for water desalination respectively is the most interesting application. The concept of solar fresh water production by parabolic trough plants has been investigated in several studies (Wilde 2005, DLR 2007). Both cooling and fresh water provision meet pressing demands in sun-rich, arid countries. Their demand appears at the same time and the same region which are suited to a reasonable economic solar thermal performance.

Other processes are solar reforming of natural gas or other organics, or thermo-chemical hydrogen production which are partly demonstrated and may open up high potential markets. Sargent & Lundy state that CSP could thus potentially get a major source of energy in the fuels and chemical sector.

Increasing demand for local added value

Many developing and transitional countries put more and more emphasis on local added value in investment decisions. They recognize the employment of national workers, the accumulation of local expertise and a high cope of national supply as a value for development. Moreover, local added value also promotes socio-economic stability. Solar thermal power stations belong to the technologies with a high potential for local added value. They have a little fraction of high-tech components, and about 50% of the investment is expended for steel, concrete, mirrors, and labour (Pitz-Paal 2007) which creates high local value (Lorych 2006).

Aiming at conflict neutral technologies

The fossil fuel energy supply system and nuclear energy technologies are increasingly involved in military conflicts and instable political environments. The discussion is concentrated on the possible transition from peaceful nuclear energy use to the production of weapon relevant material (Iran). Moreover, proliferation of weapons-grade plutonium is a latent threat. STP technologies do not incorporate conflict relevant materials. Even more important, the solar resource is abundant and inexhaustible, and thus won’t give rise to conflicts about using rights. This may reveal as an important pushing factor for STP technologies, even more as STP addresses the same market segment as fossil and nuclear power plants.

3.3 The potential role of solar thermal power plants in a future energy supply system

3.3.1 General aims of development and supporting instruments

The overall situation can be characterised as an *activation energy* model. Two main phases can be identified: The *first one* is the time until commercial competitiveness is gained. The *second phase* is the phase of participating in the electricity market at competitive conditions. Concerning the likeliness of developments these two phases have very different characteristics. The *second phase* will presumably be a "self-runner". Once economic competitiveness is gained, commercial investors will have a strong incentive to invest into STP plants. Then the dynamics gets self-reinforcing: The more capacity is built the cheaper the technology will get. This dynamics could be a stabilising factor reducing the influence of external drivers to the further deployment of STP.

The tipping points are found in the *first phase*. To achieve a development as described above, active pushing of STP technologies is necessary. Therein a critical mass and concentration of supporting factors is necessary. The most important supporting instruments which could contribute to an environment beyond a sub-critical support are those which directly address the economics of power plant projects:

– *Regulative framework conditions* with preferential market conditions for STP as they were established in Spain (and also in Algeria) have to be prolonged in all countries suitable for STP based electricity generation. Trough reliable feed-in-laws the pay back of the investment including an adequate return has to be guaranteed.

- In countries with national power companies a feed-in-law is not necessarily compulsive. In this case the required revenues can be provided in form of long term *power purchase agreements* preferably backed by an international guarantee (Trieb and Müller-Steinhagen 2007). This would be the case in most middle-east and north-African (MENA) countries which could deliver most of the STP based electricity worldwide.
- Furthermore, not only in the countries producing STP electricity but also in countries that could purchase STP based electricity via electricity transmission, feed-in-laws should include an incentive for solar thermal electricity. This would push the investment in power plants located in countries outside of the demanding countries.
- An indirect support of STP is to reduce the *subsidies* granted for fossil and nuclear power plants and to enable an electricity market under competitive conditions.
- The effects of such support schemes will be enforced by *increasing fossil fuel prices* which are expected by a lot of experts for the next decades. The more these prices increase the earlier solar thermal technologies will become competitive.
- In the optimal case a worldwide and ambitious long-term oriented *climate protection regime* has to be implemented. This means especially the ongoing internalisation of the costs of CO_2 reduction into the costs of (fossil and nuclear) electricity privileging solar thermal power stations as CO_2 neutral technologies.
- Further on, instruments like the *Clean Development Mechanism* (CDM) envisaged by the Kyoto Protocol would over-proportionally push solar thermal power technologies: CDM allows for making use of excellent sites for STP in developing countries and the respective CO_2 reduction potential in Europe.
- Last but not least, increasing *research and development* spending near to commercialisation (demo-types) is an important instrument during the activation phase. In the next 15 years a significant increase in R&D efforts is required if the cost reductions which are possible by applying technical innovations should be realised (Pitz-Paal et al. 2005).

3.3.2 Three future envisaged technology development scenarios

The different market development conditions considered for this study are outlined in three future envisaged technology development scenarios. We distinguish between an "optimistic-realistic" scenario and two extreme developments, a "very optimistic" view on the one hand and a "pessimistic" view on the other hand. The scenarios follow the two-main-phases approach explained above by differing in the way how strong especially the activation phase will be implemented (Table 3.2).

Table 3.2: Instruments influencing the diffusion scenarios

Instrument	**Scenario**		
	"Very Optimistic"	**"Optimistic-Realistic"**	**"Pessimistic"**
Feed-in-law	******	******	***
Power purchase agreements	******	******	***
Reducing subsidies for fossil and nuclear power plants	******	***	*
Increasing fossil fuel prices	******	******	***
Internalisation of the costs of CO_2 reduction	******	***	*
Clean Development Mechanism	******	***	*
Research and development spending	******	***	***

The number of stars represents the intensity of a measure.

- The "**very optimistic"** scenario bases on the assumption that both phases the activating phase as well as the competing phase can fully be explored. Especially in the first phase the maximum of "energy" has to be activated by all instruments discussed above to enable an early increase of solar thermal power plant's capacity. This means that a world wide and ambitious long-term oriented climate protection regime has to be implemented (under which all renewable energies will be pushed) and suitable regulative framework conditions will be implemented.
- The "**optimistic-realistic"** scenario illustrates the progressive targets to be met in the next decades if most of the instruments discussed above are strong enough to activate the market development especially within the next 10 to 15 years. Although the subsidies of fossil and nuclear electricity production may not be swept out and the internalisation of cost of CO_2 reduction will not advance as necessary as assumed for the very optimistic case the other instruments will be strong enough to push both the activation phase and the competing phase. Especially the feed-in-laws and the power purchase agreements supplemented by increasing fossil and nuclear fuel prices will enable a increasing diffusion of solar thermal electricity into the market.
- For the "**pessimistic" scenario** it is assumed that the driving forces will push the solar thermal development in the next decade but they will be to weak to enable a high and continuing diffusion as expected for the "optimistic-realistic" or even the "very optimistic" scenario. Solar thermal power plants won't be swept out of the renewables' portfolio but they will only increase on a very retained development path up to 2050. The "activation energy" as described above will neither suffice to push a strong first development phase nor the second phase of participating in the electricity market. We assume that the application of solar thermal power plants will have a slight increase in the U.S. whereas the feed-in laws in Europe will push both the investment in Europe and the import of solar thermal electricity from North Africa on a low level.

The market development under the scenarios is based on a review of the most recent roadmaps and technology-specific sources as there are:

- United Nations Development Programme (UNDP): "World energy assessment", 2000
- Sargent&Lundy: "Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecast", 2003
- SUNLAB: "Trough and tower development", cited in Sargent&Lundy, 2003
- DLR: "Scenario model ATHENE", SOKRATES project, 2004
- Greenpeace and ESTIA: "Solar thermal power 2020", 2003
- Greenpeace and ESTIA: "Concentrated solar thermal power - now!", 2005
- DLR: "Concentrating Solar Power for the Mediterranean Region", 2005
- DLR: "Trans-Mediterranean Interconnection for Concentrating Solar Power", 2006
- Greenpeace and EREC: "Energy [r]evolution. A sustainable world energy outlook", 2007

Except for Sunlab and Sargent&Lundy all studies refer to concentrated solar thermal power plants in general. They neither differ between trough and central receiver nor between different types of power plants (thermo oil, steam, or molten salt based troughs, for example). Whereas the earlier studies (except for UNDP) expect only a very retained capacity development and limit to the nearer future (2025 as latest) recently published sources describe long-term scenarios (until 2040 or 2050) based on a more or less optimistic view.

In addition to the considered roadmaps information gathered from other EU and German research projects, direct contacts with companies, as well as the knowledge of DLR, a leading solar thermal research centre, is introduced into the scenario development.

Figure 3.1 illustrates the proposed scenario development while Table 3.3 gives details on the installed capacity. Each of the scenarios starts in the year 2007 with an already installed capacity of 405 MW (composed of 354 MW "older" plants in the U.S. and 50 MW currently being built in Spain).

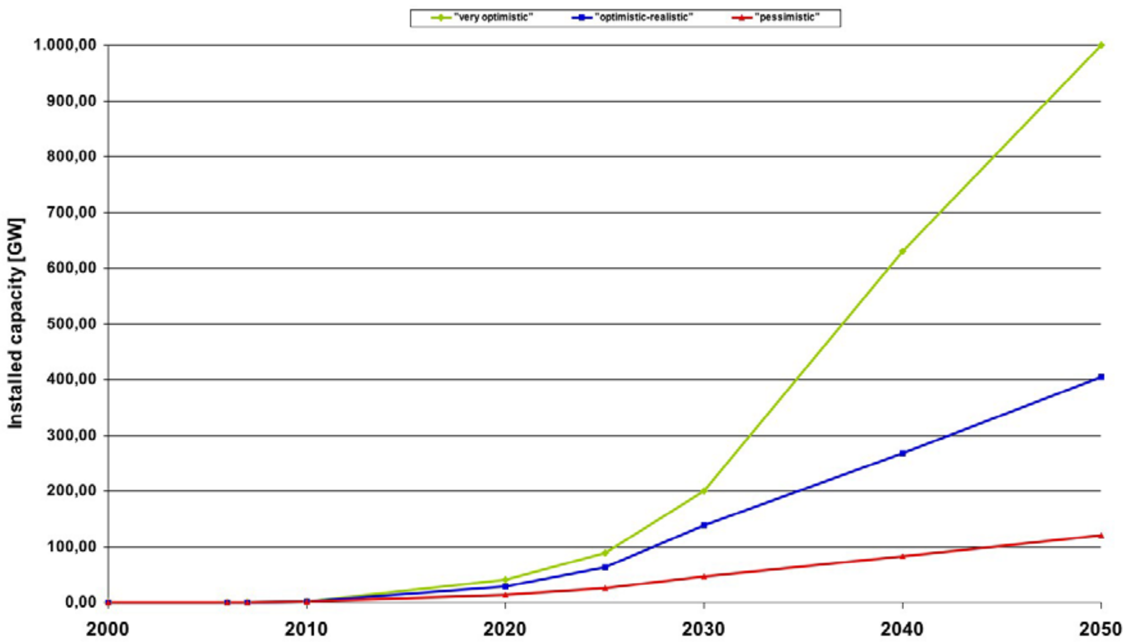

Figure 3.1: NEEDS technology development scenarios for solar thermal power plants

Table 3.3: Installed capacity within the different technology development scenarios

Scenario (volume in GW)	2000	2006	2007	2010	2020	*2025*	2030	2040	2050
"very optimistic"	0,35	0,35	0,40	2,00	40	*89*	200	630	*1.000*
"optimistic-realistic"	0,35	0,35	0,40	2,00	29	*63*	138	267	405
"pessimistic"	0,35	0,35	0,40	0,80	14	*26*	47	83	120

Table 3.4 compares the corresponding electricity generation with the world electricity demand as provided in scenarios by IEA and the recently published "2 °C scenario" within the "sustainable world energy outlook" (Greenpeace and EREC 2007). To calculate the solar thermal electricity supply the following approach is used:

- until 2020 those solar full load hours are used which are assumed for solar thermal electricity production in Spain (3,136 hours in 2007, 3,835 hours in 2010, 5,000 hours in 2015, see chapter 3.5.1);
- from 2020 on 5,500 solar full load hours are assumed. While during the calculation of electricity generation costs in chapter 3.5.1 for Spain 6,400 and for Algeria 8,000 full load hours are assumed in the scenario calculation lower figures are used. It has to be considered that part of the electricity will be used as peak-load and therefore not available for base-load supply.

Table 3.4: Solar generated electricity and its comparison with the worldwide electricity demand as proposed in scenarios by IEA, and by Greenpeace and EREC ("GP")

		2007	2010	2020	*2025*	2030	2040	2050
World electricty demand (IEA)	TWh	18.924	20.440	25.618	29.684	33.750	36.371	41.447
World electricty demand (GP&EREC)	TWh	17.031	17.308	20.234	21.763	23.292	27.018	30.935
Solar thermal electricity								
Solar full load hours	h	3.312	3.974	5.500	5.500	5.500	5.500	5.500
"very optimistic" scenario	TWh	1	8	220	492	1.100	3.465	5.500
	% IEA	0,0%	0,0%	0,9%	1,7%	3,3%	9,5%	13,3%
	% GP	0,0%	0,0%	1,1%	2,3%	4,7%	12,8%	17,8%
"optimistic-realistic" scenario	TWh	1	8	160	348	759	1.469	2.228
	% IEA	0,0%	0,0%	0,6%	1,2%	2,2%	4,0%	5,4%
	% GP	0,0%	0,0%	0,8%	*1,6%*	3,3%	5,4%	7,2%
"pessimistic" scenario	TWh	1	3	77	141	259	457	660
	% IEA	0,0%	0,0%	0,3%	0,5%	0,8%	1,3%	1,6%
	% GP	0,0%	0,0%	0,4%	*0,6%*	1,1%	1,7%	2,1%
Source of electricity demand: IEA 2006 and own estimations; Greenpeace and EREC 2007 ("2°C scenario")								

"Very optimistic" scenario

The "very optimistic" diffusion scenario is built up according to a study of Greenpeace and ESTIA published in 2003 and updated in 2005 (Greenpeace and Estia 2003/2005). Their long-term scenario describes an ambitious solar thermal power development starting from 1.6 GW in 2010 and reaching 630 GW in 2040. These figures are combined with data from the United Nations Development Programme's "world energy assessment" (Goldemberg 2000) which reports only two figures for future solar thermal capacity (15 GW in 2020 and 1,000 GW in 2050) but illustrates a smoothly continuation to the 2040 figure reported by Greenpeace. To reach this ambitious aim UNDP assumes growth rates similar to the development of wind power plants and calculates with a rate of 20-25%/y after 2010 and an average rate of 15%/y between 2020 and 2050.

Whereas the Greenpeace study is characterised by a retained development until 2030 and a strong increase towards 2040 we think that under very optimal conditions an earlier diffusion is possible. Therefore for this scenario we increase the proposed capacity in 2010 from 1.5

GW to 2 GW and in 2020 from 22 GW to 40 GW but maintain the figures for 2030, 2040, and 2050 as reported by Greenpeace and UNDP, respectively (Table 3.3).

Comparing the corresponding electricity generation (Table 3.4) with the world electricity development as proposed by IEA solar thermal electricity could represent 1.7% of total supply in 2025 increasing to 13.3% in 2050. Assuming a development according to the mentioned "2 °C scenario", it could represent 2.3% of total supply in 2025 increasing to 17.8% in 2050 which is higher because of the smaller increase of world electricity supply. These values are taken as the maximal achievable target for solar thermal power plants up to 2050.

"Optimistic-realistic" scenario

Under "optimistic-realistic" conditions as described above we expect a worldwide capacity development as it is included in the "2 °C scenario" developed by (Greenpeace and EREC 2007). As it is possible to see from Figure 3.1 in 2050 an installed capacity of 405 GW is expected. After a slow development until 2020 (160 GW) a strong increase during the next decades determines the development path until 2050 (with a growth rate of 17%/y until 2030 and an average rate of 5.5%/y between 2030 and 2050).

The capacities calculated for this scenario are similar those of the DLR study "MED-CSP", which investigated the feasibility of activating part of the valuable and powerful energy resources of North Africa for electricity production in EUMENA (Europe and Mediterranean countries) (DLR 2005) and showed the feasibility to produce such capacities during the considered decades.

Comparing the corresponding electricity generation (Table 3.4) with the world electricity development as proposed by IEA solar thermal electricity could represent 1.2% of total supply in 2025 increasing to 5.4% in 2050. Assuming a development according to the mentioned "2 °C scenario", it could represent 1.6% of total supply in 2025 increasing to 7.2% in 2050.

"Pessimistic" scenario

This scenario is modelled assuming that only 40% of the capacity installed within the optimistic-realistic scenario will be reached from 2010 to 2025. After this time the share is decreased continuously to 30% in 2050. This results in a volume of 0.8 GW in 2010, 14 GW in 2020, 26 GW in 2025, and increases to 120 GW in 2050. The capacities calculated so far are similar to the DLR study "TRANS-CSP" using only those capacities calculated for Europe and for the export from MENA to Europe (DLR 2006).

Comparing the corresponding electricity generation (Table 3.4) with the world electricity development as proposed by IEA solar thermal electricity could represent 0.5% of total supply in 2025 increasing to 1.6% in 2050. Assuming a development according to the mentioned "2 °C scenario", it could represent 0.6% of total supply in 2025, increasing to 2.1% in 2050.

3.4 Technology development perspectives

3.4.1 Innovations of solar thermal power plants

To achieve the development targets of STP technologies outlined in the former chapter, substantial development steps are a precondition. In this paragraph expectations on key technological breakthroughs and key factors influencing the implementation of technology change are described using the results of the ECOSTAR study (Pitz-Paal et al. 2005) and a study of Sargent & Lundy (S&L 2003). Whereas the latter one only considers scaling up and volume effects, the ECOSTAR study done by a consortium consisting of the leading solar thermal research institutes worked out a detailed analysis on innovation and cost reduction potentials until 2020.

ECOSTAR grouped the main technical improvements into three major categories:

- concentrators (including mirrors)
- thermal energy storage
- receivers, absorbers, and cycles (including heat collecting elements and power block)

Those technical innovations which are able to reduce costs by improving plant efficiency or reducing initial capital costs were evaluated with respect to probability of the improvement and estimated magnitude of cost reduction. Considered were the impacts on the electricity generation costs (EGC). Further the performance potential uncertainties and development risks were analyzed. The results were summarized as follows.

Concentrators

Improvements in the concentrator performance and its cost could most drastically reduce the EGC figures. Since the concentrator is a modular component development of prototypes and benchmarks of these innovations in real solar power plant operation condition in parallel with state of the art technology is a straightforward strategy. New reflector materials should be low cost and have the following traits:

- good outdoor durability
- high solar reflectivity (> 92%) for wave lengths within the range of 300 nm to 2,500 nm
- good mechanical resistance to withstand periodical washing
- low soiling coefficient (< 0.15%, similar to that of the back-silvered glass mirrors)

The supporting structure of the concentrators also needs improvement. New structures should fulfil the following requisites:

- lower weight
- higher stiffness
- more accurate tracking
- simplified assembly

Thermal energy storage

The thermal storage systems are seen as a second key factor for cost reduction of solar power plants. Development needs are very much linked to the specific requirements of the systems in terms of the used heat transfer medium and the required temperature. In general storage development needs several scale-up steps generally linked to an extended development time before a market acceptance can be reached. Requirements for storage systems are

- efficient in terms of energy and exergy losses
- low cost
- long service life
- low parasitic power requirements

The development of two special storage systems is seen as a particular challenge to decrease electricity costs: high pressure steam storage systems required for direct steam generation (DSG) plants as well as pressurized, high temperature air storage systems needed for combined gas and steam turbine cycles.

High temperatures

Higher temperatures also lead in many cases to higher system performance. The current status of receiver technology however does not exploit the full performance potential. Significant improvements in the performance of high temperature receivers are possible whereas the room for performance improvements in the temperature range below 400 °C is relatively small (cost improvements are possible).

Scaling up to 50 MW_{el}

Scaling the size from pilot projects to larger power cycles of 50 MW_{el} is seen as an essential step for all technologies except for parabolic trough systems using thermal oil which have already run through the scaling in the nine SEGS installations in California starting at 14 MW_{el} and ending at 80 MW_{el}. Scaling increases performance and reduces unit investment cost as well as unit operation and maintenance costs. The integration into larger cycles specifically for power tower systems means a significant challenge due to the less modular design. Here the development of low-risk scale-up concepts is still lacking.

In Table 3.5 the innovation potential with the highest impact on electricity generation cost reduction is summarized for each of the technologies showing the three highest priorities.

Table 3.5: Research and innovations' priorities of solar thermal power plants (Pitz-Paal et al. 2005)

Technology	**Priority A**		**Priority B**		**Priority C**	
	Innovation	**EGC reduction**	**Innovation**	**EGC reduction**	**Innovation**	**EGC reduction**
Trough using oil	concentrator structure and assembly	7-11%	low cost storage system	3-6%	increase HTF temperature	1-3%
			advanced reflectors and absorber	2-6%	reduce parasitics	2-3%
Trough using steam	scale increased to 50 MW system	14%	advanced storage	3-6%	increase HTF temperature	1-3%
	conc. structure and assembly	7-11%	Advanced reflectors and absorber	2-6%	reduce parasitics	2-3%
Central receiver (salt)	scale increased to 50 MW system	3-11%	Advanced mirrors	2-6%	advanced storage	0-1%
	heliostat size, structure	7-11%				
Central receiver (steam)	scale increased to 50 MW system	6-11%	superheated steam	6-10%	advanced mirrors	2-6%
	heliostat size, structure	7-11%	advanced storage	5-7%		
Central receiver (atmospheric air)	scale increased to 50 MW system	8-14%	advanced storage	4-9%	advanced mirrors	2-6%
	heliostat size, structure	7-11%	Increased receiver performance	3-7%		
Central receiver (combined cycle)	heliostat size, structure	7-11%	scale increased to 50 MW system	3-9%	advanced mirrors	2-6%
	include thermal storage	7–10%			increased receiver performance	1-2%

Scaling up beyond 50 MW_{el}

The pace of scale-up of plant unit sizes will determine the pace of cost reduction. According to Sargent & Lundy (S&L 2003), to achieve a cost reduction of 14% a scale-up of the power block units to 400 MW_{el} is necessary for parabolic trough plants. The S&L scenarios assume a first 400 MW_{el} parabolic trough plant in 2020. The Athene study (DLR 2004) assumes capacity units beyond 400 MW_{el} at an overall capacity worldwide of about 42 GW_{el} and beyond. This target will be achievable in 2025 both in the "very optimistic" and the "optimistic-realistic" scenarios and in 2050 even in the "pessimistic" scenario.

Deployment of large capacities (volume effects)

The achieved cost reduction due to mass production always correlates to the expansion path of STP plants achieved. The Sargent & Lundy study (S&L 2003) says a deployment rate of 600 MW_{el} per year for parabolic trough technology is necessary to achieve a cost reduction of 17% in the next 15 years. Since the new installed capacity growth with much more than 600 MW per year even along the "pessimistic" scenario (beyond 2014) this cost reduction will be reached in either case.

Combing the cost reduction potentials

Combining the cost reduction achievable due to a) technical innovations and scaling up to 50 MW_{el}, b) volume production, and c) scaling up beyond 50 MW_{el} the ECOSTAR authors expect an overall cost reduction of 55 - 65% in the next 15 years (Pitz-Paal et al. 2005). They illustrate this accumulated potential for the parabolic trough using thermo oil for which a cost reduction of 61% is calculated (Figure 3.2), but very similar figures appear feasible for the other systems investigated. About 50% of the cost reduction is caused by technical innovations while the other share is provided by scaling and volume effects.

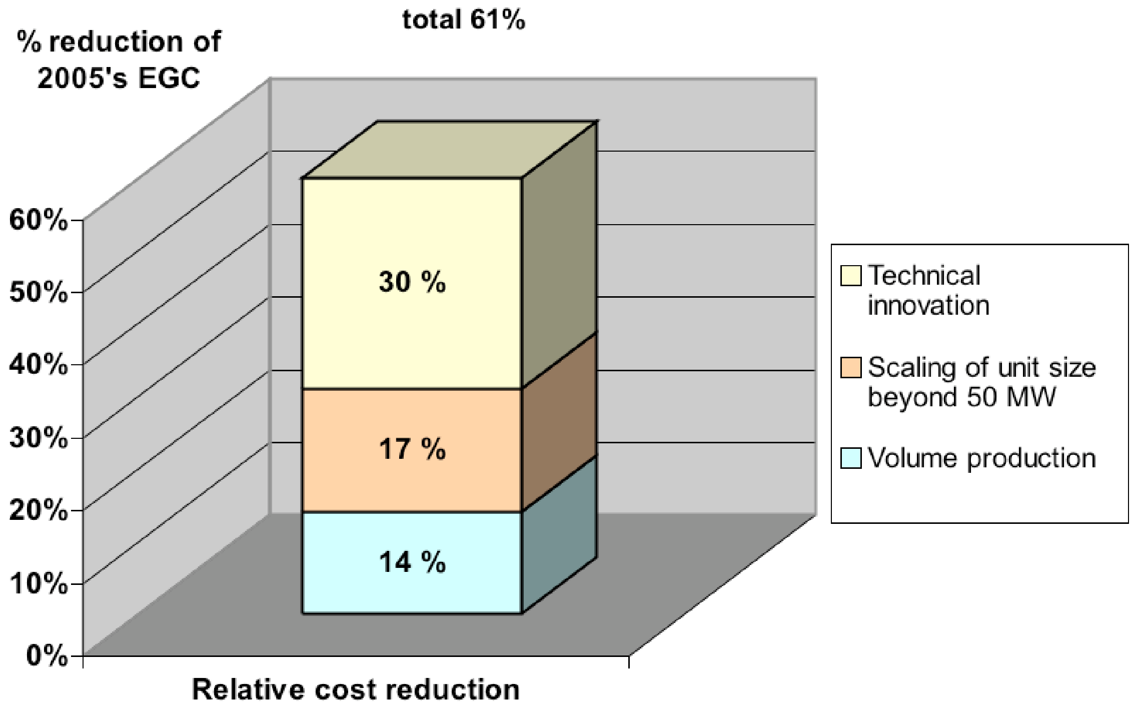

Figure 3.2: Potential relative reduction of electricity generation costs (EGC) by innovations, scaling, and series production through 2020 for the parabolic trough/thermo oil HTF system compared to today's electricity generation costs (Pitz-Paal et al. 2005)

3.4.2 Technology development under the different scenarios

Independent from the three diffusion scenarios all of the considered technologies will develop. The scenarios presented below only describe which of the technologies will dominate the development and therefore the overall cost reduction potential from our point of view. Those technologies are selected which seem to be most spread under the different scenarios. Nevertheless we acknowledge that there are a some other new and promising developments (for example the utilisation of molten salts as primary fluid, see Forsberg et al. 2007) which could lead to technologies able to supplement or possible outrun the proposed ones.

- Considering a **pessimistic** scenario development we think that solar thermal power plants won't have the "activation energy" to establish beyond the proven technology which is the parabolic trough technology operating with thermo oil as heat transfer fluid and using a molten salt storage system. The technical innovations described for these plants will be realised; the storage system will be supplemented by a concrete storage currently under development. Although feed-in-laws or equivalent instruments are weak, co-firing will decrease and solar-only operation will be enabled by using an efficient 16 hours molten-salt or concrete storage system from 2021. The plant's efficiency will slightly increase and the size is enlarged to units of 200 MW_{el} in 2025 and 400 MW_{el} in 2050.

- Along an **optimistic-realistic** scenario development we see the direct steam generation (DSG) instead of thermo oil as the state-of-the-art heat transfer system from 2025. It will be used both in conventional parabolic trough systems and in upcoming Fresnel trough technology. DSG plants have a lot of advantages because the thermo oil as well as the pumps and tanks used for operation are not needed longer; the HTF/steam exchanger drops; the efficiency increases due to higher temperatures of the heat transfer fluid, reduced pump power, and decrease of heat exchanger losses (Hennecke 2004).

  Central receivers will only play a minor role because the proposed cost reductions won't reach generation costs lower than those of parabolic troughs. Due to feed-in-laws or equivalent instruments co-firing will decrease also and solar-only operation will be enabled from 2021 by developing an efficient 16 hours high pressure steam storage system based on phase change materials (PCM). The plant's efficiency will increase and the size is enlarged to units of 200 MW_{el} in 2025 and to 400 MW_{el} in 2050 in case of trough and to units of 180 MW_{el} from 2025 in case of central receiver.

- Considering the **very optimistic** scenario development we think that in an early stage (2025) solar steam power plants will be displaced by solar combined cycle power plants. By using the heat currently thrown away to the environment for cooling or for desalting processes the electrical efficiency will slightly decrease but the total efficiency will be quite higher. Cooling and especially desalting seawater will become more and more important in the future due to a population increase and at the same a drinking water scarcity in the North African regions (DLR 2007, WWF 2007). At the same time these are countries excellent suited for solar thermal power plants. As the basis solar thermal power plant we assume the Fresnel technology described for the "optimistic-realistic" scenario.

  Central receivers operating with pressurised air enable combined gas and steam turbine cycles which increase the efficiency more than it would be possible with any other solar steam technology (Buck et al. 2002). Although efficiencies of 23-25% are proposed we do not consider them as a main technology within this scenario because to enable those temperatures required by the subsequent gas turbine process (up to 1,400 °C) a continuously co-firing with natural gas is necessary which would increase the emissions much more than using solar-only operated power plants.

3.5 Development of costs

3.5.1 Application of learning rates to the three different technology scenarios

3.5.1.1 General approach

The present chapter illustrates the calculation of future investment costs as well as of electricity generation costs (EGC) by application of learning rates. The developed learning curve is a generic cost curve because no distinction between trough and solar tower is made. In chapter 3.5.2 this "top-down" approach is compared with the "bottom-up" approach given by the ECOSTAR consortium.

Compared with other renewables like wind or photovoltaics some special aspects have to be taken into account calculating future costs:

- As already has been stated in the WP 3 - RS Ia report the existing experience curve for solar thermal power plants is based on only nine power plants of type SEGS erected in California in the 1980s with a total capacity of 354 MW (SEGS I to SEGS IX). This means that only three doublings in capacity were produced. Based on the related experience curve and the uncertainty of further cost development, Neij suggests to use an experience curve with a progress ratio of 88% and proposes a sensitivity analysis applying an additional lower sensitivity value of 83% and an upper sensitivity value of 93%. (Neij 2006).
- However, solar thermal power plants consist of three main parts with different learning curves (the collector field, the storage system, and the balance of plants (BOP) including the power block with the steam turbine and the generator). While the power block represents a conventional almost matured technology the innovative parts and therefore the components with the main cost reduction potential are the solar field and, more and more of importance in the future, the thermal storage system. Therefore we will apply progress ratios based on the different components as taken into account within the Athene model (DLR 2004).
- While the former aspects describe details in the learning rate application there is a fundamental difference between solar thermal power plants and other renewable based electricity generation: solar thermal power plants can store the primary energy in form of solar heat and use it in times when the sun does not shine. This means that balancing power can be delivered. To gain high full load hours combined with a high solar share more and more thermal storage capacity and therefore enlarged collector fields have to be built up. This means that while the costs on components' level (€/m^2 collector field, for example) will *decrease* the total investment costs per installed power (€/kW) will *increase* until a solar share of 100% is reached. In contrary, the EGC decreases continuously in the same time as the higher investment costs are over compensated by the higher capacity factor. These facts are illustrated schematically in Figure 3.3.

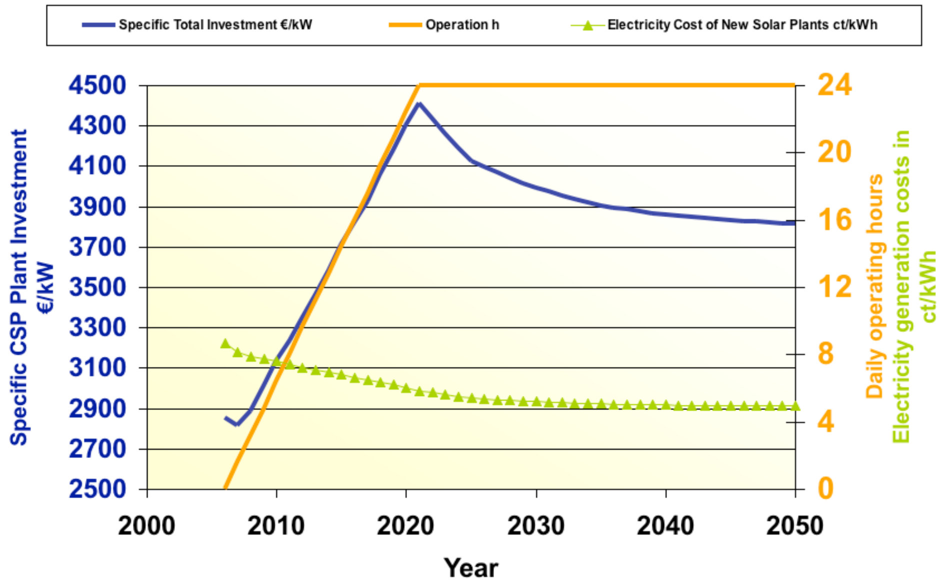

Figure 3.3: Coherence of storage capacity (and at the same time enlarged solar fields), investment costs, and electricity generation costs for a hybrid power plant and 8,000 full load hours (schematic illustration; source: DLR 2005, enhanced)

3.5.1.2 Definition of boundary conditions

The cost development calculation is based on the following assumptions on the solar thermal development path as there are

– the **site** where the power plants are located: Only locations with irradiations of more than 2,000 kWh/m^2,y are suited to a reasonable economic performance because they guarantee high solar full load hours per year. As Figure 3.4 shows by way of three locations (El Kharga in Egypt, Madrid in Spain, and Freiburg in Germany) the site specific irradiation determines the monthly electricity yield and the full load hours per year which are economically possible.

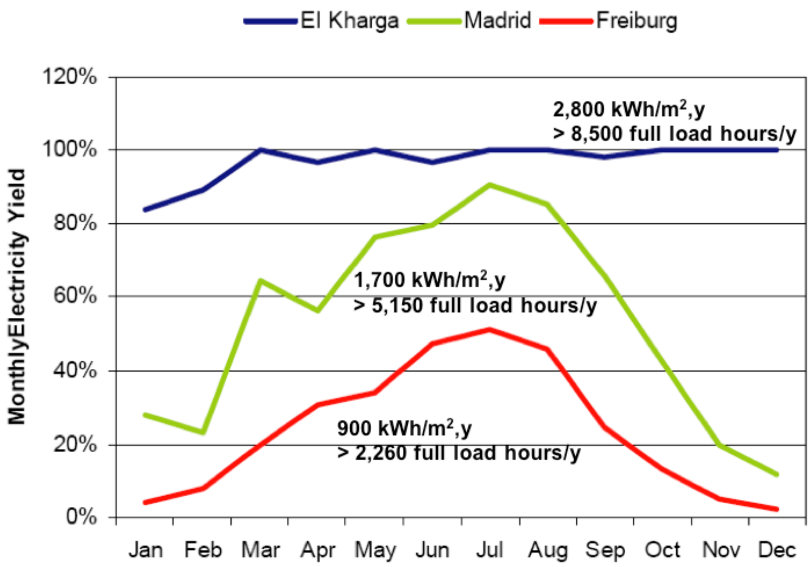

Figure 3.4: Monthly electricity yield and full load hours per year depending on site specific irradiation (including a 24 hour thermal storage) (DLR 2006)

For the use in NEEDS two different sites are chosen:

- **Case A**: a site in Spain with an irradiation of 2,000 kWh/m^2,y enabling 6,400 full load hours per year (including the use of thermal storage)
- **Case B**: a site in Algeria with an irradiation of 2,500 kWh/m^2,y enabling 8,000 full load hours per year (including the use of thermal storage). This value describes an average irradiation in the North African countries.

– the **electricity transmission**: Both cases require to include the electricity transmission to Western Europe. In case A a high voltage direct current line (HVDC) from Southern Spain to the German Border with a length of 1,822 km and in case B a HVDC from Algeria to the German Border with a length of 3,200 km is assumed (Figure 3.5);

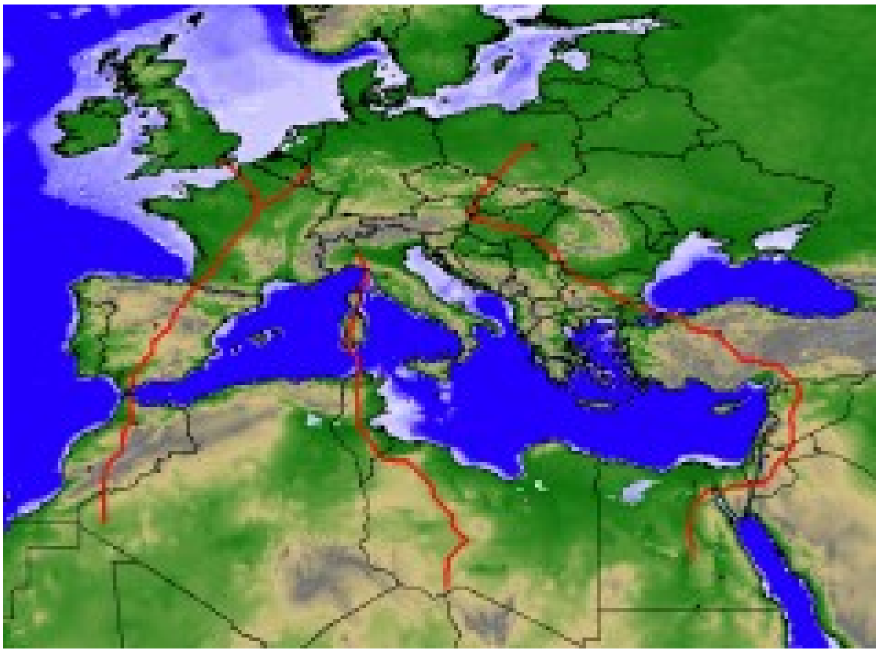

Figure 3.5: Proposed high voltage direct current transmission lines (left one: from Algeria to Germany) (DLR 2006)

– the **reference power plant**: We choose the parabolic trough being built in Granada (Andasol 1) as starting point for our cost calculations. This enables to sustain the learning process initiated by the trough power plants commercially running in the U.S. (Kramer Junction) since the eighties;

– the **solar share**: The solar thermal power plants currently being under construction in Spain are being built as hybrid plants allowing a fossil (natural gas) co-firing of 18% (solar share of 82%). Assuming 3,820 full load hours projected for Andasol 1 this means that 3,312 *solar* full load hours can be reached. To model the same solar power plant (same aperture and same storage capacity) regarding the conditions assumed for case A and case B (6,400 and 8,000 full load hours, respectively) means that the solar share decreases to 52% with 3,312 and 4,140 solar full load hours, respectively. Until 2021 we assume a linear increase of the solar share reaching 100% from 2021;

– the use of **thermal storage** systems: Proposing to use the maximum full load hours and at the same time increasing the solar share towards 100% requires an increasing storage capacity. Starting with 7.5 storage hours (planned for Andasol 1) we assume to work with a 16 hours storage capacity from 2021 which means 24 daily operating hours (see Figure 3.6).

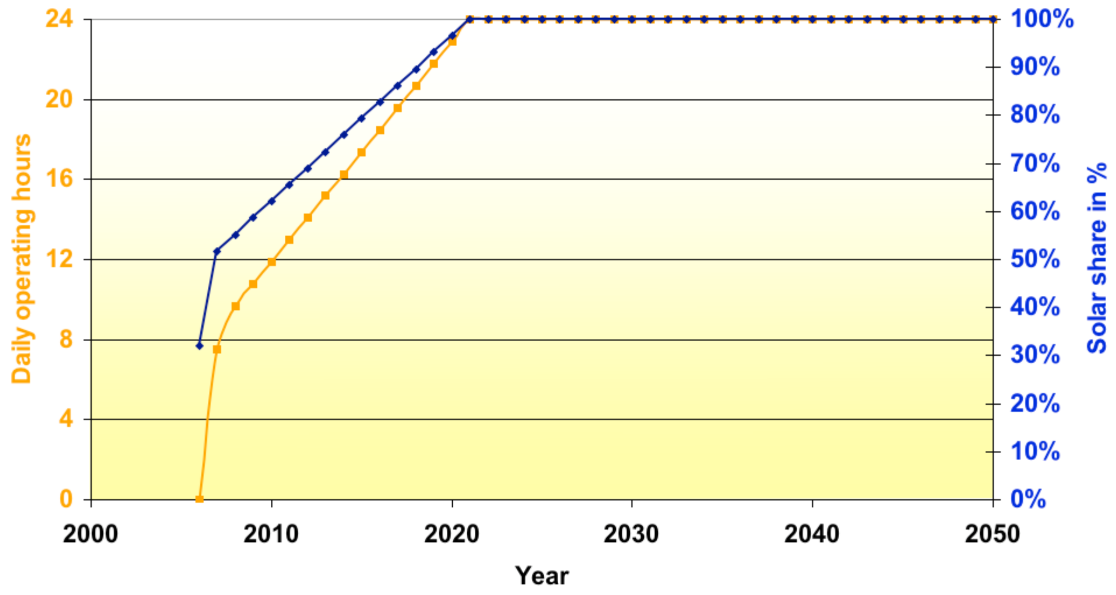

Figure 3.6: Process of increasing the storage capacity and the solar share (starting with a solar share of 52%)

Table 3.6 summarizes the parameters defined in this chapter.

Table 3.6: Basic parameters used for cost calculation

Parameter		2007		2025		2050	
		Case A	Case B	Case A	Case B	Case A	Case B
Boundary conditions							
Irradiation	$kWh/m^2,y$	2,000	2,500	2,000	2,500	2,000	2,500
Full load hours	h	6,400	8,000	6,400	8,000	6,400	8,000
Power transmission costs	ct/kWh	---	---	---	1.1	---	1.0
Solar share	%	52	52	100	100	100	100
Solar full load hours	h	3,312	4,140	6,400	8,000	6,400	8,000
Storage capacity	h	7.5	7.5	16	16	16	16

3.5.1.3 Definition of costs and specific learning rates

Since the EGC development is depending on the investment costs, the annual costs, and the learning rates in this paragraph the basic parameters are defined.

– **Basic data**:

Project discount rate	6% (specification of RS Ia)
O&M rate of investment (annual)	2.5%
Insurance rate of investment (annual)	0.5%

Specific demolition cost (Greenfield)	1% of investment
Depreciation time	25 years

- **Specific investment costs**: As initial costs for the reference plant we apply the real investment costs of Andasol 1 as reported by (Ciemat 2007): 300 €/m^2 collector field, 115 €/kWh storage capacity, and 1,350 €/kW for the power block, the BOP and its adaptation to the solar application. In terms of load the total investment costs are 5,302 €/kW. Comparing this with the investment costs derived from the former U.S. plants (3,000 €/kW) this is a large difference caused by the higher power block costs and the costs for its adaptation as well as the technology change to a power plant using a 7.5 hours thermal storage system (and therefore a doubled solar field).
- **Fixed costs of operation**: The fixed costs of operation consist of the annual O&M costs, the annual insurance costs, and the fuel costs during the first years operating in hybrid mode (co-firing with natural gas between 2007 and 2020, solar-only from 2021).
- **Fuel costs**: Since natural gas prices at power plant's border have not been available for Algeria, our own assumptions made in the MED-CSP study (DLR 2005) are used. We calculate with an initial natural gas price of 25 €/barrel (= 17.5 €/MWh = 4.86 €/GJ) and a cost escalation rate of 0.8% per year (only for the period of co-firing between 2007 and 2020).
- **Electricity generation costs (EGC)**:

  Calculation the EGC results in the following figures, describing the "current" situation. Since there are currently no reference plants being built in North Africa case B is only for purposes of comparison.

  Solar-only operation: 17.32 ct/kWh (case A) and 13.86 ct/kWh (case B)
  Hybrid operation: 12.05 ct/kWh (case A) and 10.26 ct/kWh (case B)

3.5.1.4 Application of learning curves

As described in the former paragraph it is not sufficient to use only one learning rate for the whole solar thermal power plant. Therefore in this paragraph different learning rates are developed for the collector field, the storage system, and the balance of plants (BOP).

- The **power block** represents a conventional technology which is almost matured. On a world wide level a learning rate of 5% would be reasonable but regarding the low capacities referred to in the envisaged diffusion scenarios (with a maximum of 1,000 GW in 2050 in case of the "very optimistic" scenario) a smaller learning rate should be used. On the other hand, the real cost share is its adaptation to the conditions available in a solar thermal power plant. This cost part should decrease along the increasing installed capacity. While in the Athene model a progress ratio of 0.98 (that means a learning rate of 2%) is used (DLR 2004) we propose to apply a learning rate of 5% (progress ratio of 0.95). This suitably considers the actual increase of the specific investment costs to 1,350 €/kW as derived above while the Athene model is based on investment costs of 1,050 €/kW assuming that parts of the learning curves had already been implemented. Furthermore, we think it is justified to define floor costs in case of the power block. In our opinion a cost development below 800 €/kW seems not to be realistic because of least costs for the material production, so we stop the learning curve at this value.

– A higher learning rate should be assumed for the innovative parts, which are the **collector field** and the **storage system**. For these parts we implement a progress ratio of 0.88 according to the commendation of WP 3 - RS Ia (Neij 2006). It considers that at least concerning the collector field the learning curve is not at its beginning but has partly already been implemented along the SEGS plants built in the U.S.

It should be kept in mind that we apply the same learning rates within the three technology development scenarios. Table 3.7 summarises the defined learning rates:

Table 3.7: Learning rates defined for the main parts of solar thermal power plants

Component	LR	PR	Referring to	Floor costs
Storage system	12%	88%	kWh storage capacity	---
Collector field	12%	88%	m^2 aperture	---
Power block, BOP	5%	95%	kW load	800 €/kW
LR = learning rate, PR = progress ratio				

Figure 3.7 illustrates the according cost development curve by way of the "optimistic-realistic" scenario (case A) in terms of time and referring to peak power. At the same time the figure shows how the single components contribute to the overall learning curve. As described above "peak power" considers the total power – that means the nominal power and the additional power available through the bigger solar field used for the storage system.

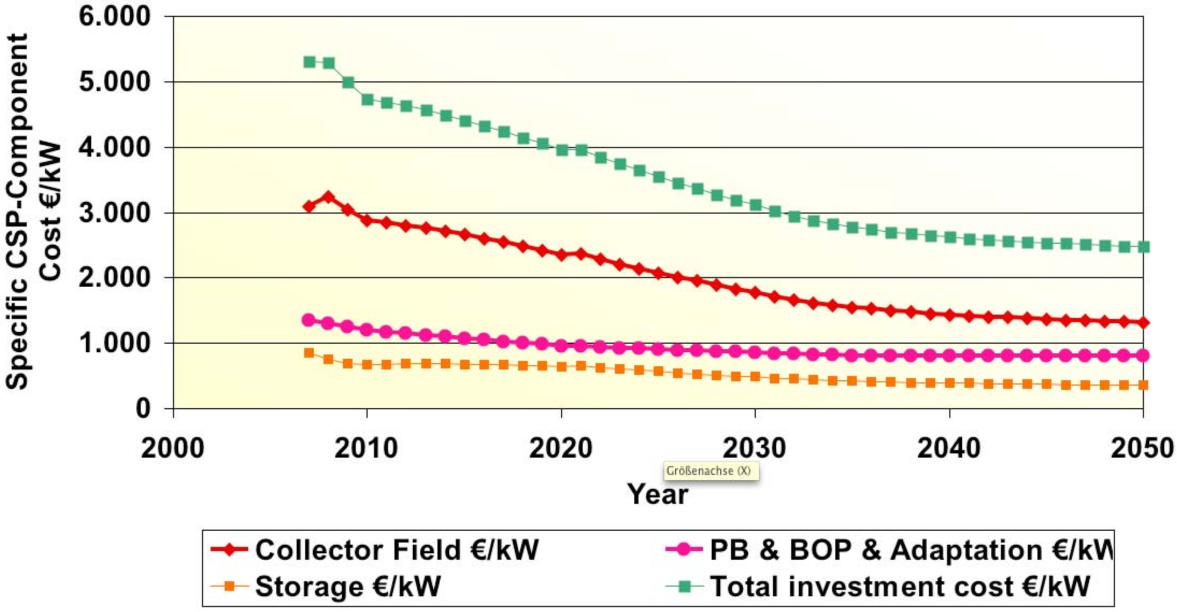

Figure 3.7: Overall plant's learning curve and the contributions of the main parts (by way of the "optimistic-realistic scenario", case A)

Finally, Figure 3.8 illustrates the learning curve of the whole power plant in terms of the cumulated installed capacity. Since we consider the same learning rates for the different scenarios there is only one single learning curve but it is scenario dependent at which time single points on the curve (that means a certain capacity) will be reached. For example, consider the final year under investigation (2050). In the "very optimistic" scenario it is located at the end of the curve where an installed capacity of 1,000 GW is provided. The learning curve considering the "pessimistic" scenario ends 600 GW earlier since only 405 GW will be reached under these conditions.

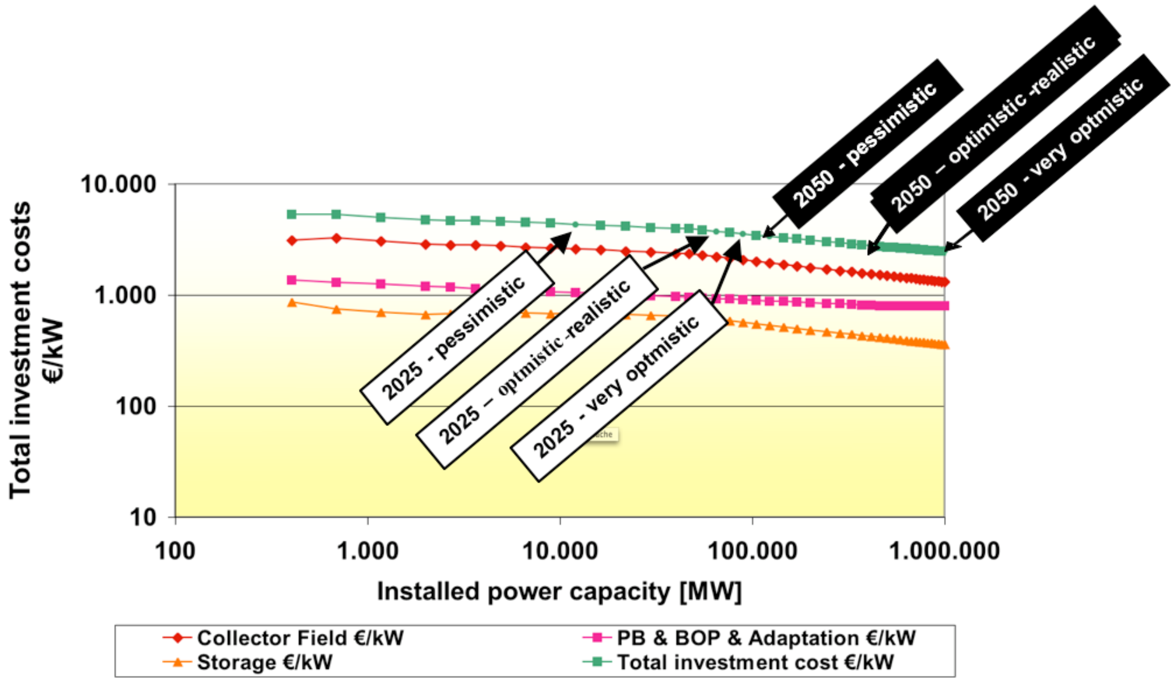

Figure 3.8: Total plant's learning curve based on the installed capacity

Anyway, the curve created so far can not be regarded as a "real" learning curve because no learning rate can be constructed:

- For the time period between 2007 and 2020 the total costs are decreasing but *different plants* are compared: Plants with different storage capacities until 2020 and plants reaching full storage capacity after 2020.
- A learning rate could only be constructed for the time period after 2020 when the solar thermal power plants are fully developed and running in a solar-only mode reaching maximum solar full load hours. But the learning process has already started in 2007 with the first solar collectors and storage units being built. Therefore a learning rate created for the late period would not describe the overall learning process.

3.5.1.5 Calculation of electricity generation costs

Hybrid-operation (until 2020), no electricity transmission

This paragraph illustrates the development of the pure electricity generation costs (EGC). Figure 3.9 illustrates the resulting EGC along the different scenarios and site specific cases (no electricity transmission assumed). As clearly can be seen from the diagram, there is a strong influence on the different locations. For 2050, the scenarios applied to case A (Spain) result in EGC within a range of 4.18 to 5.69 ct/kWh. The higher irradiation available in case B

(Algeria) reduces the EGC to a range of 3.30 to 4.49 ct/kWh that means a difference of 0.9 to 1.2 ct/kWh between case A and case B.

Within each of the cases there is an obvious difference between the three diffusion scenarios. Whereas the "optimistic-realistic" scenario yields a 12% higher EGC than the one of the "very optimistic scenario", the "pessimistic scenario" shows an increase by 36%.

The strong increase in the beginning of the scenarios is caused by the jump from the power plants already running in the U.S. to the new power plants being in construction 20 years later. It has to be kept in mind that the development between 2006 and 2020 illustrates a technology change starting with power plants with small storage capacity to solar-only plants using 16 hour storages and delivering 6,400 or 8,000 solar full load hours from 2020.

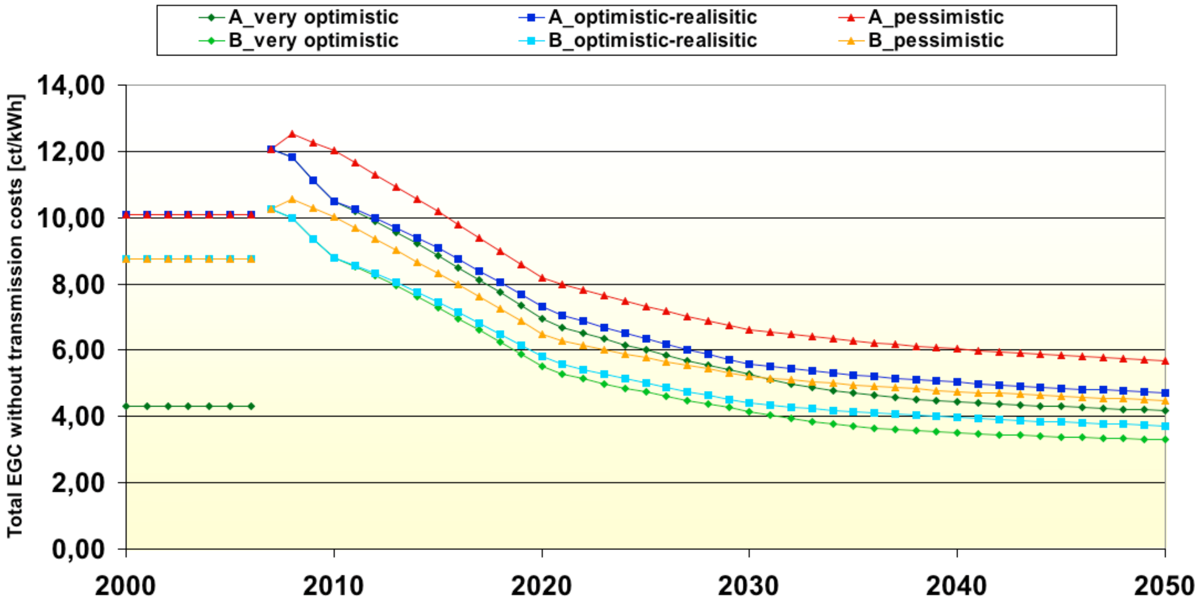

Figure 3.9: Total electricity generation costs (all scenarios), hybrid-operation until 2020, no transmission costs in case B

Hybrid-operation (until 2020), electricity transmission to Europe from 2021 in case B

To consider real conditions in Europe in case B transmission costs for the electricity transport from Algeria to Germany has to be added to the EGC which causes a cost jump in 2020 (Figure 3.10). While the EGC of case A do not change the EGC of case B raise by 1.2 ct/kWh in 2020, 1.1 ct/kWh in 2025, and 1 ct/kWh from 2030 (DLR 2006). This means that the original difference of about 0.9 to 1.2 ct/kWh between case A and case B shrinks. While in the "pessimistic" scenario electricity from Algeria will be cheaper than the one from Spain, in the "very optimistic" case the relation turns and Spanish electricity will become slight cheaper than the Algerian one.

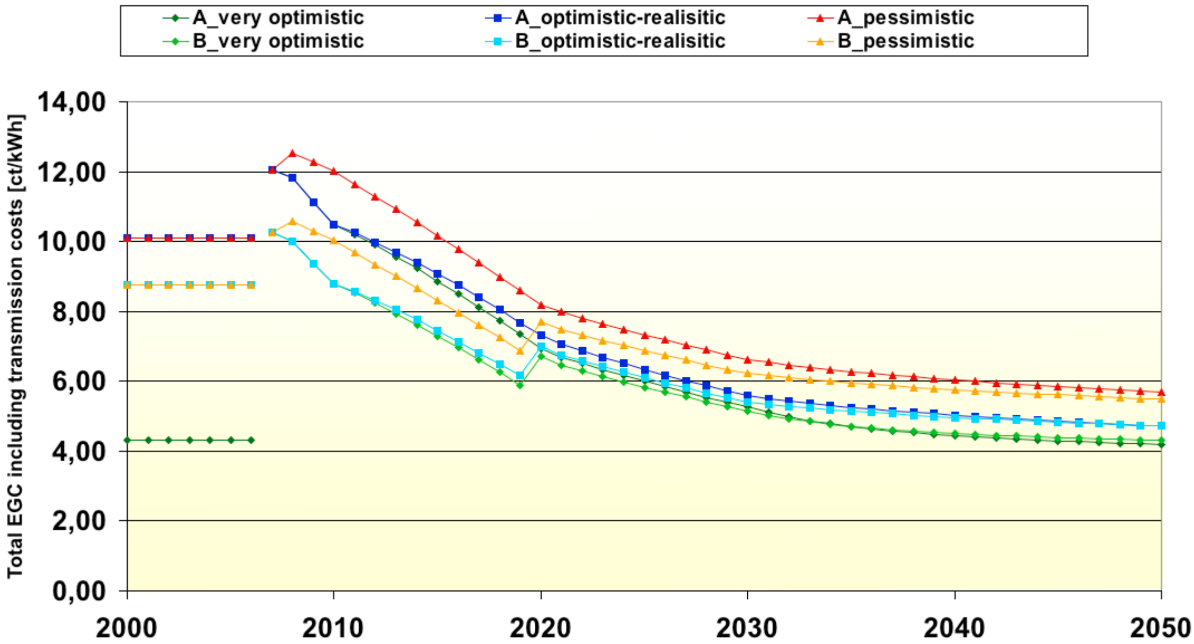

Figure 3.10: Total electricity generation costs (all scenarios), hybrid-operation until 2020, including transmission costs in case B

Solar only-operation, electricity transmission to Europe from 2021 in case B

Finally, Figure 3.11 illustrates the case that no co-firing would be used between 2007 and 2021. That means that all costs are related only to the solar full load hours which range from 3,312 to 6,400 hours in case A and from 4,140 to 8,000 hours in case B. As can be seen from the diagram this would raise the EGC by about 3.5 to 5 ct/kWh in the beginning and by smaller charges thereafter, according to the increasing solar full load hours.

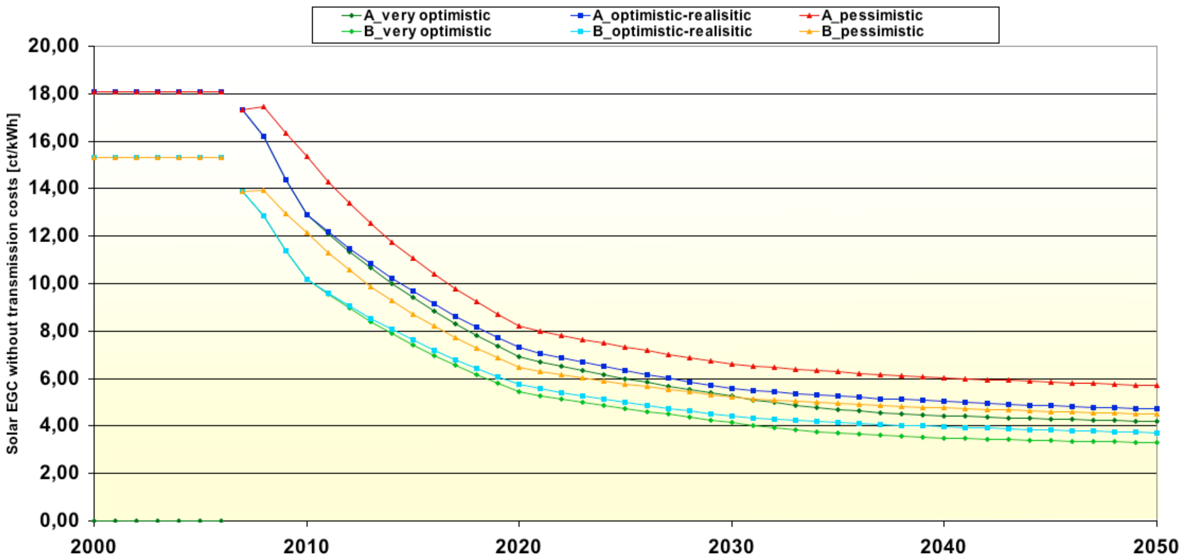

Figure 3.11: Solar electricity generation costs (all scenarios), including transmission costs in case B

Table 3.8 summarises the electricity generation costs calculated for the standard configuration.

Table 3.8: Solar thermal power plant's electricity generation costs for 2007, 2025, and 2050 (including power transmission from 2021)

Parameter		2007		2025 [b)]		2050 [b)]	
		Case A	Case B	Case A	Case B	Case A	Case B
Electricity generation costs							
"Very optimistic"	ct/kWh_{el}	12.05 [a)] 17.32 [b)]	10.26 [a)] 13.86 [b)]	6.00	5.83	4.18	4.30
"Optimistic-realistic"	ct/kWh_{el}	12.05 [a)] 17.32 [b)]	10.26 [a)] 13.86 [b)]	6.34	6.10	4.72	4.72
"Pessimistic"	ct/kWh_{el}	12.05 [a)] 17.32 [b)]	10.26 [a)] 13.86 [b)]	7.33	6.87	5.69	5.49

[a)] Hybrid operation, [b)] Solar-only operation

3.5.1.6 Sensitivity analysis

As recommended by WP 3 - RS Ia a sensitivity analysis on the learning rate is performed using the "optimistic-realistic" scenario both for case A and case B as an example. While the learning rate of the power block is hold fix the learning rate of both the storage system and the collector field is varied between 6 and 16% as Table 3.9 shows.

Table 3.9: Learning rates applied in the sensitivity analysis

Component	Original LR	Referring to	Sensitivity range	Floor costs
Storage system	12%	kWh storage capacity	6 to 16%	---
Collector field	12%	m^2 aperture	6 to 16%	---
Power block, BOP	5%	kW load	---	800 €/kW

LR = learning rate

In the following figures the implications on the *electricity generation costs* are reported for the "optimistic-realistic" scenario (hybrid-operation, not including transmission costs). In 2050, in case A (Figure 3.12) the EGC vary in a range of 3.27 and 8.87 ct/kWh_{el} (4.72 ct/kWh_{el} for the original learning rate of 12%) while in case B (Figure 3.13) they vary between 2.58 and 7.04 ct/kWh_{el} (3.72 ct/kWh_{el} for the original learning rate of 12%).

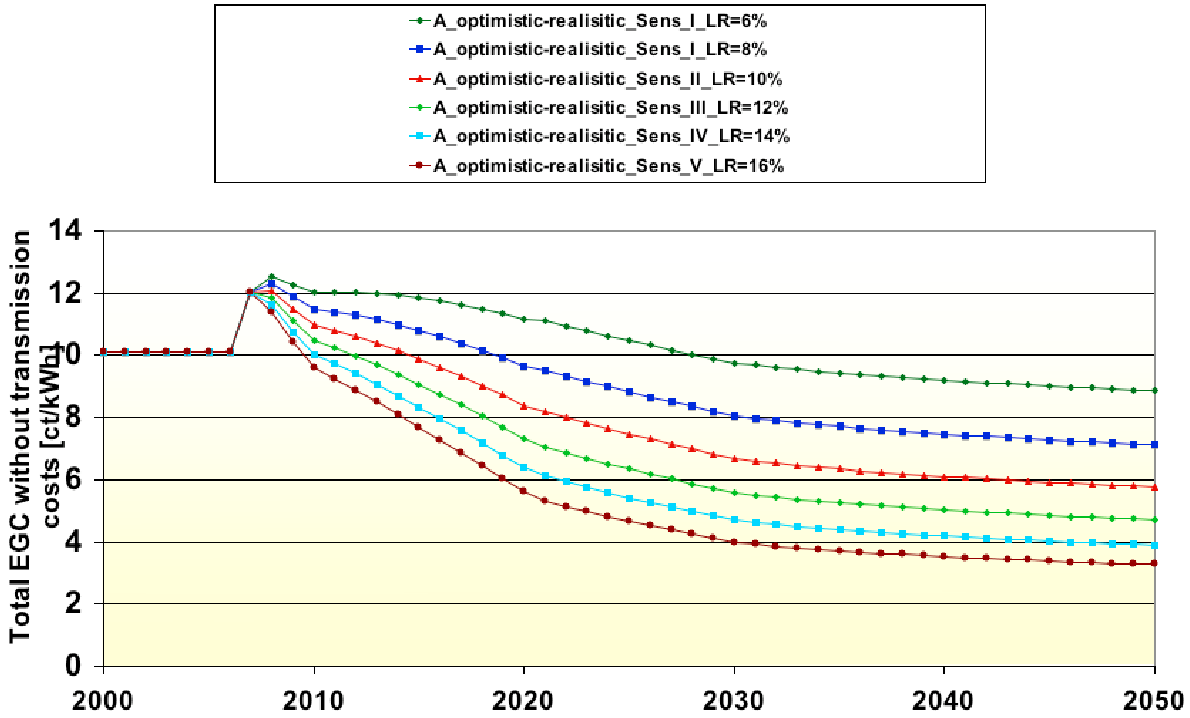

Figure 3.12: Sensitivity analysis (variation of collector and storage system learning rate) - electricity generation costs in case A of the "optimistic-realistic" scenario, no transmission costs

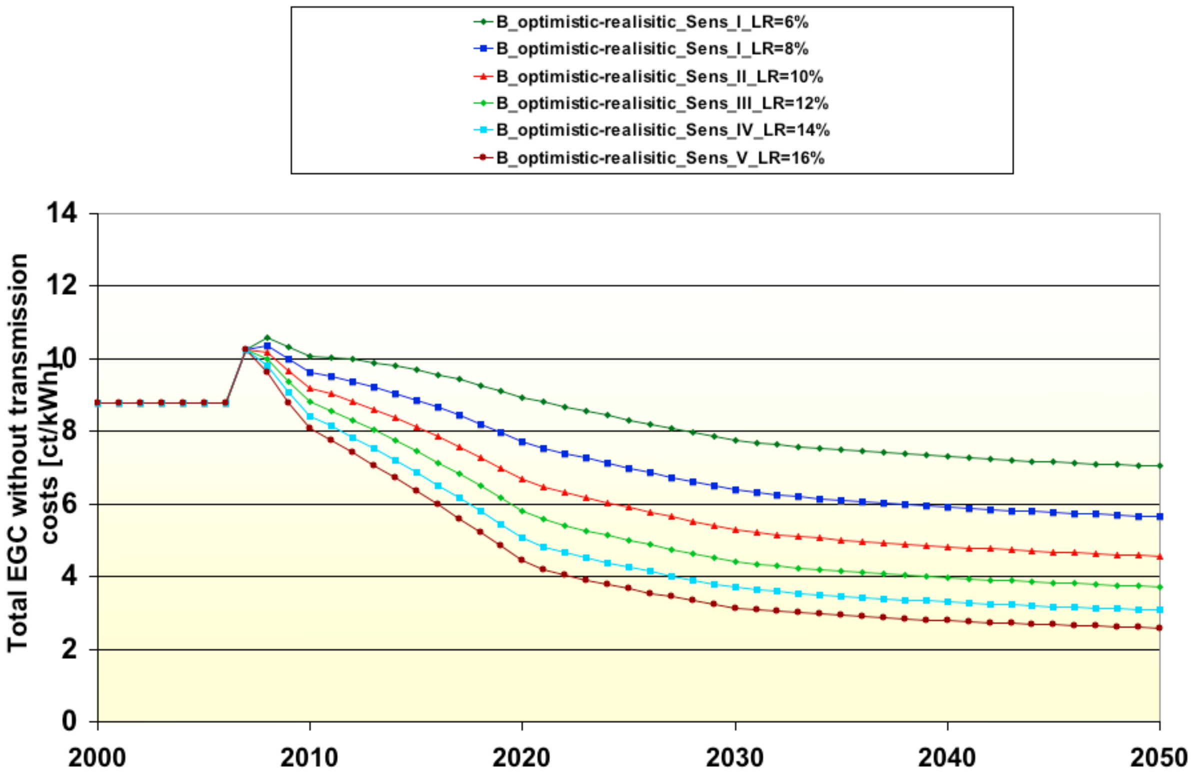

Figure 3.13: Sensitivity analysis (variation of collector and storage system learning rate) - electricity generation costs in case B of the "optimistic-realistic" scenario, no transmission costs

3.5.2 Comparison with the bottom-up approach of ECOSTAR

To verify the data provided above the figures are compared with the ECOSTAR study (see chapter 3.4.1). The study is based on initial EGC of 17.2 ct/kWh for sites similar to case A (Seville, irradiation of 2,000 kWh/m^2,y) and 12.7 ct/kWh for a site with higher irradiation as chosen for case B (desert climate, 2,700 kWh/m^2,y). Updating the last one to a site with a lower irradiation as used in case B (Algeria, 2,500 kWh/m^2,y) yields the figures shown in Table 3.10. In a similar way the figures for 2020 are provided.

Table 3.10: Comparison of solar electricity generation costs between this study and the ECOSTAR study (solar only-operation, transmission costs not included)

		2007		**2020**	
Scenario	**Unit**	**Case A**	**Case B**	**Case A**	**Case B**
ECOSTAR study	ct/kWh_{el}	17.2	13.7	6.7	5.4
NEEDS – "very optimistic"	ct/kWh_{el}	17.32	13.86	6.94	5.47
NEEDS – "realistic-optimistic"	ct/kWh_{el}	17.32	13.86	7.31	5.76
NEEDS – "pessimistic"	ct/kWh_{el}	17.32	13.86	8.21	6.47

This data is compared with our data for the current situation as well as for 2020. As the table illustrates the ECOSTAR cost data for the current situation is nearly the same as our data, whereas in 2020 our best case ("very optimistic" scenario) is similar to the case of ECOSTAR. The ECOSTAR cost data given for 2020 are reached in our "realistic-optimistic" scenario in 2023 and in our "pessimistic" scenario around the year 2029. These results show that realistic learning rates were assumed which represent the cost reduction potential provided by ECOSTAR's investigation of the innovation potential.

4 Specification of future technology configurations

4.1 Overview on the future development

Following the technology development perspectives derived in chapter 3.4 in this paragraph the future configurations are specified and the relevant parameters needed for the calculation of the material flows and for the life cycle inventory are provided. First of all Figure 4.1 shows the general technology options as well as their development between the different time frames and under the three different technology development scenarios at a glance. It should be kept in mind that this selection does not mean that no other technologies will be on the market but under our suggestion these options will be the most relevant ones and dominate the CSP market.

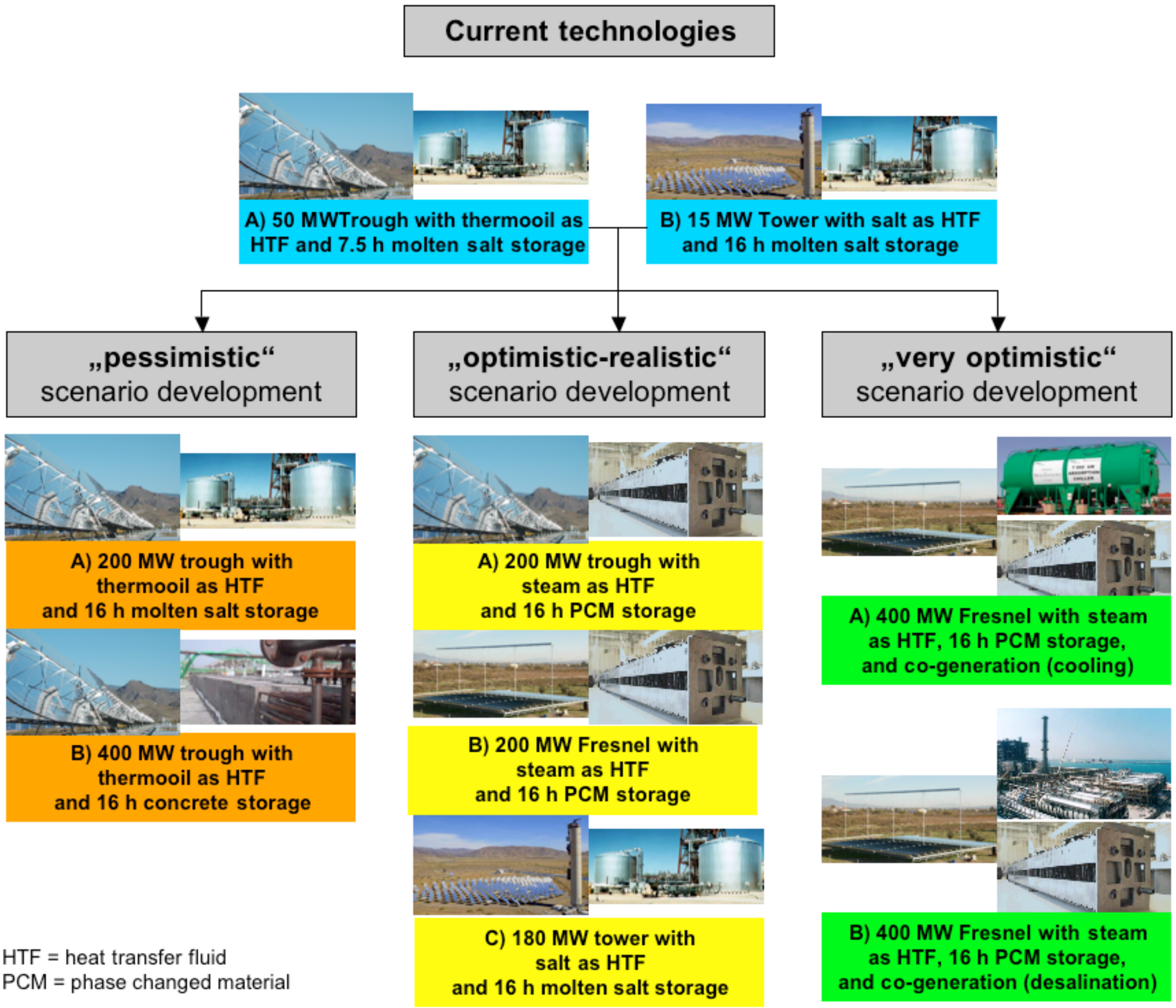

Figure 4.1: Future technology configurations depending on the three technology development scenarios

Depending on the different scenarios we will provide the following technologies:

- **Current situation**: The development pathway starts with the technologies commercially available and currently under construction in Spain (and in some modifications in the U.S.):
  - *Parabolic trough* (50 MW) using thermo oil as heat transfer fluid (HTF) and a 7.5 hours molten salt storage running in a quasi-hybrid mode (a small amount of natural gas is allowed by the Spanish renewable act to maintain the thermal storage temperature during non-generation periods);
  - *Central receiver* (solar tower, 15 MW) currently being built as a demonstration project based on the experiences got from previous solar tower and molten salt receiver experiments. Similar to the trough a small natural gas backup is allowed.
- Considering a **pessimistic scenario development** we use the proven *parabolic trough* operating further on with thermo oil as HFT but benefiting from optimised operating conditions as a higher efficiency or a higher capacity factor. Furthermore, it is differentiated between the molten salt storage currently used and a concrete storage system currently under development. The use of concrete seems promising to avoid the high greenhouse gas potential caused by the salt production.
- Within the **optimistic-realistic scenario development** three different technologies are assumed:
  - The proven *parabolic trough* technology operating with steam instead of thermo oil (direct steam generation, DSG) enables a lot of advantages as higher operating temperatures, higher efficiencies, or lower material consumption. Using steam as HTF demands a new storage material being able to use latent heat in an efficient way which means to change to phase change materials (PCM) for storage reasons.
  - As an enhancement of the parabolic trough the upcoming *Fresnel trough* technology also operating with steam is provided. Its structure allows for a very light design and even if the efficiency is only two third of the parabolic trough a decrease of the specific material consumption is due. Furthermore only one third of the area needed by a parabolic trough is required which helps to reduce the land use in highly populated areas. Considering the lower efficiency, this means a land use reduction by 50%.
  - Finally, the central receiver technology currently being provided in demonstration projects is assumed to compete and to enter the market.
- Considering a **very optimistic scenario development** the *Fresnel trough* technology operating in a combined heat and power (CHP) mode seems the most promising one. The heat is used to provide cooling or desalted water enabling a high utilisation of the energy and therefore the deployed materials.

Since only one value for each scenario and time can be referred to RS Ib the calculated results are weighted within one scenario. The weighting factors for the *present* technologies are taken from (Caldés et al. 2005) where a scenario is used assuming that 80% of the solar thermal capacity planned within the Spanish Renewable Energy Plan 2005–2010 (PER 2005) would be met with parabolic troughs while 20% would be met with central receivers. The weighting factors used within the *future* scenarios are hypothetically assumed. Figure 4.2 shows these weighing factors for each of the scenarios. It should be noted that only the main technologies are considered – further minor important technologies are not included in the figure.

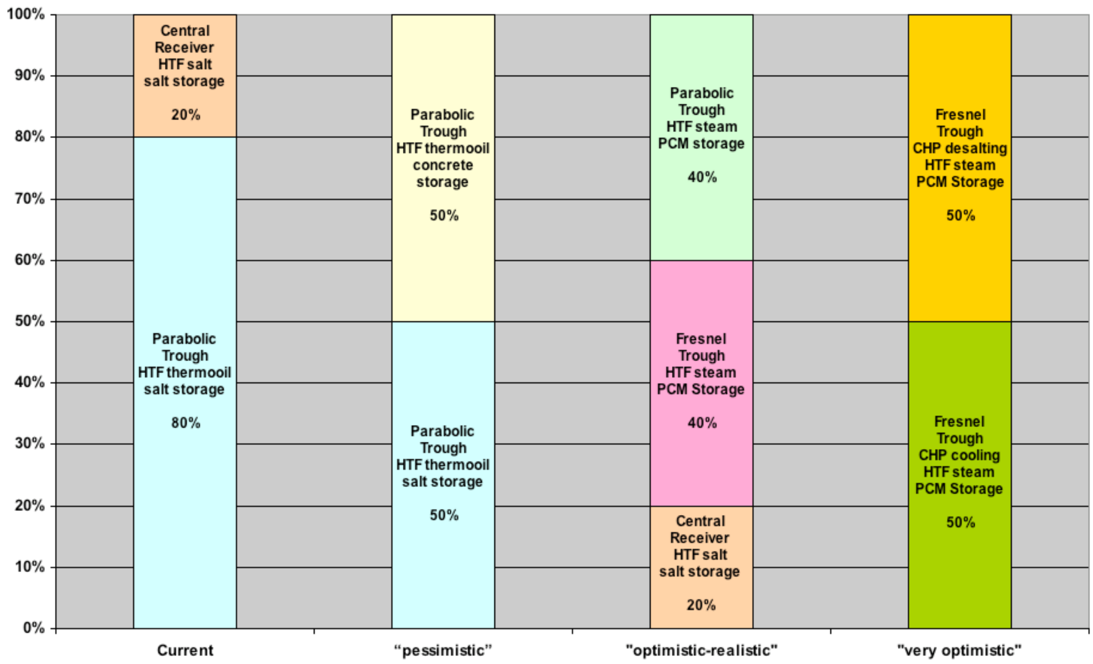

Figure 4.2: Assumed dissemination of main technologies and resulting weighting factors

While the three scenarios provide the frame under which the technology development will take place the described technologies show the change from one CSP technology to another over time. But not only these changes will influence the LCI results – in fact we assume a lot of parameter variations which describe the development within one technology over time. These parameters which are independent from the scenario development are presented in Figure 4.3.

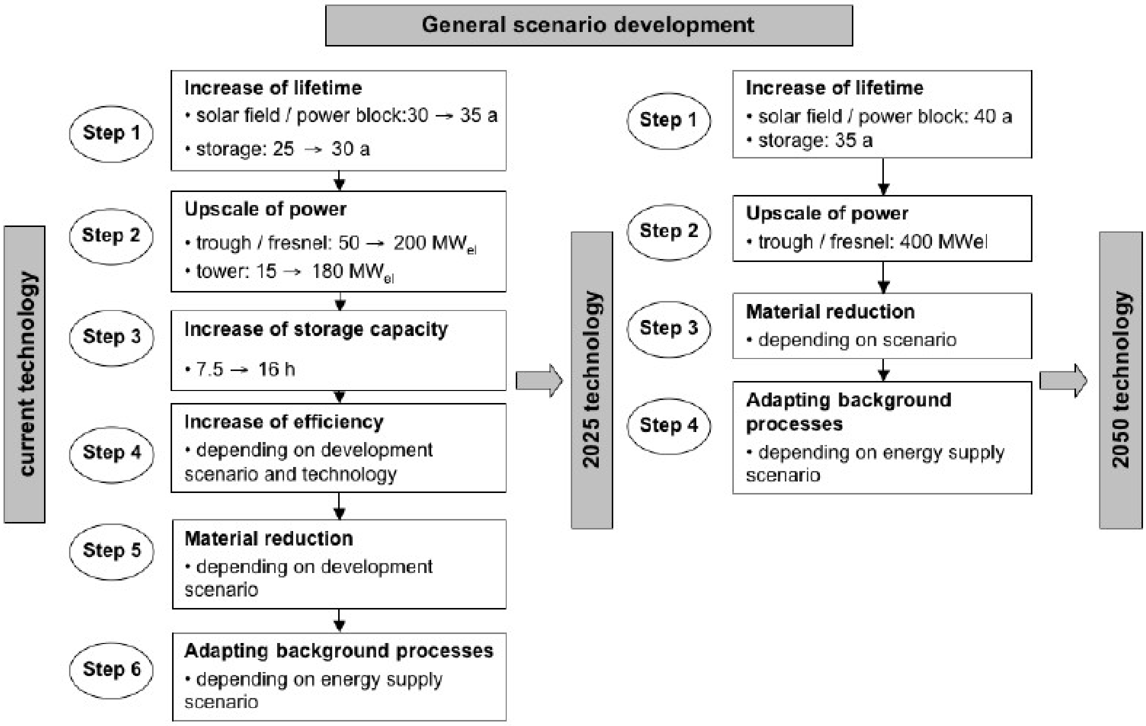

Figure 4.3: Parameter variations within the scenario development which influence the LCI results

– **Development from current technologies to 2025 technologies**

- In a *first step* for all technologies the lifetime of the solar field and the power block is increased from 30 to 35 years while the lifetime of the storage system is increased from 25 to 30 years. The lifetime of the buildings (60 years) is not changed. This seems justified since more experience will enable a longer durability, the power plants in California operating since the eighties have already proved a higher lifetime (for the solar field and the power block), and for commercially available (fossil) power plants lifetimes of 40 years are usual. Accordingly, the specific material consumption and the resulting emissions will decrease.
- In *step 2* the load is up scaled from 50 MW to 200 MW in case of trough technology and from 15 MW to 180 MW for central receivers as expected to be the general target values for CSP plants (S&L 2003, DLR 2004). To model the up scaling process within the LCA different scaling factors are used (Böhnke 1997). A scaling factor smaller than 1 means a direct reduction of the specific emissions.

Table 4.1: Scaling factors for components of solar thermal power plants

Component	Scaling factor
Solar field	1
Storage system	1
Power equipment	0.9
Steam producer	0.8
Steam turbine	0.7
Buildings	0.1
Dismantling	1

- In the *third step* the storage capacity of all power plants is increased to 16 hours enabling a solar-only operation over 24 hours. This requires a much larger solar field together with a larger storage system. Only in case of the solar tower the target capacity has already been foreseen for the current technology. Similar to the investment cost development considered in chapter 3.5 the absolute material's inventory and therefore the emissions will *increase*. In contrary to the cost development this causes increasing specific emissions (per kilowatt hour) especially through the bigger storage facility. The storage system by itself does not increase the produced electricity but it enables to use it as balancing power which means a higher "quality" of the produced electricity.
- In *step 4* the solar-to-electricity efficiencies are increased according to own assumptions and to the literature (DLR 2005, Price et al. 2002). The total efficiency is depending on the efficiencies of the solar field and the steam turbine as well as the parasitics. For parabolic trough systems the maximum (annual) efficiency will be reached at 16.2% because of technology reasons. The change to direct steam generation will enable a higher efficiency assumed to 19% reachable as maximum. The Fresnel trough will reach 11.9% and therefore only two thirds of the parabolic trough, while the central receiver's efficiency will increase to 18%.

In case of combined cycle operation the electrical efficiency of the Fresnel trough will decrease to 7.1% in case of cooling and to 9.2% in case of desalting, because parts of the lower heated steam will be used for cooling and desalting processes, and therefore not be available for electricity generation. The following table shows the efficiencies at a glance (the 2050 values are assumed to be the same as in 2025 because the most important development will take place in the next 20 years).

Table 4.2: Solarthermal main technologies and development of their annual efficiencies

	Present (2007)	**"Pessimistic"**	**"Optimistic-realistic"**	**"Very optimistic"**
Plant	Parabolic trough - HTF thermo oil - MS storage	Parabolic trough - HTF thermo oil - MS storage	Parabolic trough - HTF steam - PCM storage	Fresnel trough CHP, cooling - HTF steam - PCM storage
Electrical efficiency [%]	14.7 (p)	16.2	19	7.1 (therm. eff. = 22.1)
Plant	Tower - HTF Salt - MS storage	Parabolic trough - HTF thermo oil - Con storage	Fresnel trough - HTF steam - PCM storage	Fresnel trough CHP, desalting - HTF steam - PCM storage
Electrical efficiency [%]	15.5 (d)	16.2	11.9	9.2 (therm. eff. = 22.1)
Plant			Tower - HTF Salt - MS storage	
Electrical efficiency [%]			18	
Storage materials: MS = molten salt, Con = concrete, PCM = phase change material CHP = combined heat and power; p = proven, d = to be demonstrated				

- In the *fifth step* the material consumption for the production of the power plants is reduced according to the innovation potential provided by the ECOSTAR study (Pitz-Paal et al. 2005). To find the relevant materials where a reduction could be possible a new approach is developed. It combines the learning curve approach actual used to calculate *cost* reduction potentials with the *mass* of the most cost intensive components used within a solar thermal power plant and derives a "material learning rate" LR_m of 3%. This learning rate is applied to the most cost intensive materials and will also reduce the resulting emissions (see chapter 4.2 for a detailed description).

  Finally, in *step 6,* the background processes (see NEEDS RS Ia WP15-report) which were adapted to the individual energy scenarios for 2025 are used for the most relevant materials to show the general influence of a material and energy reduced economy. The basic calculations are done using the 440 ppm-mix energy scenario.

– **Development from 2025 to 2050 technologies**

For the second period only four of the formerly described six steps are applied:

- In a *first step* for all technologies the lifetime of the solar field and the power block is further increased to 40 years while the lifetime of the storage system is increased to 35 years.
- In *step 2* the load of the troughs is up scaled to 400 MW. For central receivers no upscale is assumed because the load of 180 MW has calculated to be the optimal design. The same scaling factors as for the first period are used.
- In the *third step* the material consumption for the production of the power plants is further reduced according to the approach provided above (see also chapter 4.2 for a detailed description).
- Finally, in *step 4,* the background processes adapted to the energy scenarios developed for 2050 are used for the most relevant materials (see above).

4.2 Approach of a "material learning curve"

In a new approach it is tried to combine the learning curve approach actual used to calculate *cost* reduction potentials with the *mass* of the most cost intensive components used within a solar thermal power plant to derive a "material learning rate".

The starting point is the observation that the ECOSTAR study does not work with learning rates but reaches nearly the same cost reduction potential as assumed in the NEEDS RS Ia WP3-report on experience curves (Neij 2006) where a learning rate (LR) of 12% for solar thermal power plants was derived. On the other hand the ECOSTAR authors state that 50% of the possible cost reduction is caused by technical innovations while the other half is provided by up-scaling and volume effects. Combining both approaches means, that 50% of the proposed learning rate refers to cost reduction by technical innovation, which defines an "innovation learning rate" LR_i of 6% (see Figure 4.4).

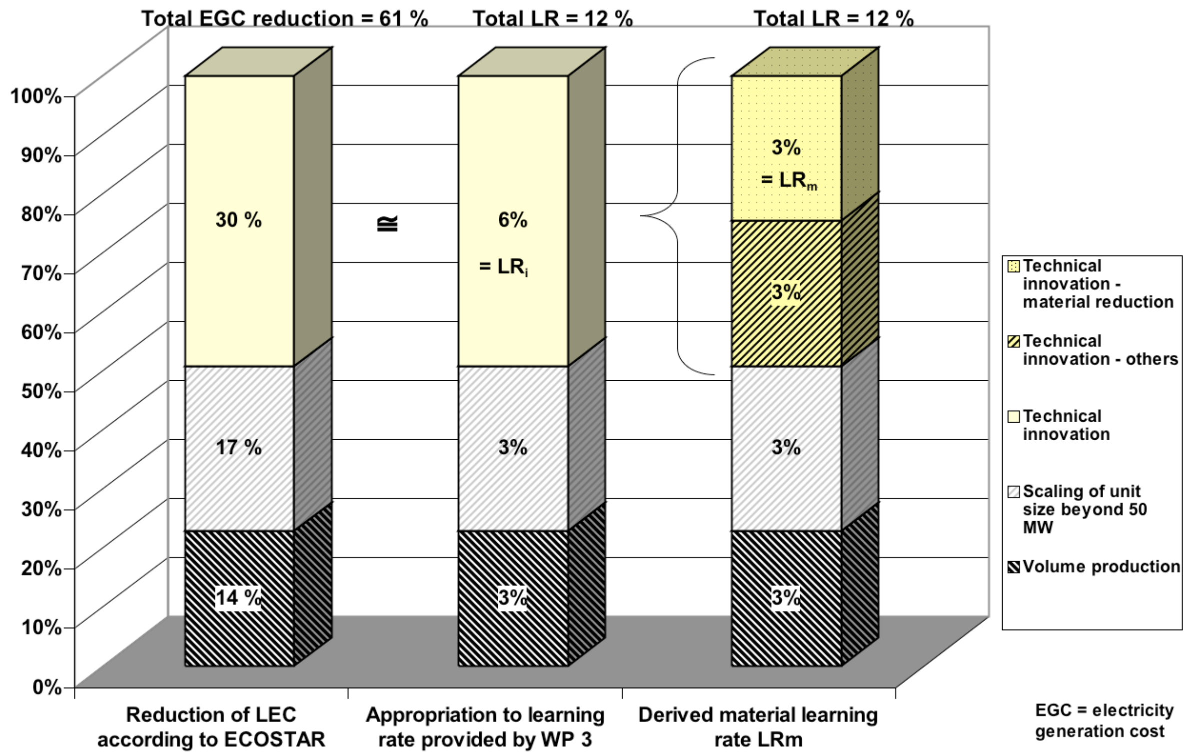

Figure 4.4: Combining the ECOSTAR approach with the learning curve approach to find a "material learning curve"

However, the cost reduction by technical innovation is not only caused by material reduction (e.g. a slighter concentrator structure and assembly), but also by increased HTF temperatures, advanced mirrors, or innovative storage concepts as shown in Table 3.5. To consider this the formerly derived learning rate LR_i is reduced (arbitrarily) by 50% to a "material learning rate" LR_m of 3%. Using the installed capacities calculated in the three technology development scenarios for solar thermal power plants (see paragraph 3.3.2) similar to a cost learning curve a "material learning curve" is derived. This learning curve is applied to the most cost intensive components which are the solar field and the storage system and within these components to the most cost intensive materials which are the consumption of steel (reinforcing, carbon, and stainless steel), aluminium, and flat glass (see chapter 5.1.2 for a detailed derivation).

Figure 4.5 demonstrates the material reduction development starting at the present technologies (=100%) and depending on the three technology development scenarios. Two distinctions should to be noted:

- For the Fresnel technology LR_m is further reduced to 1.5% in case of its solar field because compared to the trough technology Fresnel has already reached a material reduction of nearly 80% (Fresnel is used only for the "optimistic-realistic" and the "very optimistic scenario").
- For the development period between 2025 and 2050 LR_m is further reduced by 50% for all technologies to model a "floor mass" according to "floor costs" (see the dotted lines in Figure 4.5). This step is justified because the highest material reduction takes place until 2025 and for technical reasons the material mass can not be reduced under a certain level.

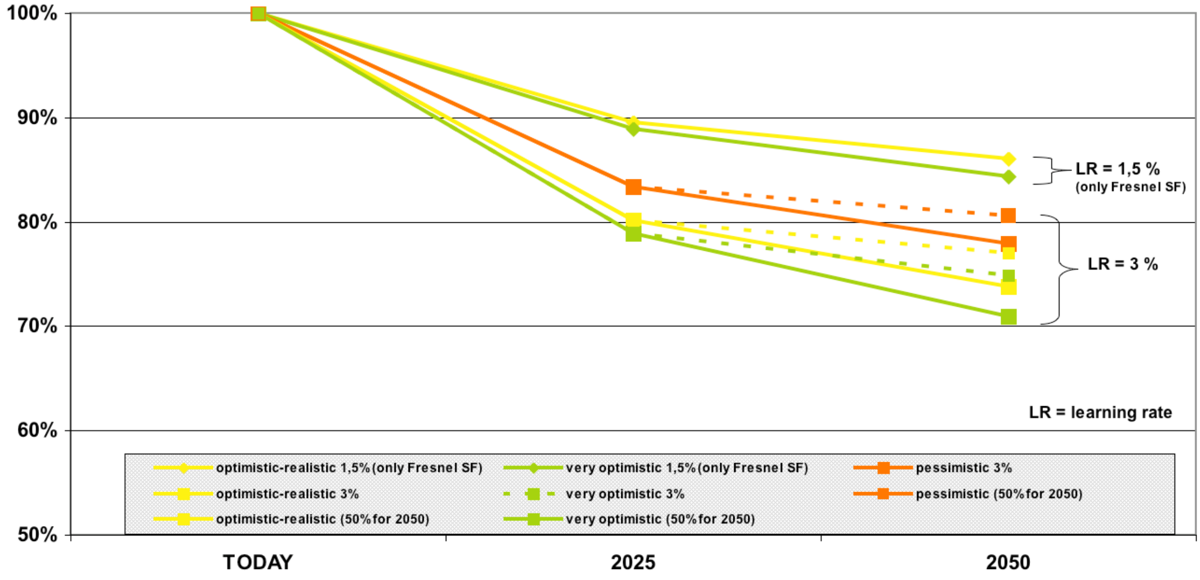

Figure 4.5: Comparison of different "material learning curves" (learning rates of 3% and 1.5%)

The results show that our assumptions lead to a material reduction of 19% in case of the "pessimistic", 23% in case of the "optimistic-realistic", and 25% in case of the "very optimistic" scenario. Considering the reduced learning rate for the Fresnel solar field reductions of 14% ("optimistic-realistic") and 16% ("very optimistic") are reachable in these cases. The reductions concerning the "optimistic-realistic" and the "very optimistic" scenarios do not differ very much because of a quite similar installed capacity in the beginning of the development (see paragraph 3.3.2).

The two other contributions to the cost reduction potential derived by ECOSTAR are the up scaling of unit size beyond 50 MW and volume production. While the *up scaling process* is considered in scenario development step 2 for *volume production* no adequate transition into inventory and therefore LCA results have been found. Volume production is assumed to have an indirect influence on LCA as the component production and therefore the up-stream processes might proceed more efficiently and less material and energy intensively than small scale production processes.

4.3 Material flow data and sources

In this chapter the sources for the future technologies which were modelled within the LCA database are described. Finally, an overview on all key parameters used for the different technologies is given. All power plants are designed for case A, that means a location with a solar irradiation of 2,000 kWh/(m^2,y) and an operation with about 6,400 full load hours. No hybrid version is considered because at least in the summer time a solar-only operation is assumed. For the remaining hours it is assumed that the missing power is balanced by future natural gas fired power plants which are modelled in another working package.

- **Parabolic trough operating with thermo oil and molten salt storage**: This trough which is used within the "pessimistic" scenario has been taken over by the present "Andasol 1" plant and was updated by applying the steps described in the former chapter. The solar field exceeds the present one by a multiple because of the additional storage capacity additionally required. The new aperture was modelled using a DLR solar trough power plants' design software and its inventory was scaled up linearly.

- **Parabolic trough operating with thermo oil and advanced concrete storage**: This trough which is also used within the "pessimistic" scenario differs from the former one only by the storage system. The inventory of the concrete storage system is taken from (Züblin et al. 2007) where DLR together with the Züblin company developed and tested a pre-commercial 6 hours 50 MW_{el} advanced concrete storage (WANDA project, Laing et al. 2008). The inventory was linearly scaled up to the storage capacity required within the "pessimistic" scenario. It is justified to exchange the storage systems because this concrete storage is developed for the same parabolic trough ("Andasol 1") used in the case above.

- **Parabolic trough operating with direct steam and phase change material (PCM) storage**: For the implementation of this type of trough which is used within the "optimistic-realistic" scenario data of a pre-commercial 5 MW power plant was used (INDITEP project, Iberinco et al. 2005, Ciemat 2007). The aim of this project is to develop advanced components to increase steam temperature from the current 400 °C to 500 °C to get a higher electrical efficiency and to prepare an engineering design for this 5 MW project. The aperture needed for the "optimistic-realistic" scenario was modelled using a DLR solar trough power plants' design software and the inventory was scaled up linearly.

  Since for direct steam technology a latent heat storage medium is needed for evaporation and is useful due to its high cost reduction potential DLR provided data for a 6 hours 50 MW_{el} storage system using phase change materials (PCM) based on PCM developments in laboratory scale. This storage system operates in three steps (Michels and Pitz-Paal 2007): During the *preheating* step a conventional concrete storage is used which is heated up (sensible heat storage). This step is followed by the *evaporation* phase served by a (cascaded) latent heat storage. The increasing heat causes (several) phase changes (e.g. from solid to liquid) but does not increase the storage temperature by itself. In the last step, the *superheating* phase, a concrete storage is used again. For the applied storage system $NaNO_3$ is used, but in general different mixtures of $NaNO_3$, KNO_3 and KCL are possible. To increase the thermal conductivity aluminium plates are placed into the salt.

- **Fresnel trough operating with direct steam and phase change material (PCM) storage**: This trough which is used within the "optimistic-realistic" and the "very optimistic" scenarios differs from the former one only by the solar field. Instead of parabolic mirrors Fresnel mirrors are used. Implemented was the data for one m^2 solar field provided by the Novatec company who developed a Fresnel solar field with a very light design. It reduces the material inventory by 80% compared with the design of a parabolic trough of type Andasol (Novatec 2007). The inventory was linearly scaled up to the aperture required within the "optimistic-realistic" and the "very optimistic" scenario considering that at the same time a bigger solar field is necessary due to the lower solar-to-heat efficiency.

- **Central receiver operating with molten salt and molten salt storage**: This tower which is also used within the "optimistic-realistic" scenario has been taken over by the present "SolarTres" plant and was updated by adapting the parameters described in the former paragraph. No new technology development was assumed.

– **Fresnel trough combined heat and power (CHP) operating with direct steam and phase change material (PCM) storage:** This trough which is used within the "very optimistic" scenario differs from the Fresnel trough used in the "optimistic-realistic" scenario only by the combined use of electricity and heat used for absorption cooling or multi-effect desalination.

  To get an exact assessment of the produced electricity an allocation of the emissions between electricity and heat is necessary. For this combined process the allocation is done based on exergyss content. This means that heat (and therefore the cooling or desalting using this heat) production is only assigned that part of the emissions that corresponds to the exergy content of the heat production in relation to total net exergy. The remaining emissions are allocated to electricity production (see Eclipse 2004 for a detailed description of this method and the formula to calculate the allocation factors). For case A (location in Spain) an ambient temperature of 20 °C is assumed which leads to the following allocation factors:

Table 4.3: Allocation factors for Fresnel combined cycle (electricity production and cooling/desalting)

Power plant	Efficiency				Temperature		Allocation factor		Emiss. factor [2]
	Power block		Total [1]		Out	Ambient			
	el	th	el	th			el	th	el
	%	%	%	%	°C	°C	%	%	%
Fresnel trough (only electricity production)	35	65	11.9	---					100
Fresnel trough CHP with cooling	21	65	7.1	22.1	110	20	53	47	88
Fresnel trough CHP with desalting	27	65	9.2	22.1	75	20	73	27	95

[1] assuming a solar-to-heat efficiency of 34%

[2] the emissions factor results from higher emissions caused by a worse electrical efficiency and lower emissions caused by the allocation.

The last column shows the impacts of combined cycle to the electricity related emissions: The worse electrical efficiency compared to Fresnel without CHP leads to higher emissions per kWh, but the allocation between electricity and heat cause lower specific emissions than without combined cycle. The combination with absorption cooling decreases the electrical emissions by net 12% while the use of multi-effect desalination decreases them by net 5%.

The following tables give a detailed overview on all key parameters used for the different technologies described above.

Table 4.4: Solarthermal main technologies in case of a "pessimistic" scenario development

				"pessimistic" scenario development			
	Unit	**Present (2007)**		**Year 2025**		**Year 2050**	
Cumulated installed capacity	GW_{el}	0.4		26		120	
Technology		Parabolic Trough "Andasol 1"	Central Receiver "SolarTres"	Parabolic Trough		Parabolic Trough	
Scenario mnemo		*Today_TRH*	*Today_TOH*	*2025_PS_TR*	*2025_PS_TRC*	*2050_PS_TR*	*2050_PS_TRC*
Load	MW_{el}	46	15	200 *)		400 *)	
Operation mode		Hybrid (15%)	Hybrid (15%)	Solar-only *)		Solar-only *)	
HTF		Thermo oil	Molten salt	Thermo oil		Thermo oil	
Storage system		Molten salt	Molten salt	Molten salt	Concrete	Molten salt	Concrete
Storage period	h	7.5	16	16 *)		16 *)	
Full load hours	h	3,820	6,230	6.400 *)		6.400 *)	
Aperture	m^2	510,120	264,825	3,840,000		7,680,000	
Annual efficiency SF	%	43.2	45.6	56 (48)		56 (48)	
Annual efficiency PB_{el}	%	34	34	29 (34)		29 (34)	
Annual efficiency total $_{el}$	%	14.7	15.5	16.2		16.2	
Lifetime SF/B/PB/ST	a	30/60/30/25	30/60/30/25	35/60/35/30 *)		40/60/40/35 *)	
Land use factor	-	2.8	5.66	2.8		2.8	

*) scenario independent

Changes in the parameter development are marked bold.

HTF = heat transfer fluid

SF = solar field / PB = power block / B = building / ST = storage system

Land use = Land use factor * Aperture

Table 4.5: Solarthermal main technologies in case of an "optimistic-realistic" scenario development

				"optimistic-realistic" scenario development					
	Unit	**Present (2007)**		**Year 2025**			**Year 2050**		
Cumulated in-stalled capacity	GW_{el}	0.4		63			405		
Technology		Parabolic Trough "Andasol 1"	Central Receiver "SolarTres"	Parabolic Trough "Inditep"	Fresnel Trough	Central Receiver	Parabolic Trough	Fresnel Trough	Central Receiver
Scen. mnemo		*Today_TRH*	*Today_TOH*	*2025_RO_TR*	*2025_RO_FR*	*2025_RO_TO*	*2050_RO_TR*	*2050_RO_FR*	*2050_RO_TO*
Load	MW_{el}	46	15	200 *)		180	400 *)		180
Operation mode		Hybrid (15%)	Hybrid (15%)	Solar-only *)			Solar-only *)		
HTF		Thermo oil	Molten salt	Direct steam		Molten salt	Direct steam		Molten salt
Storage system		Molten salt	Molten salt	PCM		Molten salt	PCM		Molten salt
Storage period	h	7.5	16	16 *)			16 *)		
Full load hours	h	3,820	6,230	6.400 *)			6.400 *)		
Aperture	m^2	510,120	264,825	3,600,000	5,700,00	3,205,440	7,200,00	11,400,000	3,205,440
Annual eff. SF	%	43.2	45.6	56	34	46.2	56	34	46.2
Annual eff. PB_{el}	%	34	34	32	35	34	32	35	34
Annual eff. tot. $_{el}$	%	14.7	15.5	19	11.9	18	19	11.9	18
Lifetime SF/B/PB/ST	a	30/60/30/25	30/60/30/25	35/60/35/30 *)			40/60/40/35 *)		
Land use factor	-	2.8	5.66	1.2		5.66	1.2		3.6

*) scenario independent

Changes in the parameter development are marked bold.

HTF = heat transfer fluid / PCM = phase change material

SF = solar field / PB = power block / B = building / ST = storage system

Land use = Land use factor * Aperture

Table 4.6: Solarthermal main technologies in case of a "very optimistic" scenario development

				"very optimistic" scenario development			
	Unit	**Present (2007)**		**Year 2025**		**Year 2050**	
Cumulated installed cap.	GW_{el}	0.4		89		1,000	
Technology		Parabolic Trough "Andasol 1"	Central Receiver "SolarTres"	Fresnel Trough Combined Heat and Power		Fresnel Trough Combined Heat and Power	
Co-Product				Cooling	Desalting	Cooling	Desalting
Scenario mnemo		*Today_TRH*	*Today_TOH*	*2025_VO_FRC*	*2025_VO_FRD*	*2050_VO_FRC*	*2050_VO_FRD*
Load	MW_{el}	46	15	200 *)		400 *)	
Operation mode		Hybrid (15%)		Solar-only *)		Solar-only *)	
HTF		Thermo oil	Molten salt	Direct steam		Direct steam	
Storage system		Molten salt		PCM		PCM	
Storage period	h	7.5	16	16 *)		16 *)	
Full load hours	h	3,820	6,230	6.400 *)		6.400 *)	
Aperture	m^2	510,120	264,825	5,700,00		11,400,000	
Annual efficiency SF	%	43.2	45.6	34		34	
Annual efficiency PB $_{el}$ / $_{th}$	%	34		21 / 65	27 / 65	21 / 65	27 / 65
Annual efficiency total $_{el}$ / $_{th}$	%	14.7	15.5	7.1 / 22.1	9.2 / 22.1	7.1 / 22.1	9.2 / 22.1
Allocation $_{el : th}$	%			53 : 47	73 : 27	53 : 47	73 : 27
Lifetime SF/B/PB/ST	a	30/60/30/25		35/60/35/30 *)		40/60/40/35 *)	
Land use factor	-	2.8	5.66	1.2		1.2	

*) scenario independent
Changes in the parameter development are marked bold.
HTF = heat transfer fluid
PCM = phase change material
SF = solar field / PB = power block / B = building / ST = storage system
Land use = Land use factor * Aperture

5 LCI results for current and future technology configurations

5.1 Inventory analysis

5.1.1 Share of components on the total inventory

Each of the solar thermal power plant configurations modelled in this work package have been developed from three basic types: the parabolic trough with thermo oil as heat transfer fluid (HTF) ("Andasol 1"), the parabolic trough with direct steam as HTF ("Inditep"), and the central receiver with HTF molten salt ("SolarTres"). Figure 5.1 shows these basic types and their derivations. Further configurations are provided by changing single parameters. All plants together yield the list of modelled plants as presented in the overview in Figure 4.1 and in Table 4.4 to Table 4.6.

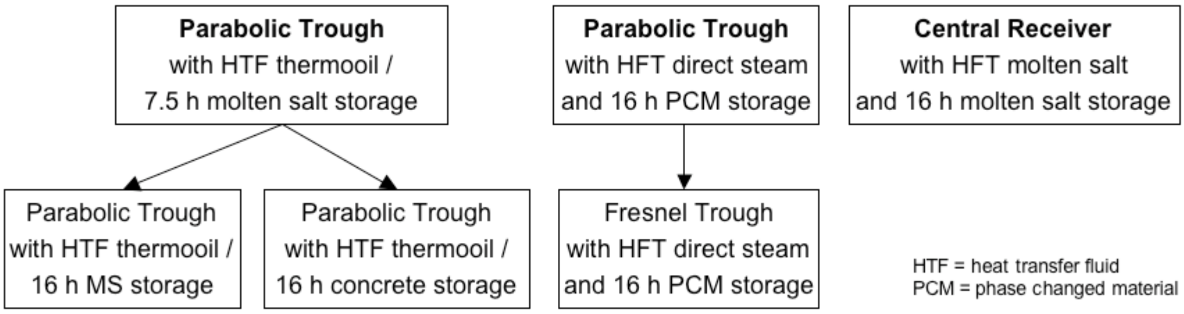

Figure 5.1: The three basic types of solar thermal power plants and their extensions

A comparison of the power plants' inventories (material and energy flows) is possible to only a limited extent since the same power plant with different storage capacities in fact describe different power plants. The reason is that each storage capacity enhancement increases the required solar field. Therefore both the designed storage capacity and the load have to be regarded in a comparison. That's why in the following analyses the inventory is scaled to 1 MWh electrical output.

The total inventory for the construction and operation of the three basic types of power plants is presented in Table 7.3 in the annex while in this paragraph only the most relevant materials are analysed.

First of all, the share in the total mass of the power plants' that their components can account for is evaluated (Figure 5.2). As shown in relative figures the following main results can be seen:

– Regarding the present technologies (bars 1 and 2) the solar field is dominating the inventory balance by 58% and 46%, respectively. It is followed by the molten salt storage with 29% and 24%, respectively.

– In case of the central receiver (bar 2) the buildings' share increases which can only be explained with the guess that bigger buildings were erected than needed for this first relatively small power plant.

– For those of the future technologies (bars 3-5) which switch from molten salt to concrete or to PCM storage media a complete different picture results. The storage materials are dominating the balance by 63% in case of concrete and by 49 and 71% in case of PCM. This is partly caused because the mass of the solar field is decreasing but primarily caused through the enormous masses of concrete used both in the concrete and in the PCM storage as the next figure shows.

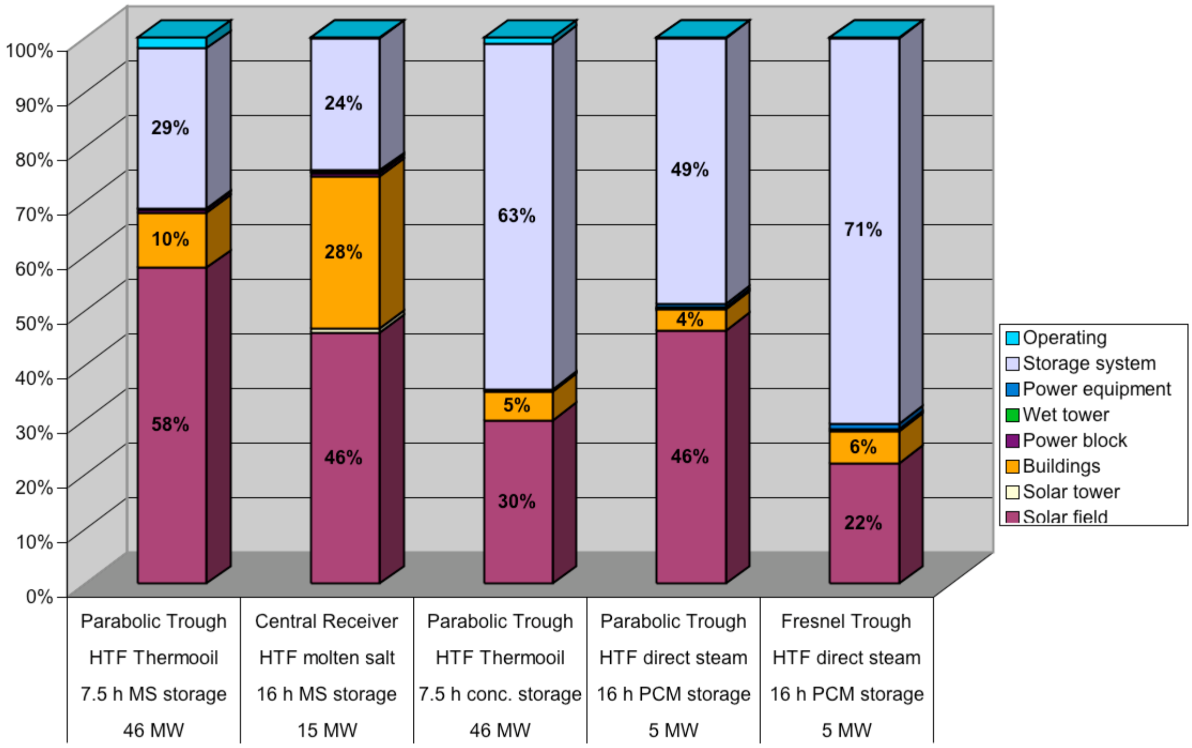

Figure 5.2: Share in the mass of the basic solar thermal power plants the components account for

To make the absolute values comparable in Figure 5.3 the inventory of each power plant is scaled to MWh electrical output. The following conclusions can be drawn:

– For the present technologies (bars 1 and 2) the central receiver has a better inventory balance than the parabolic trough (apart from the increased building's share which should not be overestimated). The reason is the higher operating temperature: Due to the higher electrical efficiency of the tower reached by a higher operating temperature (565 °C instead of 386 °C) a smaller solar field is needed to produce the same electricity than the trough[3]. Furthermore the higher temperatures also increase the temperature difference in the storage media (265 °C instead of 100 °C). Since the storage systems salt inventory is reciprocally proportional to the temperature difference, a smaller storage system is needed.

3 It should be noted that the assumed annual efficiency of 15.5% has to be demonstrated and is not proven. It seems very high compared with the efficiency of 8% proved for the last solar tower being built in Barstow, California, operating with a much higher solar irradiance of 2,500 kWh/m^2,a ("SolarTwo" project).

– The same parabolic trough as the current system but operating with a concrete storage instead of a molten salt storage (bar 3) doubles its mass balance by the enormous inventory of concrete necessary for the storage system.

– For the future direct steam based systems (bars 4 and 5) different results occur:

  - In case of the DSG parabolic trough the *solar field* is a little bit less material intensive because of a higher electrical efficiency. Regarding the Fresnel trough the efficiency decreases by about one third which would require a 1.5 times bigger solar field. On the other hand the chosen Fresnel type (Novatec) implies a material reduction by more than 80% obtained by a very light design and the absence of the heavy concrete trough anchorages. Both effects together reduce the material inventory to about 30% of the original value.
  - The PCM *storage system* consists of 43 vol.% concrete and 57 vol.% molten salt combined with aluminium plates placed into the salt. This increases its inventory compared with a molten salt storage used in the current systems but decreases it compared with a storage totally consisting of concrete.

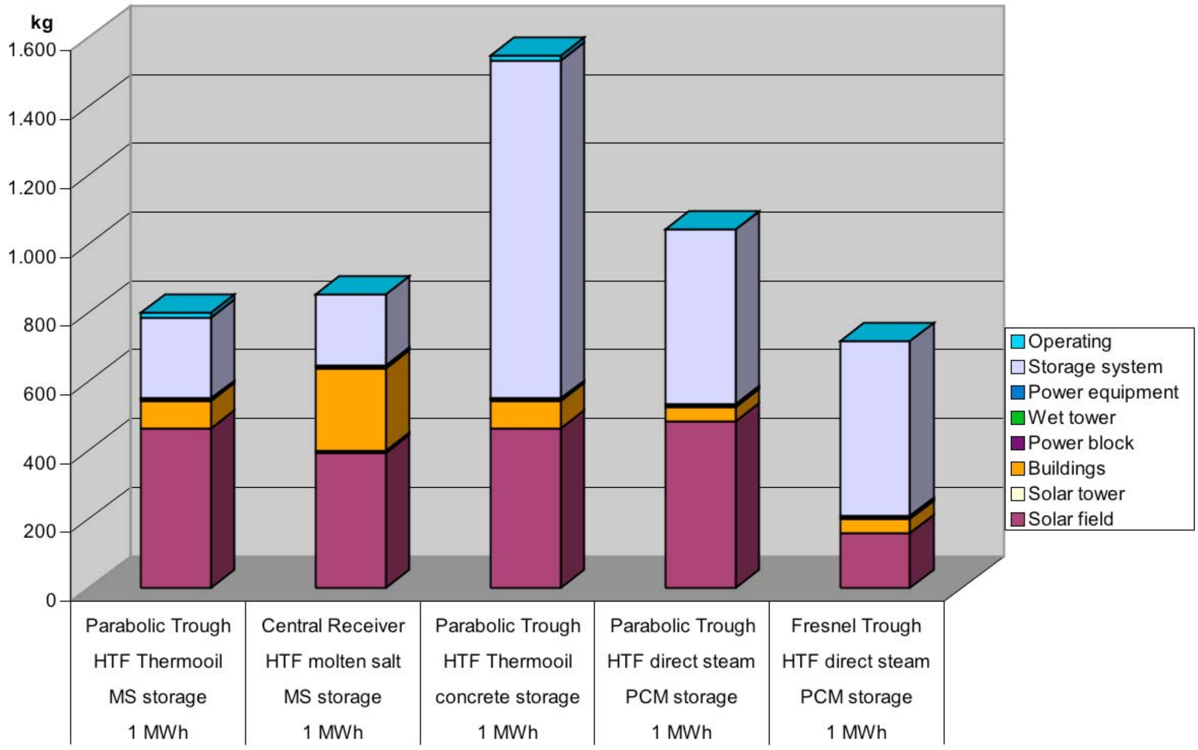

Figure 5.3: Comparison of components of the basic solar thermal power plants, scaled to 1 MW_{el} and 1 storage hour

5.1.2 Main materials used for the power plants' production

To be able to assess the impacts of the different mass balances it is necessary to know of which (main) materials the components are consisting of. For example, an increased use of concrete would have other impacts than the increase of the same amount of stainless steel. Therefore the next paragraph gives an overview on the main materials used for the solar field and the storage which are the most relevant components of the considered power plants. Again, the materials are scaled to 1 MWh electrical output.

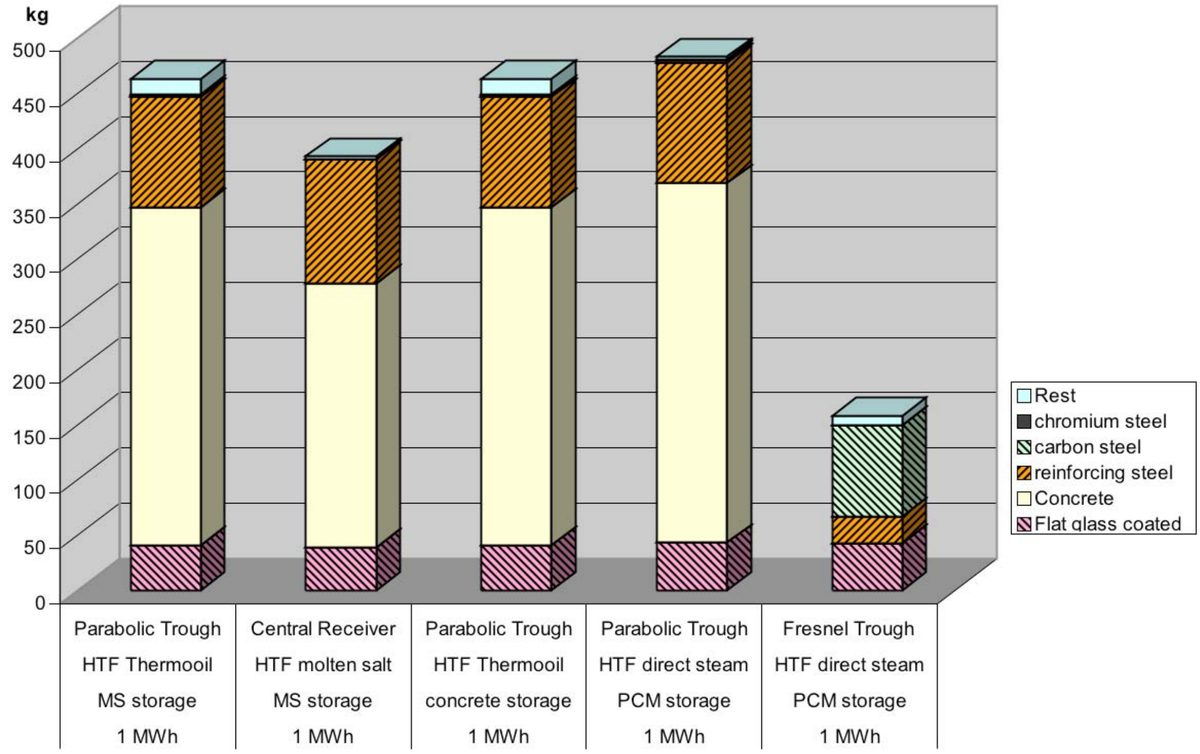

Figure 5.4: Main materials required for the solar thermal power plants' solar field, scaled to 1 MW_{el} and 1 storage hour (black stripes show the cost intensive materials)

- Figure 5.4 presents the main materials used for the different *solar fields*. In case of parabolic troughs and central receiver (bars 1 to 4) nearly two thirds of the solar field inventory consists of concrete mainly used for the trough anchorages. The Fresnel trough (bar 5) does not need these anchorages (instead metallic bars are used). The second relevant material is steel with a share of around 25% in case of parabolic trough and central receiver and of 70% for the Fresnel trough. The third important material is flat glass with a share of around 10% and 27%, respectively.

  Important for the cost calculation and the derivation of the "material learning rate" explained above are the cost intensive materials under these materials. In case of the solar field these are only steel and flat glass marked with black stripes in Figure 5.4. Only these materials are reduced along the different scenarios and time frames.

- Figure 5.5 presents the main materials used for the different *storage systems*. These are molten salt in case of the molten salt storage but also for the PCM storage (80% and 26% of the whole inventory, respectively) and concrete in case of the concrete storage but also relevant for the PCM storage (95% and 63% of the whole inventory, respectively). All storage systems need steel (between 3 and 10%) and the PCM system also uses a small amount of aluminium (4%).

  Again, the cost intensive materials are marked with stripes which are only steel and aluminium although they do not play a role regarding the mass balance.

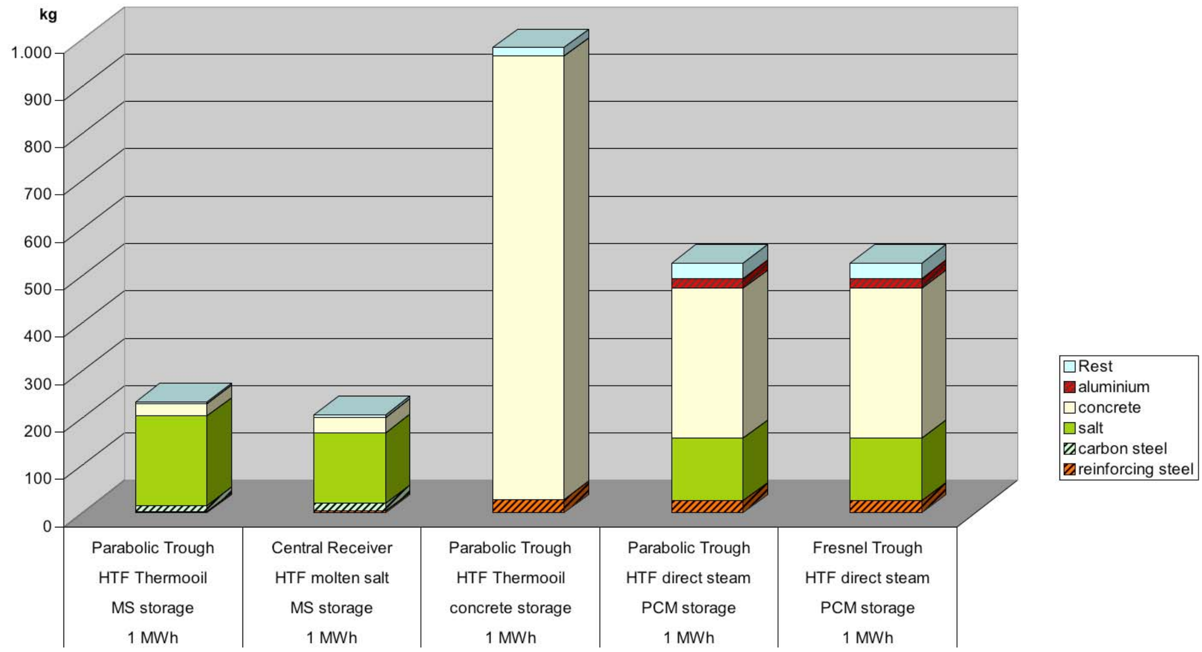

Figure 5.5: Main materials required for the solar thermal power plants' storage system, scaled to 1 MW_{el} and 1 storage hour (black stripes show the cost intensive materials)

In Table 5.1 and Table 5.2 the cost intensive materials relevant for the "material learning curve" approach are summarised and their development along the scenarios is shown. As presented in Figure 4.5 in general a "material learning rate" of 3% is used. Only in case of the Fresnel solar field a differing value of 1.5% is applied. The finally reached reduction rates (10% to 21% in 2025 and 11% to 27% in 2050) harmonize with those shown in Figure 4.5.

Table 5.1: Solar field materials chosen for applying the "material learning rate"

Solar field main materials	per MW el and storage hour	Present (2007)	2025						2050					
			"pessimistic scenario"		"optimistic-realistic scenario"		"very optimistic scenario"		"pessimistic scenario"		"optimistic-realistic scenario"		"very optimistic scenario"	
		kg	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Flat glas	Tower, salt	9.220			7.384	80%					6.805	74%		
	Trough, Salt	25.620	21.353	83%					19.953	78%				
	Trough, concrete	17.823	14.854	83%					13.881	78%				
	Trough, PCM	5.736			4.595	80%			4.235	74%				
	Fresnel, PCM	5.693			5.099	90%	5.060	89%	4.896	86%			4.801	84%
Reinforced steel	Tower, salt	26.679			21.367						19.693	74%		
	Trough, Salt	63.201	52.656	83%					49.204	78%				
	Trough, concrete	43.966	36.630	83%					34.229	78%				
	Trough, PCM	14.585			11.683	80%					10.767	74%		
	Fresnel, PCM	3.214			2.879	90%	2.857	89%			2.765	86%	2.711	84%
Carbon steel	Tower, salt													
	Trough, Salt													
	Trough, concrete													
	Trough, PCM													
	Fresnel, PCM	11.075			9.920	90%	9.526	86%			9.526	86%	9.845	89%
Chromium steel	Tower, salt													
	Trough, Salt	1.508	1.262	84%					1.179	78%				
	Trough, concrete	1.049	878	84%					820	78%				
	Trough, PCM	334			265	79%					244	73%		
	Fresnel, PCM													

Shares are given in percent of present technologies.
PCM = phase change material

Table 5.2: Storage system materials chosen for applying the "material learning rate"

Storage system main materials	per MW el and storage hour	Present (2007)	2025						2050					
			"pessimistic scenario"		"optimistic-realistic scenario"		"very optimistic scenario"		"pessimistic scenario"		"optimistic-realistic scenario"		"very optimistic scenario"	
		kg	kg	%	kg	%	kg	%	kg	%	kg	%	kg	%
Reinforced steel	Tower, salt	779			625	80%					576	74%		
	Trough, Salt	1.611	1.342	83%					1.254	78%				
	Trough, concrete	12.488	10.406	83%					9.724	78%				
	Trough, PCM	10.064			8.060	80%					7.428	74%		
	Fresnel, PCM	10.064			8.060	80%	7.938	79%			7.428	74%	7.139	71%
Carbon steel	Tower, salt	3.864			3.093	80%					3.093	80%		
	Trough, Salt	7.985	6.660	83%					6.223	78%				
	Trough, concrete													
	Trough, PCM													
	Fresnel, PCM													
Aluminium	Tower, salt													
	Trough, Salt													
	Trough, concrete													
	Trough, PCM	8.212			6.576	80%					6.061	74%		
	Fresnel, PCM	8.212			6.576	80%	6.477	79%			6.061	74%	466.008	5675%

Shares are given in percent of present technologies.
PCM = phase change material

5.2 Key emissions and land use

5.2.1 Key emissions' list

In this chapter several analyses are provided which show the emissions' development over time depending on the chosen scenarios and the different technologies. The analyses are based on a list of "key emissions" (Table 5.3) which were analysed to be the most relevant ones for the solar thermal power plant technology. They are part of the whole "NEEDS emissions' list" which can be found in the annex divided into present, 2025, and 2050 technologies (Table 7.4, Table 7.5, and Table 7.6).

5.2.2 Comparison of current technologies

First of all the solar thermal power plants currently being under construction ("Andasol 1" and "SolarTres"), which are designed to operate in a quasi-hybrid mode, are compared with a "virtual" version running as solar-only power plants. This enables us to find out the basic differences between the current and the future systems as all the future systems are designed to run in solar-only mode. In each of the following analyses the future systems are compared with these "virtual" solar-only present systems. Figure 5.6 presents the key emissions resulting from the hybrid versions as well as the "virtual" solar-only versions. All values are scaled to the hybrid parabolic trough ("Andasol 1").

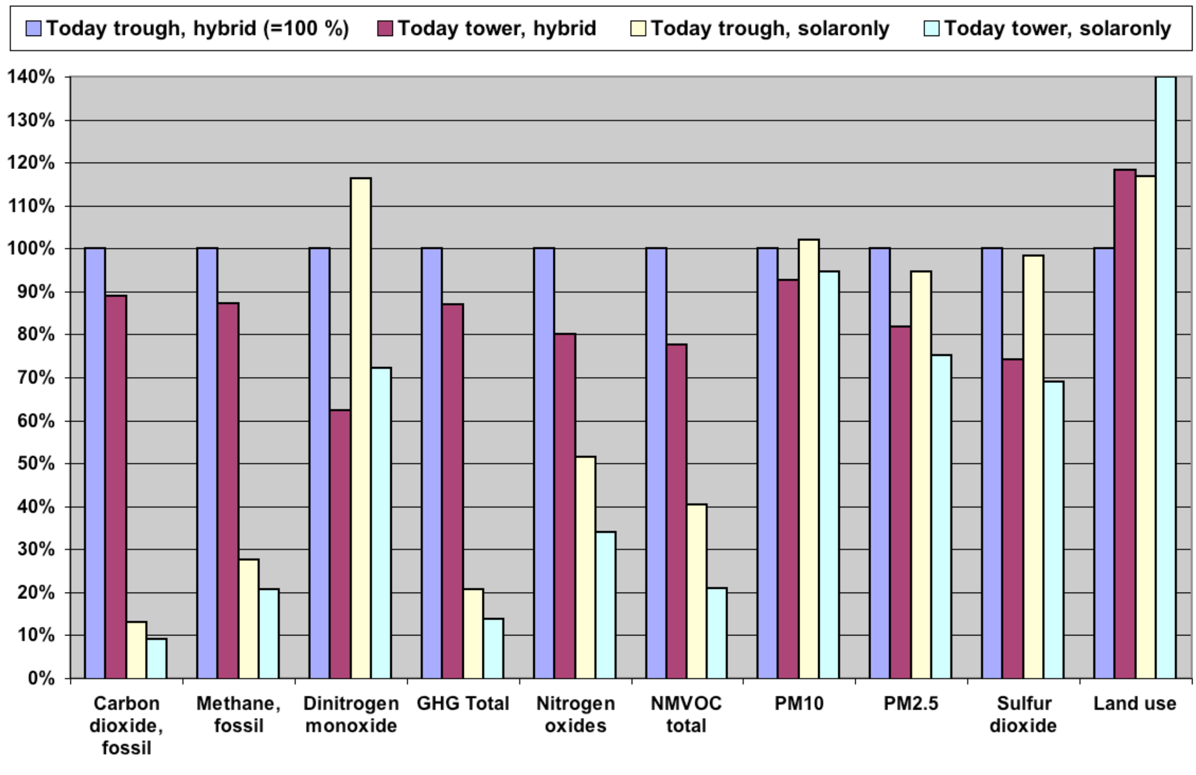

Figure 5.6: Comparison of key emissions caused by hybrid and by solar-only operated power plants

Table 5.3: Key emissions and land use of present, 2025, and 2050 solar thermal technologies

Parameter	Path	Unit		Present (2007)		2025			2050		
			per kWh$_{el}$	Hybrid	solar-only	PS	OR	VO	PS	OR	VO
CO_2, fossil	**air**	**g**	Tower, salt	129	13		8			6	
			Trough, Salt	145	19	13			11		
			Trough, concrete			13			11		
			Trough, PCM				15			11	
			Fresnel, PCM				15			11	
			Fresnel, PCM, CHP_C					12			9
			Fresnel, PCM, CHP_D					13			10
CH_4, fossil	**air**	**mg**	Tower, salt	150	35		20			14	
			Trough, Salt	171	47	35			30		
			Trough, concrete			31			27		
			Trough, PCM				31			22	
			Fresnel, PCM				33			24	
			Fresnel, PCM, CHP_C					26			19
			Fresnel, PCM, CHP_D					28			20
N_2O	**air**	**mg**	Tower, salt	24	28		20			17	
			Trough, Salt	38	45	38			33		
			Trough, concrete			0			0		
			Trough, PCM				22			19	
			Fresnel, PCM				22			19	
			Fresnel, PCM, CHP_C					20			17
			Fresnel, PCM, CHP_D					21			18
GHG	***air***	***g***	Tower, salt	140	22		14			11	
			Trough, Salt	161	33	26			21		
			Trough, concrete			14			12		
			Trough, PCM				22			17	
			Fresnel, PCM				22			17	
			Fresnel, PCM, CHP_C					19			15
			Fresnel, PCM, CHP_D					20			15
NO_x	**air**	**mg**	Tower, salt	128	54		30			24	
			Trough, Salt	160	82	60			53		
			Trough, concrete			45			40		
			Trough, PCM				61			49	
			Fresnel, PCM				63			51	
			Fresnel, PCM, CHP_C					55			44
			Fresnel, PCM, CHP_D					58			47
NMVOC total	**air**	**mg**	Tower, salt	37	10		6			5	
			Trough, Salt	47	19	15			13		
			Trough, concrete			16			14		
			Trough, PCM				11			9	
			Fresnel, PCM				11			9	
			Fresnel, PCM, CHP_C					10			8
			Fresnel, PCM, CHP_D					10			8
PM10	**air**	**mg**	Tower, salt	23	24		10			8	
			Trough, Salt	25	26	11			9		
			Trough, concrete			12			10		
			Trough, PCM				18			15	
			Fresnel, PCM				33			27	
			Fresnel, PCM, CHP_C					20			17
			Fresnel, PCM, CHP_D					21			18
PM2.5	**air**	**mg**	Tower, salt	8	7		4			3	
			Trough, Salt	10	9	6			5		
			Trough, concrete			6			5		
			Trough, PCM				10			7	
			Fresnel, PCM				10			8	
			Fresnel, PCM, CHP_C					9			7
			Fresnel, PCM, CHP_D					9			7
SO_x	**air**	**mg**	Tower, salt	37	35		16			12	
			Trough, Salt	50	49	29			25		
			Trough, concrete			27			23		
			Trough, PCM				31			22	
			Fresnel, PCM				33			23	
			Fresnel, PCM, CHP_C					25			18
			Fresnel, PCM, CHP_D					27			20
Land use	**resource**	**Mm2a**	Tower, salt	16	19		16			16	
			Trough, Salt	14	16	14			14		
			Trough, concrete			14			14		
			Trough, PCM				10			9	
			Fresnel, PCM				6			6	
			Fresnel, PCM, CHP_C					5			5
			Fresnel, PCM, CHP_D					6			6

PS = "pessimistic" scenario development
OR = "optimistic-realistic" scenario development
VO = "very optimistic" scenario development
PCM = phase change material
CHP_C = combined heat and power with cooling as co-product
CHP_D = combined heat and power with desalination as co-product

First of all it is visible that for each pollutant the central receiver causes lower values than the parabolic trough which is due to its less material intensive production as analysed in chapter 5.1.1 (see the footnote regarding its high efficiency). Only the land use of the central receiver is higher than that of the trough (+20%).

Comparing hybrid and solar-only mode, the results can be divided into three groups:

- The first group includes those emissions that are caused mainly by the fossil fuel (natural gas in this case), which are CO_2, CH_4, and therefore the GHG emissions in total. In case of a switch to solar-only operation these emissions decrease by about 80 to 90%.
- The second group includes emissions that are caused mainly by the construction phase and only for a lower part by the fossil fuel (particles, SO_x, N_2O). Regarding particles and the SO_x emissions these pollutants *decrease* only by 30% in the maximum. In case of N_2O they *increase* because N_2O is almost completely caused by the storage system (salt upstream process[4]). In this case the same amount of emissions is related to a smaller output of electricity (fewer full load hours) that means that the specific emissions increase.
  The same situation applies for the land use that mainly depends on the construction phase and increases for the solar-only mode accordingly.
- The emissions occurring in equal shares by the construction phase and the fuel supply (NO_x, NMVOC) are decreased by 50 to 80%.

The different values resulting from the land use can not yet explained at the moment and can only be validated by providing a detailed contribution analysis of the power plant’s construction phases.

5.2.3 Detailed analysis of the impacts caused by the six scenario development steps

Before evaluating the general power plant’s development from the current situation to 2050 in this paragraph we take a look to the individual steps included in the general scenario development (see chapter 4.1). Such a step-by-step analysis is only presented for one case – in the general analysis only the final impacts per scenario and time frame are given.

Figure 5.7 presents the results of the step-by-step analysis by way of the parabolic trough technology development from the current situation to 2025 considering the "pessimistic" scenario. Instancing the greenhouse gas emissions the *percentage points* of reduction or increase of the different steps are shown.

- The *first step* shows the results of increasing the lifetime of solar field, power block, and storage system. Due to the increase of 5 years a 15% emission reduction can be achieved.

[4] All salts need nitric acid for their generation which causes a large greenhouse gas potential. The reason is the N_2O which develops during the nitric acid production and which can leak into the atmosphere.

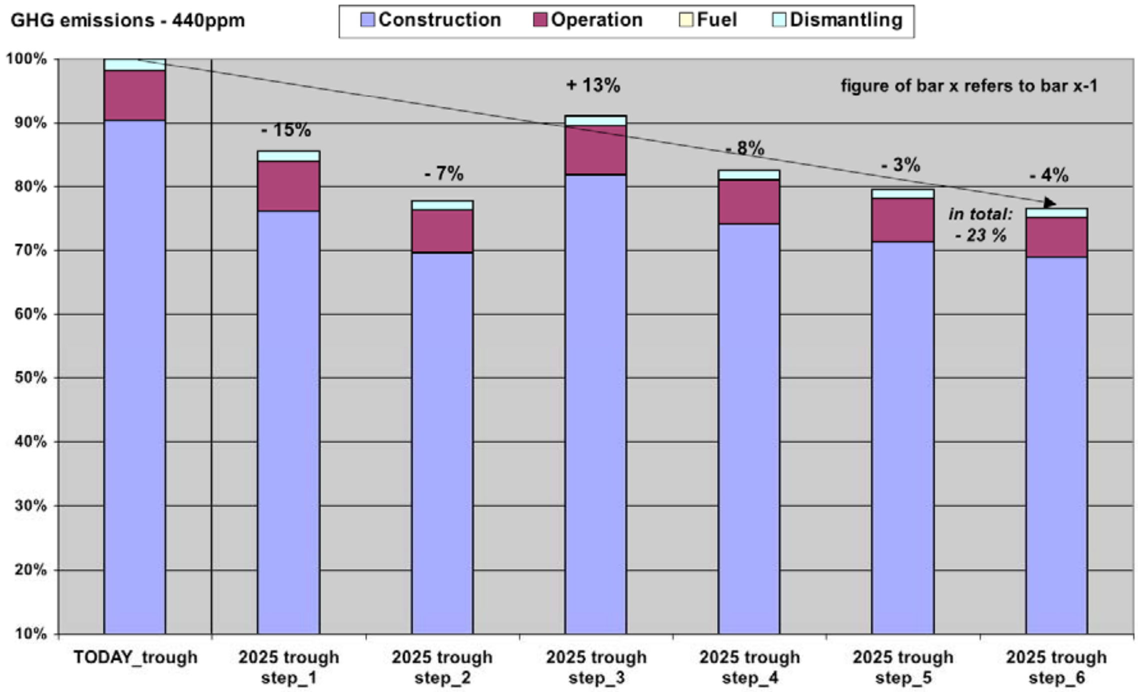

Figure 5.7: Impacts of the "pessimistic scenario" development steps on the greenhouse gas emissions of a 2025 parabolic trough power plant (440ppm-scenario)

– *Step 2* enables a further reduction of 7% caused by up scaling the load from 50 MW to 200 MW. Since an up scaling factor of 1 does not change any results (an increasing solar field is related to an increased electricity output in the same range, for example), the emission reduction is only caused by a better utilisation of the power equipment, steam producer, steam turbine and building for which scaling factors of smaller than 1 were assumed.

– One might think that with an increasing storage capacity the emissions would *decrease*. Instead, they *increase* by 13% if extending the storage capacity from 7.5 to 16 hours (*step 3*). The reason for this is the increased inventory needed for a longer electricity supply: On the one hand a bigger solar field has to be provided to collect the sun which can be stored for the night. This increase is related to a proportional higher electricity output and would not change the emissions. On the other hand the storage system has to be enlarged, which does not lead to a higher electricity output by itself but to a higher power availability. If relating a higher inventory to a constant electricity output, the specific emissions increase.

– In *step 4* the solar-to-heat efficiency is increased from 43.2% to 48% which cause a net emissions' decrease of 8%.

– *Step 5* shows the results of applying the "material learning rate" which enables a reduction of 3% in this case. The reason for this low effect is that the learning rate approach was applied to cost intensive materials only. In contrary most emissions are caused by the main materials which is concrete in this case (see chapter 5.1.2) and which has not been reduced by a learning rate.

– Finally, the adaptation of the background processes provided for 2025 causes a further emissions' decrease by 4%.

Overall, the scenario development steps altogether cause an emissions' decrease of 23% compared with the current solar-only operation.

Similar results shows the step-by-step analysis as for the SO_x emissions (see Figure 5.8). However, in contrary to the GHG emissions, the individual decrease or increase is much more pronounced. The SO_x emissions mainly occur through the steel production process which means that changes of the infrastructure (the storage system, for example) have direct influences on the emissions. A further difference is the higher share of the operation phase on the overall emissions caused mainly by the use of the thermo oil. Finally, the adaptation of the background processes for 2025 results in a reduction of 19% which is much more than evaluated for the GHG emissions.

Overall, the scenario development steps altogether cause an emissions' decrease of 41% compared with the current solar-only operation.

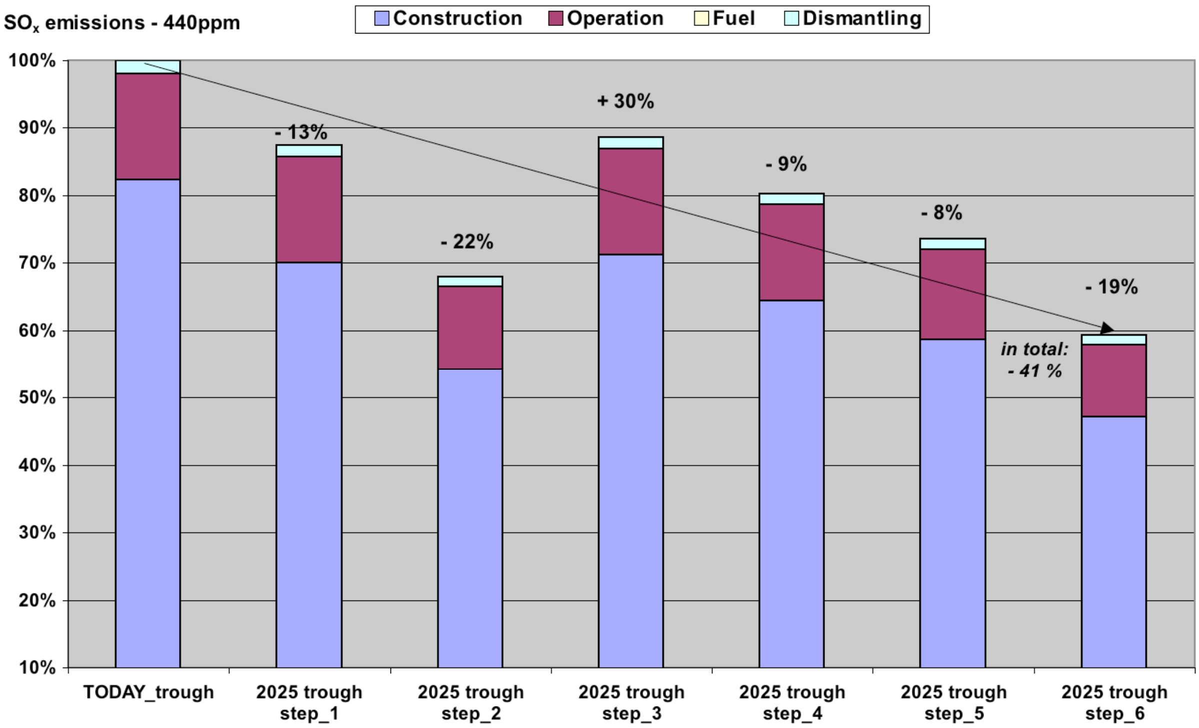

Figure 5.8: Impacts of the "pessimistic scenario" development steps on the SO_x emissions of a 2025 parabolic trough power plant (440ppm-scenario)

All results being presented in the succeeding paragraphs follow this calculation prototype but show only the final results after applying all steps together. The presentation follows the three development scenarios and summarizes the results over all scenarios in a final chapter. For each scenario we selected the values of CO_2, GHG in total, and SO_x as part of the key emissions and completed by the land use[5] for a detailed analysis. Furthermore, in each figure we show the share of the individual phases construction, operation, and dismantling on the total results.

[5] For „land use“ only the most relevant item „Occupation, built up area incl. mineral extraction and dump sites” was selected, in the following referred to as “land use cat. 2”.

5.2.4 Results of the scenario development from present situation to 2050

5.2.4.1 Results of the "pessimistic" scenario development

Figure 5.9 presents the results considering the "pessimistic" scenario development:

- **CO_2 emissions**: The pollutants of the parabolic trough using a molten salt storage are nearly the same as those of the trough equipped with a concrete storage. Compared with the *current trough* (solar-only variant) both decrease to 70% in 2025 and to 58% in 2050. This means that the production of the newly developed concrete storage causes the same CO_2 emissions as the molten salt one because only the storage system was changed in the second alternative. Compared with the *current central receiver* the future troughs reach nearly the same level than the current receiver already shows. It should be noted that the future troughs have lower emissions caused by the construction though they are compensated by the emissions resulting from the operation phase (mainly due to the reimbursement of the thermo oil).
- **GHG emissions**: Considering not only the CO_2 emissions but the GHG emissions in total (here only CO_2, CH_4, and N_2O), a complete different situation occurs. The GHG emissions of the concrete storage based trough are nearly half of those of the salt based one (decrease to 77% / 41% (salt/concrete) in 2025 and to 64% / 34% (salt/concrete) in 2050 in relation to the *current trough*). The reasons are the relatively high N_2O emissions nearly completely caused by the salt upstream process. By exchanging the salt storage with a concrete storage these emissions disappear which results in decreased GHG emissions in total. Compared with the *current central receiver*, the concrete based trough also results in much lower GHG values, because the solar tower operates with a molten salt storage, too.
- **SO_x emissions**: The emissions of the concrete storage based trough decrease a little bit more than those of the salt based one. Compared with the *current trough* (solar-only variant) they decrease to 59% / 55% in 2025 and to 51% / 47% in 2050 depending on the different material inventory of the storage systems.
- **Land use cat. 2**: The land use decreases to 90% / 92% in 2025 and does not change in 2050, compared with the *current trough* (solar-only variant). The only influence on the land use development is the electrical efficiency because the more efficient the trough works the fewer mirrors and therefore the fewer land is needed. Since the efficiency is assumed to increase until 2025 and not to change until 2050 there is no change in land use from 2025 to 2050.

  The higher lifetime expected for the future installations does not influence the land use category. It is compensated by the higher amount of electricity generated because the land use is measured in the unit [m^2a] and therefore increases the longer the power plant is in operation.

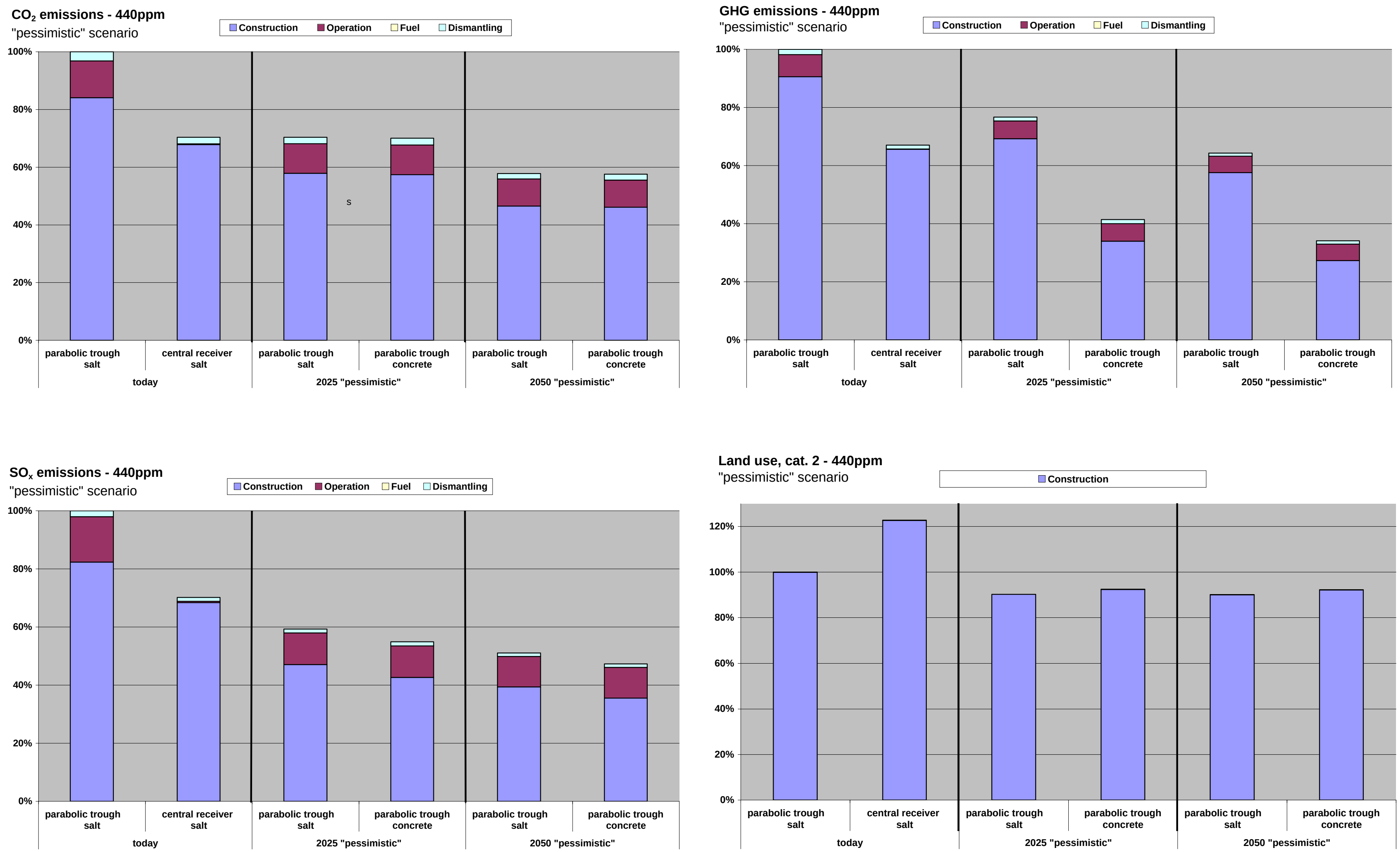

Figure 5.9: "Pessimistic scenario" development from present to 2050 (emissions of CO_2, GHG in total, SO_x, and land use as example) (440ppm-scenario)

5.2.4.2 Results of the "optimistic-realistic" scenario development

Figure 5.10 presents the results considering the "optimistic-realistic" scenario development:

- **CO_2 emissions**: According to the optimisation by the individual scenario development steps the emissions of the direct steam (DSG) based *troughs* decrease to 77% in 2025 and to 58% / 59% (parabolic trough / Fresnel trough) in 2050, compared with the *current trough* (solar-only variant).
- The effects caused by the change of the system (conventional vs. direct steam based trough) are not visible directly because they cancel out each other: On the one hand the operation based emissions nearly almost *disappear* because the CO_2 intensive thermo oil used as heat transfer fluid is exchanged with steam. Furthermore according to the lower inventory of solar field and power management their emissions *decrease*. On the other hand the molten salt storage system is exchanged with a PCM based storage system consisting of salt, concrete, and aluminium and causing a disproportionate *increase* of inventory and emissions (mainly due to the use of aluminium). This is visible through the higher amount of dismantling based emissions which occur due to the dismantling of the materials used for the PCM storage system. Summarising, the emissions of the power plant *decrease* due to the novel DSG based concept, but this decrease is cancelled out by an *increase* caused by the novel PCM storage system.

  The Fresnel trough performs only a little bit better than the parabolic trough despite of its 80% less material intensive solar field construction. The reason for this is that on the one hand its efficiency is only two third of the parabolic trough, on the other hand the inventory balance is dominated by the huge PCM storage system.

  Considering the *central receiver* its CO_2 reduction is only caused according to the optimisation by the scenario development steps. Due to its low emissions in the present its future emissions result to 40% in 2025 and to 30% in 2050 compared with the *current trough*.
- **GHG emissions**: Again, considering not only the CO_2 emissions but the GHG emissions in total (here only CO_2, CH_4, and N_2O), a different situation occurs. The GHG emissions decrease much stronger than the CO_2 emissions and reach 65% in 2025 and 51% / 52% (parabolic trough / Fresnel trough) in 2050 in relation to the current trough. The reason is the decreased salt inventory of the PCM storage system compared with the pure salt storage concept. This reduces the N_2O emissions with their high global warming potential.

  The situation of the central receiver is quite similar because no variation of the general concept occurs.
- **SO_x emissions**: The situation regarding the SO_x emissions is quite similar to the CO_2 emissions (decrease to 63% / 66% in 2025 and to 45% / 47% in 2050) compared with the current trough. The central receiver decreases to 32% in 2025 and to 23% in 2050
- **Land use cat. 2**: The land use decreases to 60% / 37% / 105% (parabolic trough / Fresnel trough / central receiver) in 2025 and does not change in 2050. Regarding the *central receiver* the decrease is caused by the improved efficiency in 2025 compared with

the current situation. The large decrease in case of the *trough systems* is mainly caused by the change of technology: The parabolic trough assumed for the future (model Inditep) performs much better in land use than the current Andasol power plant. As mentioned before, the Fresnel system requires only 50 percent of the land used by a parabolic trough due to its quite different design.

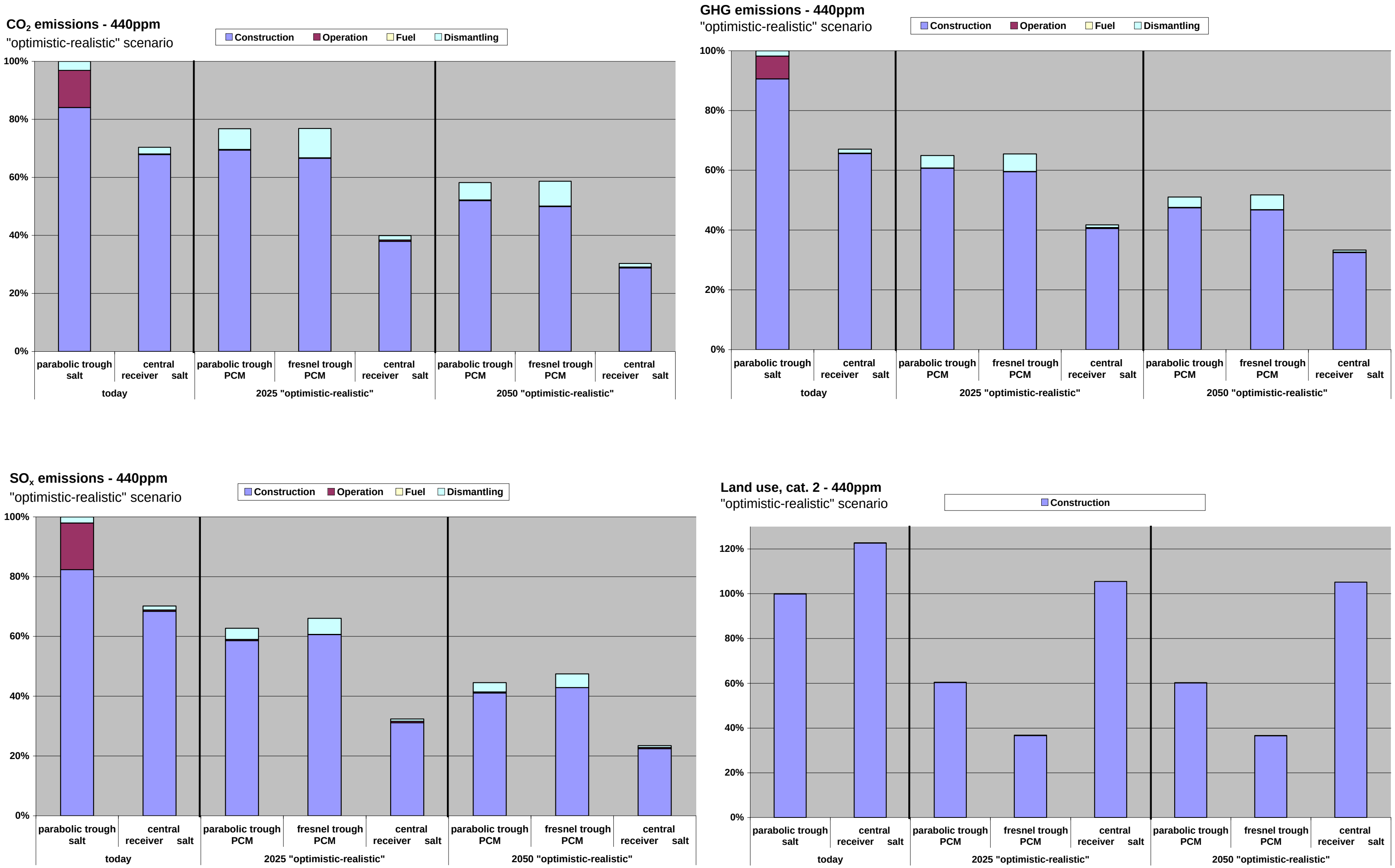

Figure 5.10: "Optimistic-realistic scenario" development from present to 2050 (emissions of CO_2, GHG in total, SO_x, and land use as example) (440ppm-scenario)

5.2.4.3 Results of the "very optimistic" scenario development

Figure 5.11 presents the results considering the "very optimistic" scenario development:

The two technologies modelled within the "very optimistic" scenario are derived from the Fresnel trough used within the "optimistic-realistic" scenario. Therefore the decrease of both emissions and land use is quite similar. It is caused by both the allocation between electricity and heat (used for cooling and desalting) and its resulting emission factor shown in Table 4.3 as well as the further inventory reduction according to the "material learning rate". Since the electricity allocation is worse for the combination with a desalting process than for a cooling process, its overall results presented in the following figure are worse, too.

- **CO_2 emissions**: Decrease to 65% / 69% (CHP with cooling / desalting) in 2025 and to 48% / 51% in 2050.
- **GHG emissions**: Decrease to 56% / 59% in 2025 and to 44% / 46% in 2050.
- **SO_x emissions**: Decrease to 52% / 55% in 2025 and to 37% / 40% in 2050.
- **Land use cat. 2**: Decrease to 33% / 35% in 2025 and to 32 / 34% in 2050.

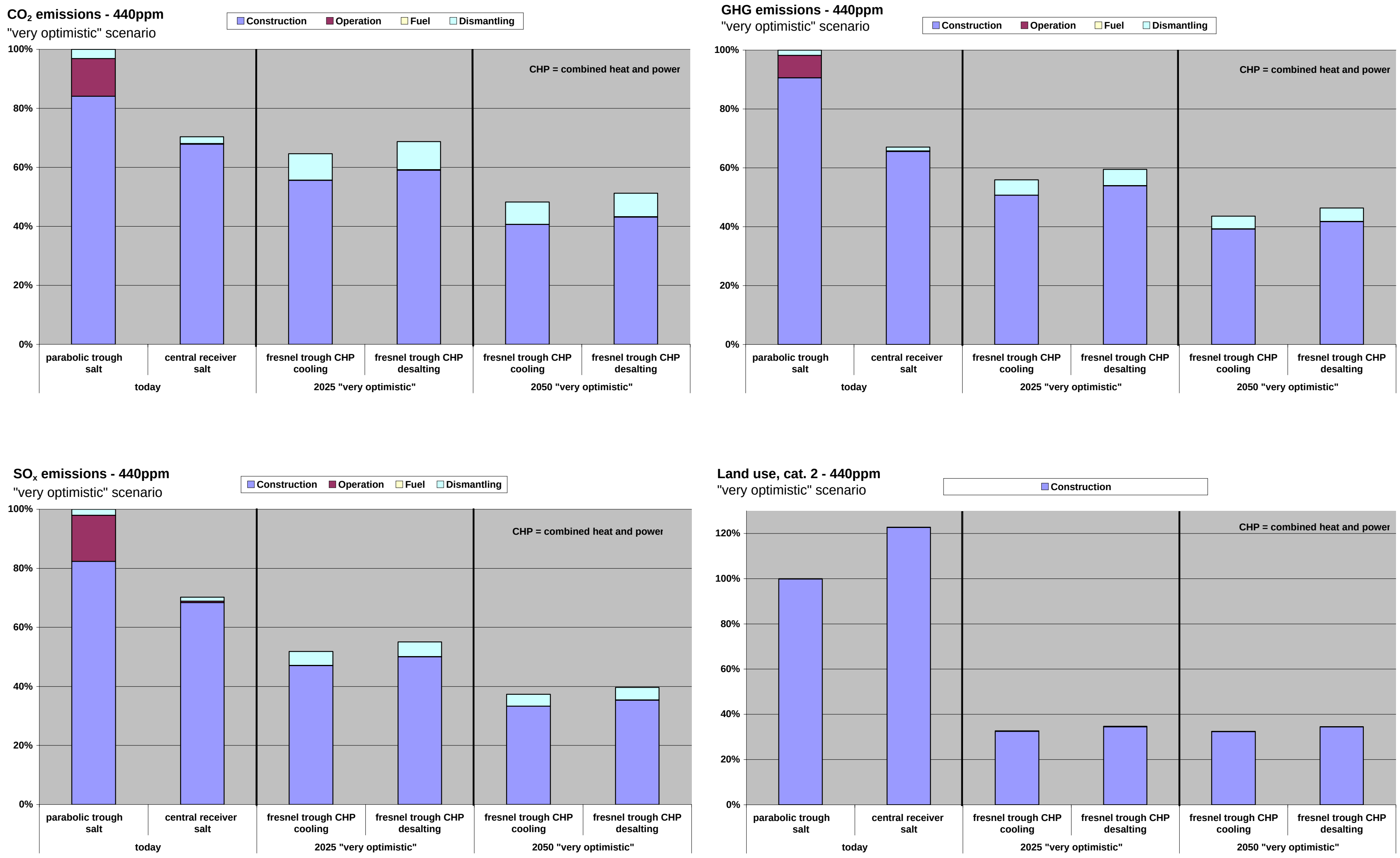

Figure 5.11: "Very optimistic scenario" development from present to 2050 (emissions of CO_2, GHG in total, SO_x, and land use as example) (440ppm-scenario)

5.2.4.4 Comparison of all technology options

Finally, we consider all technology options together to present the differences between the three scenario developments. In the following pictures the blue bars show the present, the red bars the "pessimistic", the yellow ones the "optimistic-realistic", and the green bars the "very optimistic" options. For each scenario the different technologies are weighted according to their assumed share (see Figure 4.2) and an average value is calculated for each pollutant to be reported to the RS Ib model. This mean is presented as a black bar.

- **CO_2 emissions** (Figure 5.12):
  - Considering the parabolic trough the highest reduction of the CO_2 emissions takes place from present situation to 2025 whereas from 2025 to 2050 only a lower reduction occurs. Furthermore, from the worst to the best scenario only a small continuous reduction is visible.
    - Considering 2025, the "optimistic-realistic" cases show higher emissions compared with both the "pessimistic" and the "very optimistic" cases. The reason is the change from the thermo oil based troughs to the steam based ones which require another storage concept, the PCM storage system. The first change is responsible for *decreasing* the emissions resulting from the operation phase, the latter for *increasing* the emissions occurring from the construction phase and therein especially the storage component. This diminishes the material reduction reached by the other power plant's components. Going from the "optimistic-realistic" to the "very optimistic" case a higher reduction is reachable due to the switch to combined cycle production which finally results in emissions lower than those of the "pessimistic" case.
    - In 2050 a further reduction over all cases is visible, but the same pattern as described above occurs.
  - Both in 2025 and in 2050 the central receiver provided in the "optimistic-realistic" scenario shows the lowest emissions.
  - Considering the mean, the CO_2 emissions decrease to 70% / 69% / 67% ("pesimistic", "optimistic-realistic", "very optimistic") in 2025 and to 58% / 53% / 50% in 2050 showing a continuous optimisation from the "pessimistic" to the "very optimistic" scenario as well as a over time. Therein, the higher emissions of the parabolic trough in case of the "optimistic-realistic" scenario are compensated by the quite low emissions of the central receiver.
- **GHG emissions** (Figure 5.13): Regarding the greenhouse gas emissions in total (here only CO_2, CH_4, and N_2O), a larger reduction throughout the scenario development is visible. The reason is the reduction of salt used in the different storage systems as already explained before (no use of salt in the concrete storage – lower use of salt in the PCM storage). It effects that all concrete storage or PCM storage based power plants performs better than the current molten salt based ones.

  Summarising, the mean GHG emissions decrease to 59% / 61% / 58% in 2025 and to 49% / 48% / 45% in 2050 depending on the three scenarios. Again, these results show a continuous optimisation from the "pessimistic" to the "very optimistic" scenario as well as a over time.

- **SO_x emissions (**Figure 5.14**)**: Regarding the SO_x emissions a quite similar pattern in the reduction of the future emission figures occur. Whereas the change from the thermo oil based troughs ("pessimistic" scenario) to the steam based ones ("optimistic-realistic" scenario) result in higher SO_x emissions, the switch to the CHP processes (producing chill and desalted water in the "very optimistic" scenario) lets the emissions sink below the figures of the "pessimistic" scenario.

  Overall, the mean SO_x emissions develop to 57% / 58% / 53% in 2025 and to 49% / 42% / 38% in 2050 depending on the three scenarios.

- **Land use cat. 2 (**Figure 5.15**)**: The land use mainly decreases in case of the 2025 "optimistic-realistic" and "very optimistic" scenarios, reaches 91% / 60% / 34% in 2025, and does not change in 2050 (see explanation in the former sections).

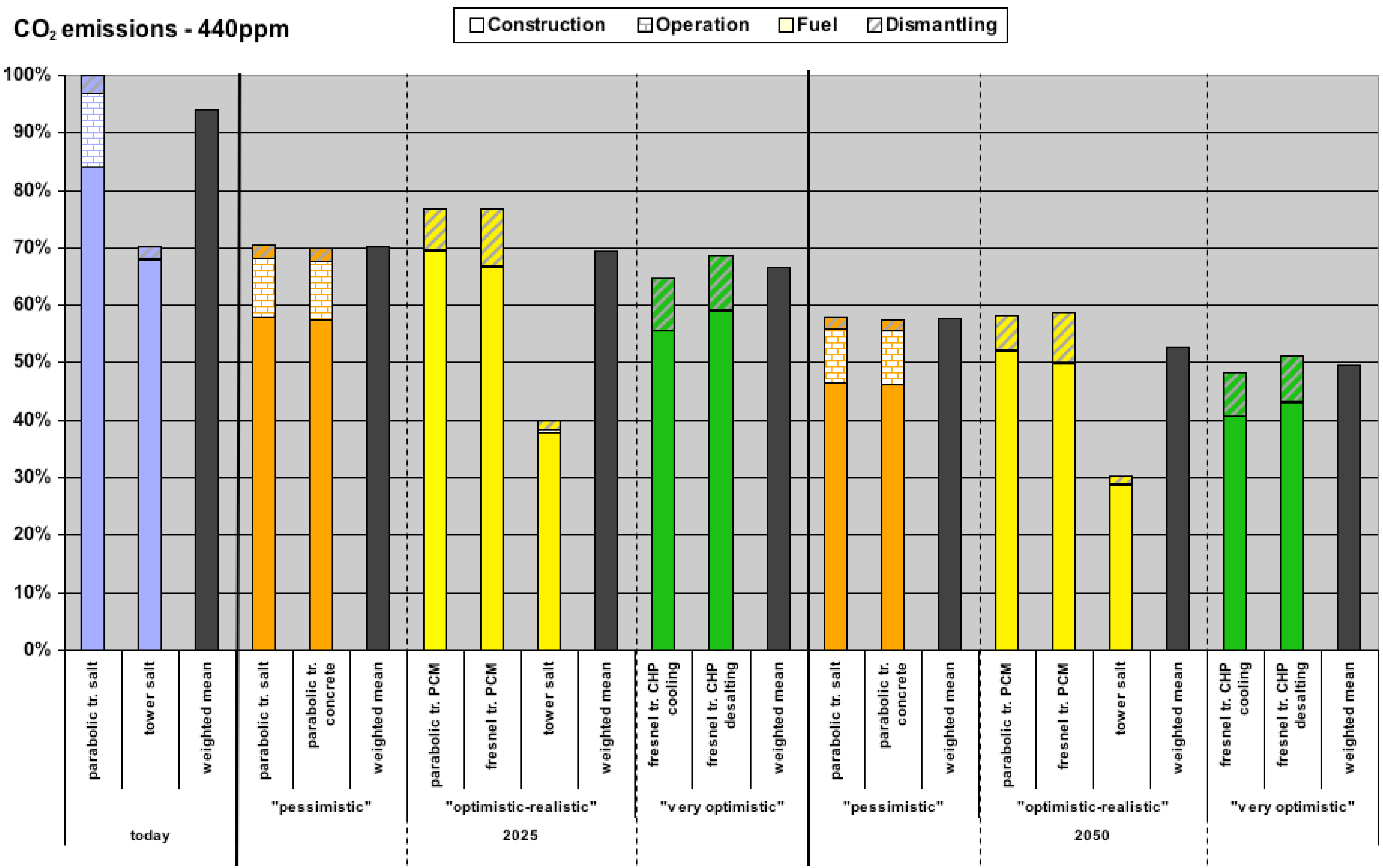

Figure 5.12: Development of CO_2 emissions from present to 2050 (all scenarios; present trough = 100%) (440ppm-scenario)

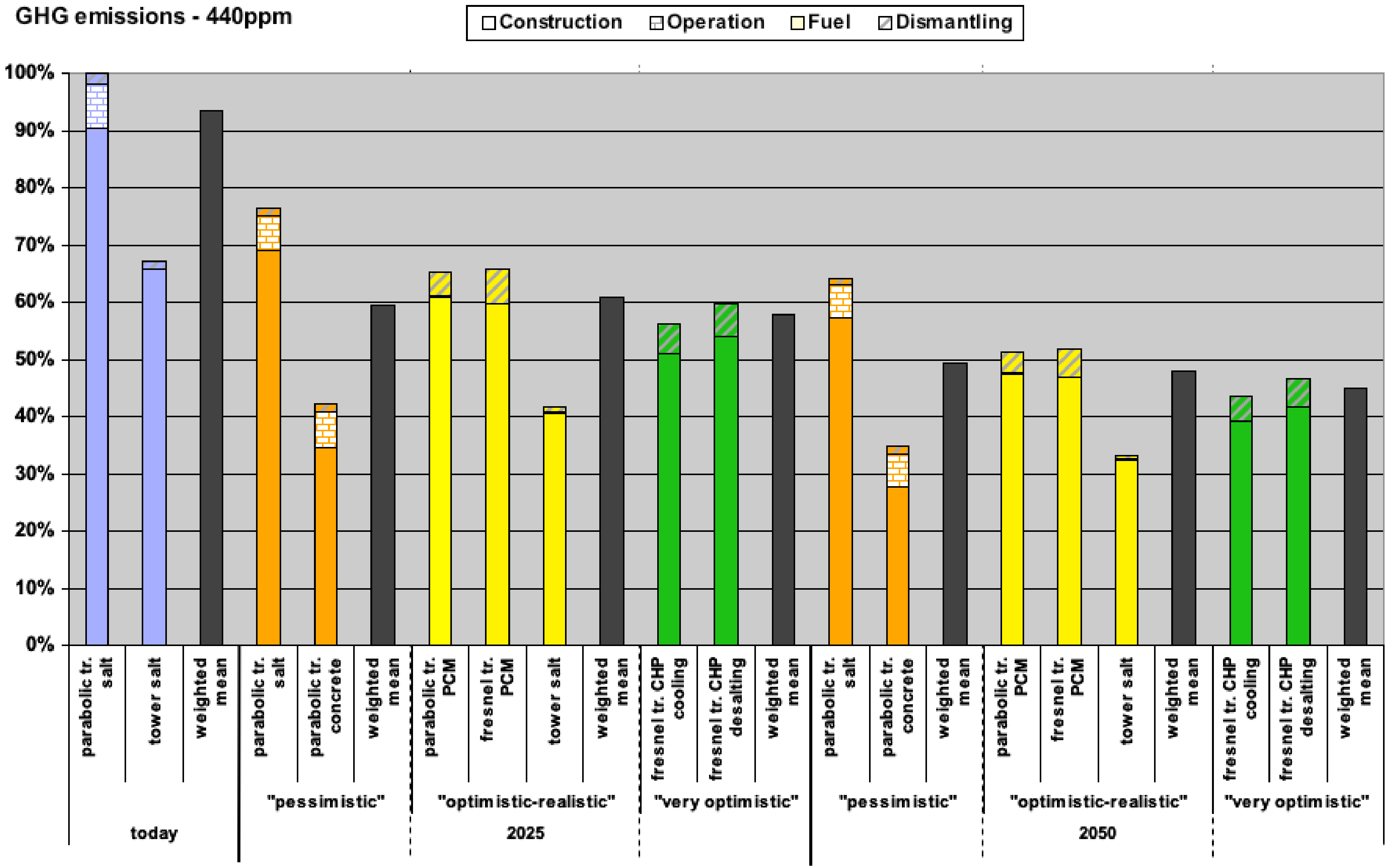

Figure 5.13: Development of GHG emissions from present to 2050 (all scenarios; present trough = 100%) (440ppm-scenario)

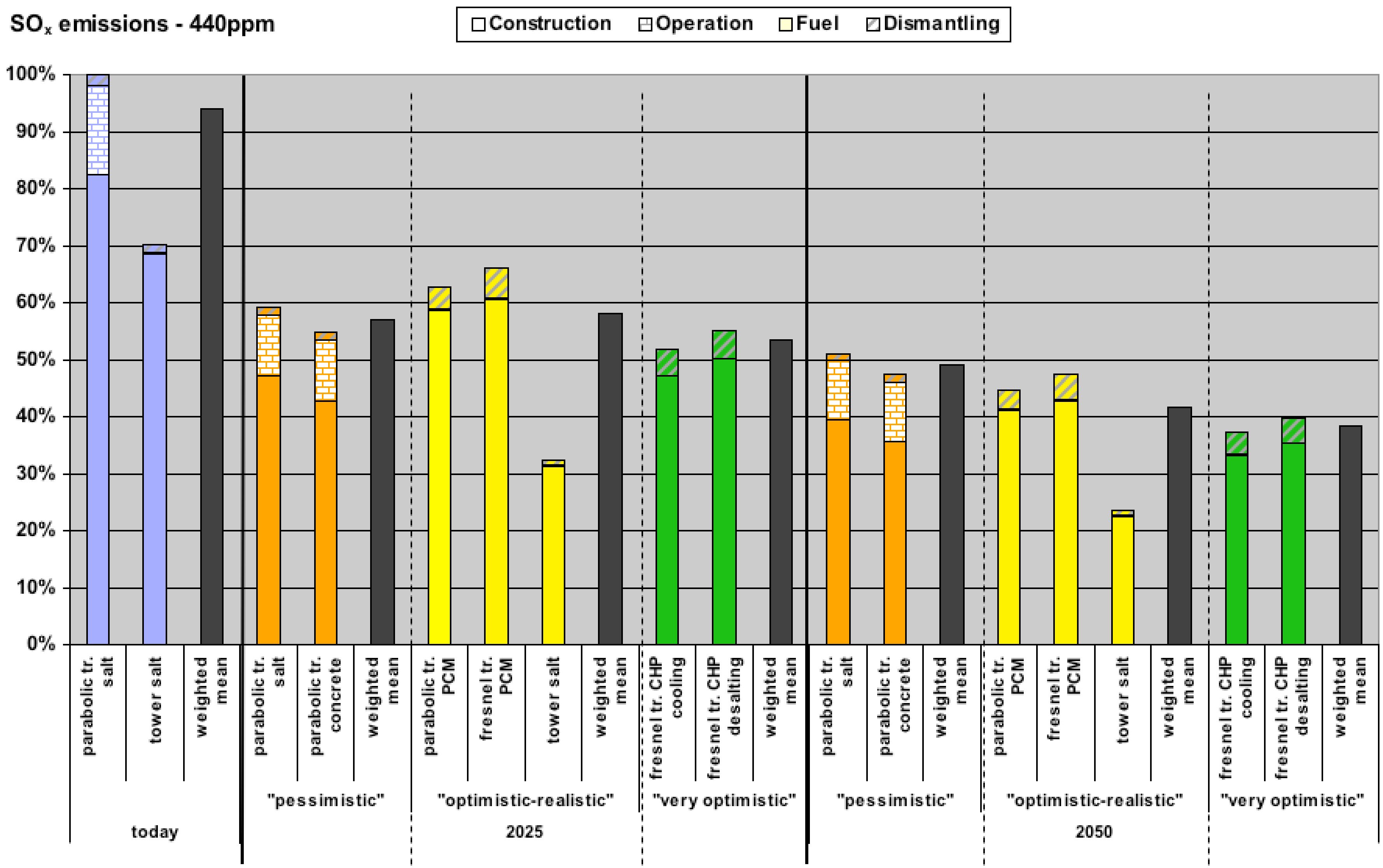

Figure 5.14: Development of SO_x emissions from present to 2050 (all scenarios; present trough = 100%) (440ppm-scenario)

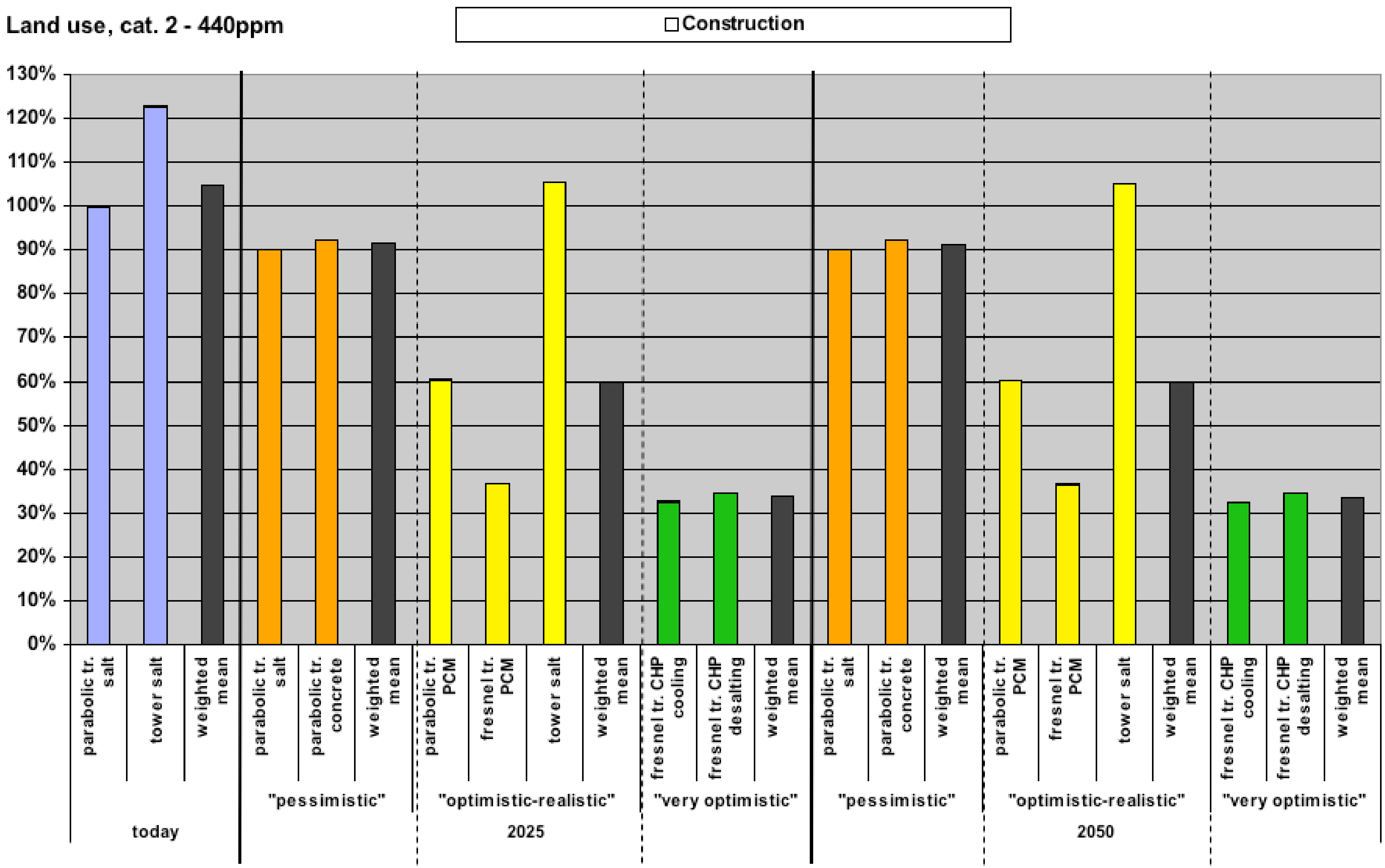

Figure 5.15: Land use development from present to 2050 (all scenarios; present trough = 100%) (440ppm-scenario)

5.3 Including the electricity transmission to Germany

5.3.1 Electricity transmission from Spain to Germany (case A)

Since in NEEDS the electricity generation in European countries is considered an electricity transmission system from Southern Spain to Germany is assumed. To model this to each of the power plants considered so far a high voltage direct current (HVDC) line with a length of 1,822 km (Southern Spain to the German border) is added. Its life cycle inventory data (see Table 7.3 in the annex) is taken from (May 2005) who modelled a 10 GW HVDC from Algeria to the German border (Aachen) over a distance of 3,200 km. The inventory is reduced to the distance required for this case. The assumed HVDC line has a transmission capacity of 77.1 TWh calculated over its lifetime of 50 years from which the emissions caused by the transport of one kilowatthour are derived. These emissions are added to the emissions caused by the power plants' construction phase. The N_2O emissions occurring during electricity transmission are added to the operation phase (1.44 E-9 kg/(kWh,km)). A transmission efficiency of 92% is assumed. Table 7.7 in the annex presents the final results including the electricity transmission to Germany.

It should be noted that the inventory of the current HHVVDC lines has not been updated to 2025/2050 as it was done with the power plants by applying the individual scenario development steps. This means that the real emissions caused by the HVDC should be lower than provided here. Since the share of the transmission process on the overall figures provided for the electricity generation is relatively small (only 5%) this influence can be neglected.

5.3.2 Developing case B (Algeria) from case A (Spain)

Similar to the cost analysis the LCI results depend on the site where the power plants are located. The higher the solar irradiation is, the lower are the emissions, because a higher efficiency enables a higher electricity production using the same infrastructure. As described in chapter 3.5.1.2 two different sites are chosen:

– **Case A**: a site in Spain with an irradiation of 2,000 kWh/m^2,y enabling 6,400 full load hours per year (including the use of thermal storage)
– **Case B**: a site in Algeria with an irradiation of 2,500 kWh/m^2,y enabling 8,000 full load hours per year (including the use of thermal storage);

In a first approximation the emissions resulting from the solar thermal power plants analysed so far for case A (without (without transmission) are decreased by 20% regarding the higher irradiation in case B. However, this approach does not consider the better performance due to a more efficient incidence with which the sun enters the mirrors in the southern regions. This means similar to case that an electricity transmission system to Western Europe has to be added.

For the electricity transmission a 10 GW HVDC from Algeria to the German border (Aachen) over a distance of 3,200 km is included (see above). Due to the longer distance a lower transmission efficiency has to be assumed (87% instead of 92%).

5.3.3 Deriving a mean value for European Solar Thermal Electricity

Finally, we define the share of electricity production between Spain and Algeria to calculate a mean of the emissions caused by case A and by case B power plants. According to (DLR 2006) it is assumed that 10% originate from Spain and 90% from Algeria. The final list of emissions is presented in Table 7.8 in the annex. Figure 5.16 shows the development of case A, case B, and the mean (black bar) by choosing the greenhouse gas emissions as an example.

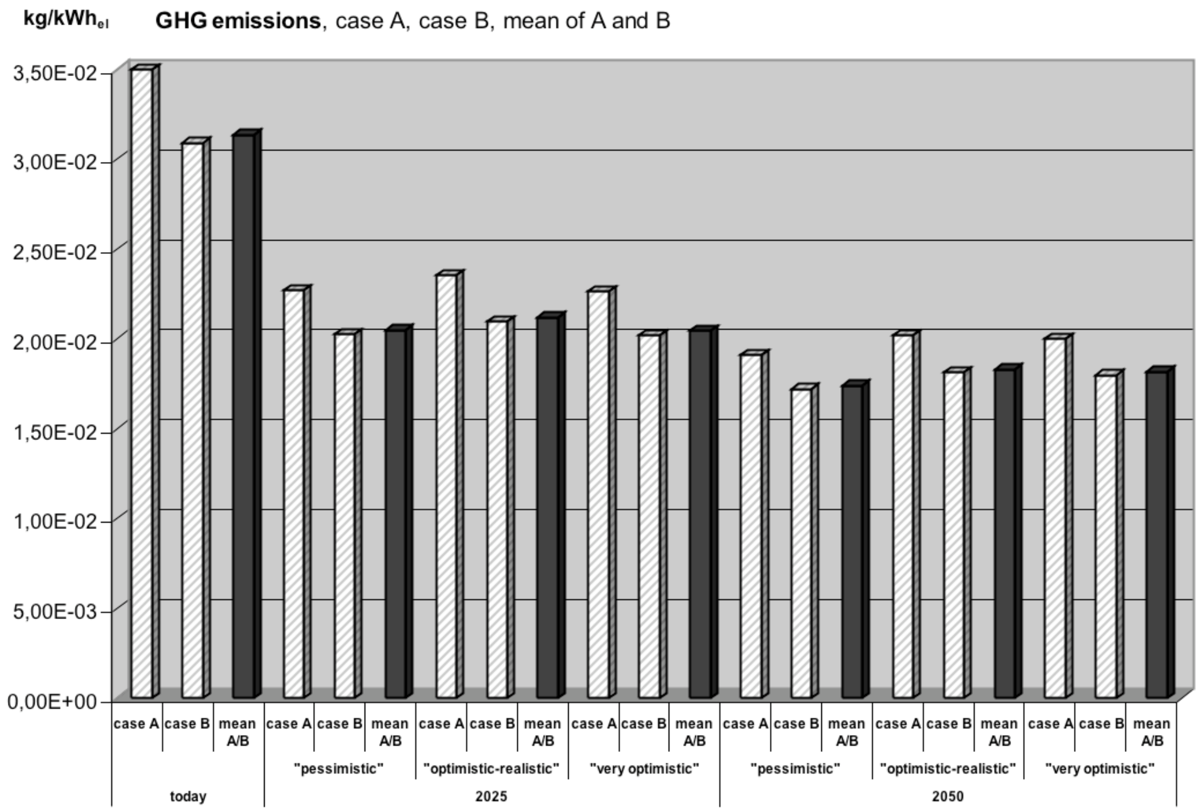

Figure 5.16: Development of GHG emissions for case A, case B, and mean of A and B (final value) (440ppm-scenario)

5.4 Conclusions

Summarising the results presented above the following conclusions can be drawn:

- In the present situation "hybrid" and "solar-only" operated solar thermal power plants differ in three aspects:
  - Emissions caused mainly by fossil fuels (CO_2 and CH_4) decrease by about 80 to 90% if switching to a solar-only mode.
  - Emissions caused mainly during the construction phase and only for a lower part by the use of fossil fuels (particles, SO_x, N_2O) are reduced only by 30% in the maximum (in case of particles and SO_x) or increase in case of N_2O because N_2O is only caused by the salt inventory of the storage system.
  - The emissions occurring in equal shares by the construction phase and the fuel supply (NO_x, NMVOC) are decreased by 50 to 80%.

- To be able to find out the crucial differences between the future solar-only operated power plants and the power plants used in the present situation only the solar-only versions of the operated current power plants are used as basis for comparison.
- The highest reduction of emissions is caused through the transition period between the current and the 2025 scenarios based on the assumptions that in the second period from 2025 to 2050 only minor technology changes will take place. Therefore the emissions in 2050 differ only by nearly 10-15 percentage points from those ones in 2025.
- Unlike previously assumed the results do not differ very much between comparing the three technology development scenarios. In general the emissions resulting from the operation phase *decrease* by exchanging the thermo oil against direct steam as heat transfer fluid. This advantage is cancelled out by the effects caused by the novel storage concepts needed for direct steam operation which slightly *increase* the emissions in total.
- The latter is in contrary to the proposed cost minimizing potential of novel storage systems e.g. by (Tamme 2006) or (Nava and Herrmann 2007) who show that with increasing storage capacity the levelised electricity costs could be reduced (up to 20% in case of 16 storage hours). This shows the necessity to optimize the new storage concepts towards minimised material requirements in the future. Although the "material learning rate" was applied to some cost intensive materials it should be noted that the modelled concepts (both the concrete and the PCM storage) are provided in a pre-commercial status or even in a demonstration phase and should have the potential to be built less material intensive anymore.
- The newly developed approach of a "material learning curve" leads only to minor changes in the inventory and therefore in the resulting emissions. The reason is that usually the materials mainly influencing the LCI are not the cost intensive materials. Only these ones were reduced using the learning curve approach.
- The contribution analysis showed that in case of thermo oil based power plant concepts the operation phase contributes with 10 to 20% to the results mainly caused by the thermo oil upstream process. In contrary in steam based concepts no thermo oil has to be exchanged during operation which minimises its share of the emissions. This aspect and the larger inventory of the concrete and PCM based storage systems lead to a higher importance of the dismantling phase.

5.5 Temporal and spatial disaggregation

Temporal disaggregation

As required in RS IIa Table 5.4 presents the temporal sequence of the four life cycle phases for solar thermal power plants. The start of commercial operation is numbered as year 1 while the previous years of construction are presented with negative numbers. The figures combined with the contribution analysis show that most emissions occur during the first two years of construction.

Table 5.4: Temporal disaggregation for solar thermal power plants considered for the current situation

Phase	Unit	Present		Year 2025		Year 2050	
		Trough	Tower	Trough	Tower	Trough	Tower
Construction	Start year	- 2	- 2	- 2	- 2	- 2	- 2
	End year	- 1	- 1	- 1	- 1	- 1	- 1
Operation	Start year	1	1	1	1	1	1
	End year	30	30	35	35	40	40
Fuel supply	Start year	1	1	---	---	---	---
	End year	30	30	---	---	---	---
Disposal	Start year	31	31	36	36	41	41
	End year	31	31	36	36	41	41

Spatial disaggregation

A further requirement of RS IIa regards information on where the main life cycle phases are located. Table 5.5 and Table 5.6 show this for the two cases A (Spain) and B (Algeria). While in case A all materials originate from European countries of group R1, in case B most of the emissions occur outside of Europe because a high share of steel and concrete will be manufactured within those countries in which the power plants will be located.

Table 5.5: Spatial disaggregation for solar thermal power plants in case A (Spain)

	Solar trough						Central Receiver					
%	R1	R2	R3	R4	R5	Africa	R1	R2	R3	R4	R5	Africa
Construction	40		60				50		50			
Operation	50		50				60		40			
Fuel Supply *)			100						100			
Disposal			100						100			

*) only in case of present technologies

The European regions R1, R2, R3, R4, and R5 are used according to the definition given by RS IIa. R1 includes the Switzerland and Germany; R3 includes Spain and Portugal.

Table 5.6: Spatial disaggregation for solar thermal power plants in case B (Algeria)

	Solar trough						Central Receiver					
%	R1	R2	R3	R4	R5	Africa	R1	R2	R3	R4	R5	Africa
Construction	40					60	50					50
Operation	50					50	60					40
Fuel Supply *)						100						100
Disposal						100						100

*) only in case of present technologies

The European regions R1, R2, R3, R4, and R5 are used according to the definition given by RS IIa. R1 includes the Switzerland and Germany.

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7 Annex

7.1 Tables

Table 7.1: Material and energy flows required for the construction of different storage systems (original data)

Storage type **originally referring to** **scaled to** **Material/Energy**		**Concrete** **6 h, 50 MW,el** **1 MWh,th**	**Molten salt** **7.5 h, 46 MW,el** **1 MWh,th**	**PCM** **16 h, 600 MW,th** **1 MWh,th**
Electricity	kWh	191		191
diesel burned in building machine	MJ	11.984		11.984
Concrete	kg	137.061	3.770	42.186
Reinforcing steel	kg	4.163	374	3.355
Carbion steel	kg		1.851	
Chromium steel	kg		108	
Graphite foil	kg	14		14
Mineral wool	kg	1.578	228	1.578
Thermooil	kg	1.000		
KNO_3	kg		27.733	17.625
Sand	kg		91	
Foam glas	kg		120	
Aluminium	kg			2.737
Wood	m3	0,03		0,03
Total (only mass)	kg	143.815	34.276	67.494

Table 7.2: Material and energy flows required for the construction of a 1 km distance 10 GW high voltage direct current (HVDC) transmission system (original data)

Material/Energy	**Unit**	**HVDC Overhead km**	**HVDC Submarine km**
reinforcing steel, at plant	kg	150.000	
concrete, normal, at plant	m3	163	
aluminium, production mix, at plant	kg	34.800	
ceramic tiles, at regional storage	kg	4.000	
chromium steel 18/8, at plant	kg	12.800	192.000
copper, at regional storage	kg		152.000
lead, at regional storage	kg		136.000
paper, woodfree, coated, at integrated mill	kg		48.000
polybutadiene, at plant	kg		8.000
polypropylene, granulate, at plant	kg		18.400
transport, lorry 40t	tkm	709.252	
transport, transoceanic freight ship	tkm	279.414	8.000
Transformation, from water bodies, artificial	m2	1,24E-10	
Transformation, from sparsely vegetated areas, steppe, tundra, badlands	m2	5,48E-09	
Transformation, from forest	m2	2,07E-09	
Transformation, from arable	m2	1,26E-08	
Transformation, from beaches, dunes, sands, desert	m2	3,56E-09	
Transformation, from urban, discontinuously built	m2	2,46E-11	
Transformation, from sea and ocean	m2		4,13E-07
Transformation, to industrial area	m2	2,39E-08	4,13E-07
Occupation, industrial area	m2a	1,19E-06	2,07E-05

Table 7.3: Material and energy flows required for the construction and operation of solar thermal power plants (only basis technologies; original and partly revised data)

			Parabolic Trough	Central receiver	Parabolic Trough	Fresnel Trough
			"Andasol I" 46 MW	"SolarTres" 15 MW	"Inditep" 5 MW	"Novatec" 5 MW (only solarfield)
Solar Field	Flat glass coated	kg	6.148.846	3.180.904	458.875	285.234
	Antireflexglas, absorber	kg				7.844
	Copper	kg	16.246	36.639	3.507	1.732
	wire drawing, copper	kg		36.575	582	1.732
	Occupation, industrial aera	m2	2.225.000	1.500.000	125.895	45.780
	Paint	kg	54.054	42.900	4.620	
	Concrete	kg	46.410.000	19.635.000	974	
	reinforcing steel	kg	15.168.192	9.204.250	3.471.650	161.057
	steel, converter, unalloyed	kg				554.939
	sheet rolling	kg				518.933
	excavation hydraulic digger	m3		8.250	1.166.799	
	chromium steel	kg	361.889		26.733	
	graphite	kg	187		21	
	glass tube, borosilicate	kg	20.565		14.905	
	aluminium oxide	kg	3		1,1	
	aluminium	kg				2.209
	Diphenil Ether 73.5% and phenol 26.5% w/w	kg	1.995.000			
	rock wool	kg				8.557
	EPDM rubber	kg				125
	silicone product	kg				50
	synthetic rubber	kg				34.228
	nylon 6,6	kg				535
	cast iron	kg	575		43,02	
	manganese	kg	575		43,02	
	nickel	kg	46		5,18	
	chromium	kg	46		5,18	
	lubricating oil	kg	8.321	107.569	933,45	
	polyethylene, HDPE	kg	5.011		721,56	
	TOTAL	kg	70.189.556	32.243.837	5.149.836,61	1.056.510
Tower	Concrete	kg		476.000		
	reinforcing steel	kg		52.000		
	excavation hydraulic digger	m3		200		
	TOTAL	kg		528.000		
Buildings and urbanization	Concrete	kg	9.416.875	10.602.900	1.023.573	
	reinforcing steel	kg	450.000	351.447	48.913	
	excavation hydraulic digger	m3		500		
	HDPE tube	kg		80.300		
	PVC tube A	kg		23.473		
	wood broad	kg	176		19	
	Flat glass uncoated	kg	1.700		185	
	cement	kg	86.000		9.348	
	silica sand	kg	258.000		28.043	
	sanitary ceramics	kg	250.000		27.174	
	gravel	kg	1.825.000	8.500.000	198.370	
	TOTAL	kg	12.287.751	19.558.120	1.335.625	
Power block	reinforcing steel	kg	563.450	378.071	8.889	
	ceramic tiles	kg	31.600	16.922	208	
	chromium steel	kg	44.050	4.550	4.819	
	Copper	kg	3.750		410	
	Aluminium	kg	950		624	
	TOTAL	kg	643.800	399.543	14.950	
Cooling Tower	Concrete	kg	200.590	200.590	65.552	
	reinforcing steel	kg	29.808	29.779	9.732	
	TOTAL	kg	230.398	230.369	75.284	
Power Equipment	chromium steel	kg	57.000	57.000	234.104	
	pipe drawing	kg			234.104	
	magnesium alloy, AZ91	kg	15.000	15.000		
	PVC tube A	kg	15.000	15.000		
	TOTAL	kg	87.000	87.000	234.104	
Storage	reinforcing steel	kg	386.578	268.924		
	carbon steel	kg	1.916.292	1.333.073		
	chromium steel	kg	112.276	78.105		
	pipe drawing	kg	107.986	75.121		
	KNO3 (60% NaNO3 und 40% KNO3)	kg	28.703.974			
	Ca(NO3)2	kg		1.514.774		
	KNO3	kg		10.752.532		
	Heat used for melting the salt and heating tank	MJ	11.000.000	7.040.000		
	concrete	kg	3.902.132	2.714.527		
	rock wool	kg	235.883	164.093		
	foam glas	kg	124.427	86.558		
	sand	kg	94.090	65.454		
	TOTAL	kg	35.475.653	16.978.039		
Construction	diesel burned in building machine	MJ	19.992.800	1.967.202		
	transport, lorry 40 t	tkm	261.371	2.010.354	28.410	
Dismantling	diesel burned in building machine	MJ	8.802.800		956.826	
Operating	Diphenil Ether 73.5% and phenol 26.5% w/w, 4,5%/a	kg/a	89.700			
	water, demineralised	kg/a	11.222.640	5.826.150	839.300	
	water, deionised	kg/a	3.335.315	1.805.803	938.170	
	water, unspecific	kg/a	545.172.440	295.166.785	51.116.025	
	paint	kg/a	54	43	4,6	
	Copper	kg/a	11	0	3,5	
	Copper wire drawing	kg/a			0,6	
	Flat glass coated, 0,1 %/a	kg/a	6.162	3.181	459	
	chromium steel	kg/a			27	
	glass tube, borosilicate	kg/a			15	
	aluminium oxide	kg/a			0,0	
	reinforcing steel	kg/a			48	
	nickel	kg/a			0,0	
	chromium	kg/a			0,0	
	lubricating oil	kg/a			0,9	
	polyethylene, HDPE	kg/a			0,7	
	TOTAL without water per year	kg/a	95.927	3.224	559	
	TOTAL without water	kg	2.398.174	80.597	16.780	

Table 7.4: Emissions' list of the modelled solar thermal power plants (present technologies)

Parabolic Trough, hybrid (Andasol I) **TODAY_TOH** **Central receiver, hybrid (SolarTres)**
Parabolic Trough, solar only **TODAY_TO** **Central receiver, solaronly**

Parameter (per kWh,el)	Path	Unit	TODAY_TRH	TODAY_TOH	TODAY_TR	TODAY_TO
Coal, brown, in ground	resource	kg	1,098E-03	8,657E-04	9,868E-04	7,104E-04
Coal, hard, unspecified, in ground	resource	kg	3,816E-03	3,821E-03	3,938E-03	3,977E-03
Gas, natural, in ground	resource	Nm3	6,212E-02	5,493E-02	4,265E-03	2,085E-03
Oil, crude, in ground	resource	kg	2,513E-03	1,350E-03	2,643E-03	1,295E-03
Uranium, in ground	resource	kg	6,170E-08	4,990E-08	5,608E-08	4,146E-08
Freshwater (lake, river, groundwater)	resource	m3	2,941E-04	3,249E-04	3,185E-04	2,658E-04
Occupation, agricultural and forestal area	resource	m2a	7,646E-04	5,478E-04	8,549E-04	5,968E-04
Occupation, built up area incl. mineral extraction and dump sites	resource	m2a	1,282E-02	1,553E-02	1,502E-02	1,843E-02
Transformation, from arable, unspecified	resource	m2	4,360E-04	2,158E-05	5,127E-04	2,521E-05
Transformation, from arable, intensive	resource	m2	0,000E+00	0,000E+00	0,000E+00	0,000E+00
Transformation, from forest, unspecified	resource	m2	2,281E-05	1,912E-05	9,376E-06	6,562E-06
Transformation, from pasture and meadow, unspecified	resource	m2	7,642E-07	8,525E-07	4,626E-07	5,766E-07
Transformation, from pasture and meadow, extensive	resource	m2	0,000E+00	0,000E+00	0,000E+00	0,000E+00
Transformation, from pasture and meadow, intensive	resource	m2	1,259E-08	1,692E-08	1,466E-08	1,977E-08
Transformation, from shrub land, sclerophyllous	resource	m2	2,647E-07	3,402E-07	2,884E-07	3,602E-07
Transformation, from unknown	resource	m2	6,731E-06	6,629E-06	6,774E-06	6,676E-06
Ammonia	air	kg	1,212E-05	7,750E-06	1,419E-05	9,054E-06
Arsenic	air	kg	3,084E-09	1,738E-09	3,447E-09	1,865E-09
Cadmium	air	kg	1,345E-09	8,244E-10	1,511E-09	8,998E-10
Carbon dioxide, fossil	air	kg	1,454E-01	1,295E-01	1,892E-02	1,331E-02
Carbon monoxide, fossil	air	kg	1,627E-04	1,627E-04	1,241E-04	1,301E-04
Carbon-14	air	kBq	1,085E-04	8,872E-05	9,833E-05	7,365E-05
Chromium	air	kg	1,175E-07	6,091E-08	1,356E-07	6,903E-08
Chromium VI	air	kg	2,836E-09	1,415E-09	3,283E-09	1,611E-09
Dinitrogen monoxide	air	kg	3,826E-05	2,383E-05	4,453E-05	2,761E-05
Iodine-129	air	kBq	1,076E-07	8,716E-08	9,706E-08	7,201E-08
Lead	air	kg	1,092E-07	8,466E-08	1,257E-07	9,710E-08
Methane, fossil	air	kg	1,715E-04	1,496E-04	4,732E-05	3,547E-05
Mercury	air	kg	4,231E-09	4,302E-09	4,166E-09	4,296E-09
Nickel	air	kg	2,234E-08	1,570E-08	2,484E-08	1,708E-08
Nitrogen oxides	air	kg	1,595E-04	1,279E-04	8,209E-05	5,407E-05
NMVOC total	air	kg	4,727E-05	3,670E-05	1,913E-05	9,936E-06
thereof:						
Benzene	air	kg	2,518E-06	8,112E-07	2,007E-06	7,974E-08
Benzo(a)pyrene	air	kg	2,146E-10	1,942E-10	1,902E-10	1,693E-10
Formaldehyde	air	kg	2,403E-07	2,163E-07	4,459E-08	3,667E-08
PAH	air	kg	2,438E-08	2,206E-08	4,482E-09	3,833E-09
PM10	air	kg	2,514E-05	2,330E-05	2,565E-05	2,380E-05
PM2.5	air	kg	9,969E-06	8,168E-06	9,432E-06	7,494E-06
PCDD/F (measured as I-TEQ)	air	kg	3,289E-14	3,409E-14	3,449E-14	3,627E-14
Radon-222	air	kBq	1,969E+00	1,608E+00	1,782E+00	1,332E+00
Sulfur dioxide	air	kg	5,005E-05	3,715E-05	4,921E-05	3,454E-05
Global Warming Potential (non-biogenic)	air	kg CO2-eq.	1,611E-01	1,405E-01	3,360E-02	2,287E-02
Global Warming Potential (biogenic)	air	kg CO2-eq.	-2,741E-05	1,705E-05	-3,285E-05	-1,708E-05
Aerosols, radioactive, unspecified	air	kBq	2,519E-08	2,031E-08	2,258E-08	1,667E-08
Hydrogen-3, Tritium	air	kBq	6,103E-04	4,936E-04	5,496E-04	4,071E-04
Iodine-131	air	kBq	6,045E-06	4,784E-06	5,515E-06	3,995E-06
Iodine-133	air	kBq	1,923E-10	1,885E-10	1,917E-10	1,696E-10
Iodine-135	air	kBq	0,000E+00	0,000E+00	0,000E+00	0,000E+00
Krypton-85	air	kBq	4,795E-05	3,802E-05	4,378E-05	3,177E-05
Krypton-85m	air	kBq	3,081E-06	2,875E-06	3,006E-06	2,548E-06
Noble gases, radioactive, unspecified	air	kBq	1,034E+00	8,375E-01	9,326E-01	6,919E-01
Sulfur hexafluoride	air	kg	8,050E-09	1,415E-08	9,261E-09	1,645E-08
Thorium-230	air	kBq	5,904E-08	4,837E-08	5,194E-08	3,895E-08
Uranium-234	air	kBq	1,772E-07	1,448E-07	1,589E-07	1,189E-07
Uranium-235	air	kBq	8,408E-09	6,863E-09	7,609E-09	5,689E-09
Uranium-238	air	kBq	2,977E-07	2,382E-07	2,729E-07	2,014E-07
Ammonium, ion	water	kg	7,372E-08	7,227E-08	7,415E-08	7,100E-08
Arsenic, ion	water	kg	4,118E-08	4,307E-08	4,248E-08	4,511E-08
Cadmium, ion	water	kg	2,875E-08	3,074E-08	3,017E-08	3,283E-08
Carbon-14	water	kBq	4,193E-05	3,397E-05	3,784E-05	2,807E-05
Cesium-137	water	kBq	2,012E-05	1,631E-05	1,815E-05	1,348E-05
Chromium, ion	water	kg	3,151E-09	3,013E-09	3,041E-09	2,928E-09
Chromium VI	water	kg	6,156E-07	6,424E-07	6,341E-07	6,736E-07
COD	water	kg	1,177E-04	7,847E-05	1,243E-04	7,931E-05
Copper, ion	water	kg	2,482E-07	2,212E-07	2,650E-07	2,350E-07
Lead	water	kg	7,180E-08	7,489E-08	7,360E-08	7,740E-08
Mercury	water	kg	3,523E-09	3,744E-09	3,643E-09	3,946E-09
Nickel, ion	water	kg	9,326E-07	7,699E-07	1,009E-06	8,245E-07
Nitrate	water	kg	5,677E-07	1,157E-06	6,389E-07	1,320E-06
Oils, unspecified	water	kg	9,547E-06	8,330E-06	9,375E-06	8,085E-06
PAH	water	kg	3,047E-09	1,753E-09	3,312E-09	1,808E-09
Phosphate	water	kg	2,812E-06	2,966E-06	2,932E-06	3,147E-06
Hydrogen-3, Tritium	water	kBq	4,605E-02	3,732E-02	4,154E-02	3,083E-02
Iodine-131	water	kBq	5,500E-09	4,653E-09	5,030E-09	3,899E-09
Iodine-133	water	kBq	2,626E-10	2,575E-10	2,618E-10	2,317E-10
Krypton-85	water	kBq	0,000E+00	0,000E+00	0,000E+00	0,000E+00
Thorium-230	water	kBq	3,749E-05	3,060E-05	3,393E-05	2,536E-05
Uranium-234	water	kBq	3,297E-07	2,691E-07	2,984E-07	2,231E-07
Uranium-235	water	kBq	5,440E-07	4,440E-07	4,924E-07	3,681E-07
Uranium-238	water	kBq	1,356E-06	1,126E-06	1,070E-06	8,140E-07
Arsenic	soil	kg	1,533E-10	1,362E-10	2,582E-11	1,971E-11
Cadmium	soil	kg	1,569E-11	1,400E-11	1,723E-11	1,521E-11
Chromium	soil	kg	2,379E-09	2,023E-09	8,534E-10	6,069E-10
Chromium VI	soil	kg	1,436E-09	1,199E-09	1,102E-09	8,317E-10
Lead	soil	kg	1,602E-10	1,185E-10	1,818E-10	1,311E-10
Mercury	soil	kg	3,930E-13	4,918E-13	4,529E-13	5,501E-13
Oils, unspecified	soil	kg	6,745E-06	5,384E-06	6,611E-06	5,101E-06

Table 7.5: Emissions’ list of the modelled solar thermal power plants (2025 technologies)

2025_PS_TR	**Parabolic Trough, thermoil, salt storage**	**2025_RO_TO**	**Central receiver, salt, salt storage**
2025_PS_TRC	**Parabolic Trough, thermoil, concrete storage**	**2025_VO_FRC**	**Fresnel, combined cycle (cooling)**
2025_RO_TR	**Parabolic Trough, direct steam, PCM storage**	**2025_VO_FRD**	**Fresnel, combined cycle (desalting)**
2025_RO_FR	**Fresnel, direct steam, PCM storage**		

	Parameter (per kWh,el)	Path	Unit	2025_PS_TR	2025_PS_TRC	2025_RO_TR	2025_RO_FR	2025_RO_TO	2025_VO_FRC	2025_VO_FRD
Resources	Coal, brown, in ground	resource	kg	1,402E-04	1,546E-04	1,449E-04	1,394E-04	8,829E-05	1,164E-04	1,237E-04
	Coal, hard, unspecified, in ground	resource	kg	2,375E-03	2,669E-03	3,332E-03	3,825E-03	2,086E-03	3,128E-03	3,325E-03
	Gas, natural, in ground	resource	Nm3	3,661E-03	2,464E-03	1,950E-03	1,911E-03	1,496E-03	1,662E-03	1,766E-03
	Oil, crude, in ground	resource	kg	2,005E-03	2,023E-03	1,701E-03	1,744E-03	7,470E-04	1,489E-03	1,582E-03
	Uranium, in ground	resource	kg	2,644E-08	3,122E-08	3,290E-08	3,171E-08	1,780E-08	2,704E-08	2,874E-08
	Freshwater (lake, river, groundwater)	resource	m3	2,985E-04	3,345E-04	4,110E-04	7,085E-04	3,461E-04	6,272E-04	6,667E-04
	Occupation, agricultural and forestal area	resource	m2a	7,053E-04	5,053E-04	5,619E-04	5,748E-04	4,132E-04	5,004E-04	5,319E-04
	Occupation, built up area incl. mineral extraction and dump sites	resource	m2a	1,356E-02	1,389E-02	9,076E-03	5,521E-03	1,585E-02	4,901E-03	5,209E-03
Extended List	Transformation, from arable, unspecified	resource	m2	3,978E-04	4,068E-04	2,693E-04	1,559E-04	1,858E-05	1,385E-04	1,472E-04
List for External	Transformation, from arable, intensive	resource	m2	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
Cost Assessment	Transformation, from forest, unspecified	resource	m2	7,128E-06	4,910E-06	6,607E-06	6,789E-06	4,152E-06	5,956E-06	6,331E-06
	Transformation, from pasture and meadow, unspecified	resource	m2	3,236E-07	3,130E-07	6,862E-07	8,377E-07	3,872E-07	7,405E-07	7,871E-07
	Transformation, from pasture and meadow, extensive	resource	m2	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
	Transformation, from pasture and meadow, intensive	resource	m2	1,139E-08	1,127E-08	1,072E-08	9,055E-10	1,457E-08	8,024E-10	8,529E-10
	Transformation, from shrub land, sclerophyllous	resource	m2	1,976E-07	1,971E-07	4,572E-07	5,554E-07	2,399E-07	4,913E-07	5,222E-07
	Transformation, from unknown	resource	m2	7,560E-06	1,503E-05	1,008E-05	8,425E-06	5,586E-06	6,944E-06	7,381E-06
Emissions to air	Ammonia	air	kg	1,198E-05	1,065E-06	7,484E-06	7,672E-06	6,378E-06	6,795E-06	7,223E-06
	Arsenic	air	kg	2,480E-09	1,610E-09	2,705E-09	2,428E-09	2,329E-09	1,609E-09	1,710E-09
	Cadmium	air	kg	1,175E-09	5,009E-10	1,055E-09	9,786E-10	1,035E-09	7,403E-10	7,869E-10
	Carbon dioxide, fossil	air	kg	1,332E-02	1,326E-02	1,547E-02	1,441E-02	7,549E-03	1,267E-02	1,348E-02
	Carbon monoxide, fossil	air	kg	8,209E-05	8,655E-05	7,106E-05	8,696E-05	6,807E-05	6,931E-05	7,368E-05
	Carbon-14	air	kBq	5,161E-05	6,053E-05	6,407E-05	6,155E-05	3,557E-05	5,263E-05	5,594E-05
	Chromium	air	kg	9,104E-08	5,901E-08	1,623E-07	1,271E-07	4,548E-08	1,128E-07	1,199E-07
	Chromium VI	air	kg	2,205E-09	1,397E-09	3,990E-09	3,140E-09	1,070E-09	2,786E-09	2,962E-09
	Dinitrogen monoxide	air	kg	3,806E-05	1,754E-07	2,167E-05	2,207E-05	1,964E-05	1,940E-05	2,064E-05
	Iodine-129	air	kBq	4,338E-08	4,970E-08	5,517E-08	5,323E-08	2,965E-08	4,532E-08	4,818E-08
	Lead	air	kg	8,466E-08	8,226E-08	4,357E-08	4,471E-08	4,143E-08	3,385E-08	3,598E-08
	Methane, fossil	air	kg	3,520E-05	3,147E-05	3,090E-05	2,967E-05	1,995E-05	2,608E-05	2,774E-05
	Mercury	air	kg	2,688E-09	3,259E-09	2,823E-09	1,502E-09	2,425E-09	1,241E-09	1,319E-09
	Nickel	air	kg	1,838E-08	6,638E-09	1,542E-08	1,442E-08	1,274E-08	1,155E-08	1,228E-08
	Nitrogen oxides	air	kg	5,955E-05	4,484E-05	6,059E-05	6,325E-05	3,022E-05	5,477E-05	5,822E-05
	NMVOC total	air	kg	1,497E-05	1,610E-05	1,137E-05	1,106E-05	6,135E-06	9,541E-06	1,014E-05
	thereof:									
	Benzene	air	kg	1,687E-06	2,054E-06	7,514E-08	7,702E-08	4,388E-08	6,631E-08	7,049E-08
	Benzo(a)pyrene	air	kg	7,945E-11	8,651E-11	7,886E-10	8,147E-10	6,333E-11	6,463E-10	6,870E-10
	Formaldehyde	air	kg	3,425E-08	6,808E-08	9,038E-08	9,654E-08	2,397E-08	8,539E-08	9,077E-08
	PAH	air	kg	3,162E-09	2,952E-09	3,395E-08	3,481E-08	1,934E-09	2,965E-08	3,152E-08
	PM10	air	kg	1,088E-05	1,206E-05	1,832E-05	3,343E-05	9,590E-06	2,008E-05	2,135E-05
	PM2.5	air	kg	5,953E-06	5,844E-06	9,585E-06	1,044E-05	3,946E-06	8,513E-06	9,049E-06
	PCDD/F (measured as I-TEQ)	air	kg	2,275E-14	2,653E-14	1,645E-14	1,531E-14	1,443E-14	6,257E-15	6,651E-15
	Radon-222	air	kBq	8,259E-01	9,770E-01	1,065E+00	1,025E+00	5,730E-01	8,737E-01	9,287E-01
	Sulfur dioxide	air	kg	2,916E-05	2,702E-05	3,087E-05	3,251E-05	1,594E-05	2,550E-05	2,711E-05
Extended List	Global Warming Potential (non-biogenic)	air	kg CO2-eq.	2,563E-02	1,428E-02	2,218E-02	2,241E-02	1,415E-02	1,892E-02	2,012E-02
List for External	Global Warming Potential (biogenic)	air	kg CO2-eq.	-2,496E-05	2,178E-05	5,423E-05	3,911E-05	2,471E-05	3,430E-05	3,646E-05
Cost Assessment	Aerosols, radioactive, unspecified	air	kBq	8,734E-09	9,812E-09	1,187E-08	1,152E-08	5,948E-09	9,724E-09	1,034E-08
	Hydrogen-3, Tritium	air	kBq	2,299E-04	2,627E-04	2,997E-04	2,897E-04	1,572E-04	2,460E-04	2,615E-04
	Iodine-131	air	kBq	1,768E-07	3,473E-07	3,463E-07	3,257E-07	1,647E-07	2,891E-07	3,073E-07
	Iodine-133	air	kBq	8,416E-11	1,998E-10	1,367E-10	1,194E-10	8,633E-11	1,062E-10	1,129E-10
	Iodine-135	air	kBq	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
	Krypton-85	air	kBq	1,540E-06	3,098E-06	2,973E-06	2,778E-06	1,452E-06	2,466E-06	2,622E-06
	Krypton-85m	air	kBq	1,035E-06	2,447E-06	1,689E-06	1,477E-06	1,059E-06	1,314E-06	1,397E-06
	Noble gases, radioactive, unspecified	air	kBq	4,168E-01	4,776E-01	5,301E-01	5,115E-01	2,849E-01	4,355E-01	4,629E-01
	Sulfur hexafluoride	air	kg	4,803E-09	4,821E-09	1,691E-09	1,674E-09	1,008E-08	1,443E-09	1,533E-09
	Thorium-230	air	kBq	2,472E-08	2,827E-08	3,101E-08	2,995E-08	1,714E-08	2,551E-08	2,712E-08
	Uranium-234	air	kBq	7,426E-08	8,688E-08	9,489E-08	9,142E-08	5,151E-08	7,792E-08	8,283E-08
	Uranium-235	air	kBq	3,526E-09	4,171E-09	4,546E-09	4,375E-09	2,446E-09	3,730E-09	3,965E-09
	Uranium-238	air	kBq	1,092E-07	1,167E-07	2,223E-07	2,177E-07	7,493E-08	1,737E-07	1,846E-07
Emissions to Water	Ammonium, ion	water	kg	4,813E-08	5,209E-08	4,355E-08	5,169E-08	4,154E-08	4,351E-08	4,625E-08
	Arsenic, ion	water	kg	2,677E-08	2,884E-08	4,217E-08	4,586E-08	2,551E-08	4,007E-08	4,260E-08
	Cadmium, ion	water	kg	1,968E-08	2,061E-08	1,837E-08	2,356E-08	1,890E-08	2,075E-08	2,205E-08
	Carbon-14	water	kBq	1,739E-05	1,985E-05	2,195E-05	2,119E-05	1,186E-05	1,805E-05	1,918E-05
	Cesium-137	water	kBq	8,125E-06	9,333E-06	1,034E-05	9,977E-06	5,559E-06	8,495E-06	9,030E-06
	Chromium, ion	water	kg	1,949E-09	2,553E-09	2,891E-09	2,899E-09	1,688E-09	2,544E-09	2,705E-09
	Chromium VI	water	kg	4,105E-07	4,908E-07	5,421E-07	4,244E-07	3,898E-07	3,725E-07	3,959E-07
	COD	water	kg	9,108E-05	9,648E-05	6,646E-05	7,407E-05	4,504E-05	6,313E-05	6,711E-05
	Copper, ion	water	kg	1,872E-07	1,640E-07	1,723E-07	3,455E-07	1,418E-07	3,047E-07	3,239E-07
	Lead	water	kg	4,760E-08	5,137E-08	5,998E-08	8,117E-08	4,477E-08	7,140E-08	7,590E-08
	Mercury	water	kg	2,383E-09	2,742E-09	2,478E-09	3,024E-09	2,279E-09	2,664E-09	2,832E-09
	Nickel, ion	water	kg	6,662E-07	6,306E-07	9,516E-07	8,909E-07	4,985E-07	7,878E-07	8,374E-07
	Nitrate	water	kg	4,621E-07	4,626E-07	4,746E-07	2,447E-07	9,394E-07	2,108E-07	2,240E-07
	Oils, unspecified	water	kg	6,449E-06	5,276E-06	8,286E-06	8,916E-06	4,735E-06	7,669E-06	8,152E-06
	PAH	water	kg	2,246E-09	1,491E-09	3,900E-09	3,215E-09	1,164E-09	2,832E-09	3,010E-09
	Phosphate	water	kg	1,906E-06	2,035E-06	2,333E-06	2,732E-06	1,805E-06	2,396E-06	2,547E-06
Extended List	Hydrogen-3, Tritium	water	kBq	1,939E-02	2,210E-02	2,447E-02	2,362E-02	1,321E-02	2,012E-02	2,138E-02
List for External	Iodine-131	water	kBq	2,511E-09	3,403E-09	3,526E-09	3,352E-09	1,868E-09	2,862E-09	3,042E-09
Cost Assessment	Iodine-133	water	kBq	1,150E-10	2,730E-10	1,868E-10	1,631E-10	1,179E-10	1,450E-10	1,542E-10
	Krypton-85	water	kBq	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
	Thorium-230	water	kBq	1,572E-05	1,860E-05	2,027E-05	1,951E-05	1,091E-05	1,663E-05	1,768E-05
	Uranium-234	water	kBq	1,383E-07	1,636E-07	1,783E-07	1,716E-07	9,594E-08	1,463E-07	1,555E-07
	Uranium-235	water	kBq	2,282E-07	2,699E-07	2,942E-07	2,831E-07	1,583E-07	2,413E-07	2,565E-07
	Uranium-238	water	kBq	5,567E-07	5,518E-07	7,799E-07	7,693E-07	3,854E-07	6,399E-07	6,802E-07
Emissions to Soil	Arsenic	soil	kg	1,865E-11	1,290E-11	2,335E-11	2,374E-11	1,203E-11	2,073E-11	2,204E-11
	Cadmium	soil	kg	1,178E-11	7,947E-12	1,139E-11	1,064E-11	8,637E-12	1,015E-11	1,079E-11
	Chromium	soil	kg	6,605E-10	3,111E-10	5,582E-10	5,466E-10	3,907E-10	4,863E-10	5,169E-10
	Chromium VI	soil	kg	8,761E-10	9,259E-10	1,855E-09	1,862E-09	5,869E-10	1,589E-09	1,689E-09
	Lead	soil	kg	1,367E-10	6,583E-11	9,889E-11	1,008E-10	8,117E-11	9,256E-11	9,839E-11
	Mercury	soil	kg	3,244E-13	3,270E-13	2,904E-13	1,170E-13	3,950E-13	1,085E-13	1,153E-13
	Oils, unspecified	soil	kg	4,613E-06	3,299E-06	6,838E-06	7,046E-06	3,012E-06	6,015E-06	6,393E-06

Table 7.6: Emissions' list of the modelled solar thermal power plants (2050 technologies)

2050_PS_TR	**Parabolic Trough, thermoil, salt storage**	**2050_RO_TO**	**Central receiver, salt, salt storage**
2050_PS_TRC	**Parabolic Trough, thermoil, concrete storage**	**2050_VO_FRC**	**Fresnel, combined cycle (cooling)**
2050_RO_TR	**Parabolic Trough, direct steam, PCM storage**	**2050_VO_FRD**	**Fresnel, combined cycle (desalting)**
2050_RO_FR	**Fresnel, direct steam, PCM storage**		

	Parameter (per kWh,el)	Path	Unit	2050_PS_TR	2050_PS_TRC	2050_RO_TR	2050_RO_FR	2050_RO_TO	2050_VO_FRC	2050_VO_FRD
Resources	Coal, brown, in ground	resource	kg	2,068E-05	3,441E-05	3,128E-05	2,966E-05	1,584E-05	2,630E-05	2,796E-05
	Coal, hard, unspecified, in ground	resource	kg	1,940E-03	2,189E-03	2,527E-03	2,968E-03	1,622E-03	2,328E-03	2,474E-03
	Gas, natural, in ground	resource	Nm3	3,262E-03	2,233E-03	1,584E-03	1,574E-03	1,255E-03	1,361E-03	1,446E-03
	Oil, crude, in ground	resource	kg	1,814E-03	1,829E-03	1,371E-03	1,415E-03	5,992E-04	1,189E-03	1,264E-03
	Uranium, in ground	resource	kg	2,561E-08	2,958E-08	2,775E-08	2,728E-08	1,609E-08	2,300E-08	2,445E-08
	Freshwater (lake, river, groundwater)	resource	m3	2,817E-04	3,122E-04	3,892E-04	6,891E-04	3,316E-04	6,094E-04	6,478E-04
	Occupation, agricultural and forestal area	resource	m2a	5,969E-04	4,249E-04	4,462E-04	4,612E-04	3,354E-04	4,092E-04	4,350E-04
	Occupation, built up area incl. mineral extraction and dump sites	resource	m2a	1,354E-02	1,386E-02	9,045E-03	5,492E-03	1,580E-02	4,874E-03	5,181E-03
Extended List	Transformation, from arable, unspecified	resource	m2	3,482E-04	3,559E-04	2,355E-04	1,362E-04	1,631E-05	1,209E-04	1,285E-04
List for External	Transformation, from arable, intensive	resource	m2	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
Cost Assessment	Transformation, from forest, unspecified	resource	m2	6,113E-06	4,207E-06	5,397E-06	5,587E-06	3,435E-06	4,925E-06	5,235E-06
	Transformation, from pasture and meadow, unspecified	resource	m2	2,722E-07	2,629E-07	5,682E-07	7,054E-07	3,277E-07	6,238E-07	6,630E-07
	Transformation, from pasture and meadow, extensive	resource	m2	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
	Transformation, from pasture and meadow, intensive	resource	m2	1,002E-08	9,919E-09	9,371E-09	7,523E-10	1,278E-08	6,609E-10	7,026E-10
	Transformation, from shrub land, sclerophyllous	resource	m2	1,652E-07	1,646E-07	3,766E-07	4,653E-07	2,027E-07	4,125E-07	4,385E-07
	Transformation, from unknown	resource	m2	6,219E-06	1,262E-05	7,769E-06	6,413E-06	4,312E-06	5,344E-06	5,680E-06
Emissions to air	Ammonia	air	kg	1,025E-05	8,948E-07	6,374E-06	6,542E-06	5,444E-06	5,789E-06	6,153E-06
	Arsenic	air	kg	2,129E-09	1,383E-09	1,539E-09	1,395E-09	1,359E-09	6,564E-10	6,978E-10
	Cadmium	air	kg	1,010E-09	4,312E-10	7,386E-10	6,861E-10	7,084E-10	4,257E-10	4,525E-10
	Carbon dioxide, fossil	air	kg	1,094E-02	1,089E-02	1,283E-02	1,285E-02	5,735E-03	1,118E-02	1,189E-02
	Carbon monoxide, fossil	air	kg	6,768E-05	7,134E-05	5,263E-05	6,545E-05	4,979E-05	5,346E-05	5,682E-05
	Carbon-14	air	kBq	5,014E-05	5,754E-05	6,899E-05	6,797E-05	4,210E-05	5,747E-05	6,109E-05
	Chromium	air	kg	7,592E-08	4,843E-08	1,326E-07	1,040E-07	3,904E-08	9,224E-08	9,805E-08
	Chromium VI	air	kg	1,839E-09	1,147E-09	3,260E-09	2,568E-09	9,217E-10	2,277E-09	2,421E-09
	Dinitrogen monoxide	air	kg	3,261E-05	1,352E-07	1,854E-05	1,889E-05	1,682E-05	1,677E-05	1,782E-05
	Iodine-129	air	kBq	4,224E-08	4,744E-08	4,637E-08	4,567E-08	2,673E-08	3,842E-08	4,084E-08
	Lead	air	kg	7,153E-08	6,942E-08	1,796E-08	1,787E-08	1,613E-08	1,397E-08	1,485E-08
	Methane, fossil	air	kg	2,984E-05	2,661E-05	2,542E-05	2,768E-05	1,400E-05	2,397E-05	2,548E-05
	Mercury	air	kg	2,222E-09	2,681E-09	2,224E-09	1,146E-09	1,928E-09	9,683E-10	1,029E-09
	Nickel	air	kg	1,560E-08	5,519E-09	1,122E-08	1,062E-08	9,385E-09	8,150E-09	8,663E-09
	Nitrogen oxides	air	kg	5,258E-05	4,003E-05	4,898E-05	5,150E-05	2,421E-05	4,406E-05	4,683E-05
	NMVOC total	air	kg	1,333E-05	1,428E-05	9,155E-06	9,018E-06	4,998E-06	7,612E-06	8,091E-06
	thereof:									
	Benzene	air	kg	1,598E-06	1,911E-06	6,049E-08	6,264E-08	3,542E-08	5,306E-08	5,640E-08
	Benzo(a)pyrene	air	kg	6,591E-11	7,171E-11	4,165E-10	4,335E-10	4,676E-11	3,638E-10	3,867E-10
	Formaldehyde	air	kg	2,930E-08	5,829E-08	7,649E-08	8,197E-08	2,036E-08	7,241E-08	7,697E-08
	PAH	air	kg	2,694E-09	2,505E-09	2,596E-08	2,669E-08	1,304E-09	2,276E-08	2,419E-08
	PM10	air	kg	9,074E-06	1,007E-05	1,502E-05	2,721E-05	7,788E-06	1,672E-05	1,778E-05
	PM2.5	air	kg	5,097E-06	5,000E-06	7,289E-06	8,020E-06	2,968E-06	6,901E-06	7,336E-06
	PCDD/F (measured as I-TEQ)	air	kg	1,876E-14	2,191E-14	8,335E-15	5,877E-15	6,319E-15	4,708E-15	5,004E-15
	Radon-222	air	kBq	8,011E-01	9,266E-01	8,983E-01	8,817E-01	5,181E-01	7,431E-01	7,899E-01
	Sulfur dioxide	air	kg	2,512E-05	2,327E-05	2,194E-05	2,336E-05	1,154E-05	1,835E-05	1,951E-05
Extended List	Global Warming Potential (non-biogenic)	air	kg CO2-eq.	2,148E-02	1,175E-02	1,721E-02	1,749E-02	1,131E-02	1,472E-02	1,565E-02
List for External	Global Warming Potential (biogenic)	air	kg CO2-eq.	-2,001E-05	2,008E-05	4,519E-05	3,256E-05	2,727E-05	2,924E-05	3,108E-05
Cost Assessment	Aerosols, radioactive, unspecified	air	kBq	1,067E-08	1,151E-08	9,315E-09	9,200E-09	4,991E-09	8,557E-09	9,096E-09
	Hydrogen-3, Tritium	air	kBq	2,239E-04	2,508E-04	1,970E-04	1,936E-04	1,053E-04	1,619E-04	1,721E-04
	Iodine-131	air	kBq	1,514E-07	2,973E-07	2,987E-07	2,849E-07	1,449E-07	2,526E-07	2,686E-07
	Iodine-133	air	kBq	7,224E-11	1,713E-10	1,165E-10	1,017E-10	7,604E-11	9,047E-11	9,616E-11
	Iodine-135	air	kBq	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
	Krypton-85	air	kBq	1,318E-06	2,651E-06	2,945E-06	2,809E-06	1,536E-06	2,477E-06	2,633E-06
	Krypton-85m	air	kBq	8,880E-07	2,098E-06	1,439E-06	1,258E-06	9,327E-07	1,120E-06	1,190E-06
	Noble gases, radioactive, unspecified	air	kBq	4,059E-01	4,559E-01	4,452E-01	4,385E-01	2,566E-01	3,688E-01	3,921E-01
	Sulfur hexafluoride	air	kg	4,013E-09	4,023E-09	1,334E-09	1,356E-09	8,793E-09	1,163E-09	1,237E-09
	Thorium-230	air	kBq	2,379E-08	2,672E-08	2,611E-08	2,569E-08	1,538E-08	2,160E-08	2,296E-08
	Uranium-234	air	kBq	7,184E-08	8,231E-08	8,000E-08	7,858E-08	4,646E-08	6,618E-08	7,035E-08
	Uranium-235	air	kBq	3,420E-09	3,956E-09	3,835E-09	3,764E-09	2,212E-09	3,173E-09	3,372E-09
	Uranium-238	air	kBq	1,007E-07	1,068E-07	1,748E-07	1,731E-07	6,517E-08	1,328E-07	1,412E-07
Emissions to Water	Ammonium, ion	water	kg	4,315E-08	4,646E-08	3,610E-08	4,324E-08	3,490E-08	3,471E-08	3,689E-08
	Arsenic, ion	water	kg	2,189E-08	2,356E-08	3,373E-08	3,737E-08	2,067E-08	3,218E-08	3,420E-08
	Cadmium, ion	water	kg	1,614E-08	1,689E-08	1,491E-08	1,960E-08	1,533E-08	1,705E-08	1,812E-08
	Carbon-14	water	kBq	1,694E-05	1,896E-05	1,946E-05	1,919E-05	1,136E-05	1,615E-05	1,717E-05
	Cesium-137	water	kBq	7,909E-06	8,904E-06	8,673E-06	8,540E-06	4,998E-06	7,184E-06	7,636E-06
	Chromium, ion	water	kg	1,630E-09	2,130E-09	2,361E-09	2,402E-09	1,383E-09	2,089E-09	2,220E-09
	Chromium VI	water	kg	3,377E-07	4,024E-07	4,374E-07	3,465E-07	3,176E-07	3,000E-07	3,188E-07
	COD	water	kg	8,032E-05	8,485E-05	5,270E-05	5,945E-05	3,547E-05	5,008E-05	5,324E-05
	Copper, ion	water	kg	1,573E-07	1,372E-07	1,409E-07	2,892E-07	1,169E-07	2,524E-07	2,683E-07
	Lead	water	kg	3,926E-08	4,238E-08	4,927E-08	6,832E-08	3,636E-08	5,961E-08	6,336E-08
	Mercury	water	kg	1,957E-09	2,255E-09	2,017E-09	2,517E-09	1,852E-09	2,191E-09	2,329E-09
	Nickel, ion	water	kg	5,513E-07	5,186E-07	7,772E-07	7,359E-07	4,126E-07	6,468E-07	6,875E-07
	Nitrate	water	kg	4,032E-07	4,035E-07	4,022E-07	2,016E-07	8,144E-07	1,722E-07	1,830E-07
	Oils, unspecified	water	kg	5,510E-06	4,498E-06	6,684E-06	7,265E-06	3,808E-06	6,174E-06	6,562E-06
	PAH	water	kg	1,887E-09	1,240E-09	3,180E-09	2,625E-09	9,847E-10	2,304E-09	2,449E-09
	Phosphate	water	kg	1,563E-06	1,668E-06	1,874E-06	2,243E-06	1,462E-06	1,940E-06	2,063E-06
Extended List	Hydrogen-3, Tritium	water	kBq	1,889E-02	2,112E-02	2,180E-02	2,151E-02	1,274E-02	1,811E-02	1,925E-02
List for External	Iodine-131	water	kBq	2,394E-09	3,148E-09	1,866E-09	1,762E-09	9,430E-10	1,489E-09	1,582E-09
Cost Assessment	Iodine-133	water	kBq	9,868E-11	2,340E-10	1,591E-10	1,389E-10	1,039E-10	1,236E-10	1,314E-10
	Krypton-85	water	kBq	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00	0,000E+00
	Thorium-230	water	kBq	1,525E-05	1,764E-05	1,710E-05	1,679E-05	9,862E-06	1,415E-05	1,504E-05
	Uranium-234	water	kBq	1,341E-07	1,551E-07	1,504E-07	1,476E-07	8,674E-08	1,244E-07	1,323E-07
	Uranium-235	water	kBq	2,213E-07	2,560E-07	2,481E-07	2,436E-07	1,431E-07	2,053E-07	2,182E-07
	Uranium-238	water	kBq	4,941E-07	4,884E-07	6,132E-07	6,117E-07	3,221E-07	5,013E-07	5,329E-07
Emissions to Soil	Arsenic	soil	kg	1,619E-11	1,125E-11	1,892E-11	1,939E-11	9,784E-12	1,698E-11	1,805E-11
	Cadmium	soil	kg	1,097E-11	7,702E-12	9,464E-12	8,918E-12	7,232E-12	8,948E-12	9,512E-12
	Chromium	soil	kg	5,818E-10	2,823E-10	4,621E-10	4,543E-10	3,278E-10	4,084E-10	4,341E-10
	Chromium VI	soil	kg	7,505E-10	7,907E-10	1,421E-09	1,450E-09	4,843E-10	1,248E-09	1,326E-09
	Lead	soil	kg	1,222E-10	6,158E-11	8,276E-11	8,520E-11	6,844E-11	8,008E-11	8,512E-11
	Mercury	soil	kg	2,804E-13	2,825E-13	2,484E-13	9,735E-14	3,447E-13	9,216E-14	9,796E-14
	Oils, unspecified	soil	kg	4,001E-06	2,872E-06	5,510E-06	5,704E-06	2,408E-06	4,814E-06	5,117E-06

Table 7.7: Emissions' list of the modelled solar thermal power plants (weighted results, case A = Spain, including HVDC transmission to Germany)

	Parameter (per kWh,el)				Pessimistic		realistic-optimistic		very optimistic	
		Path	Unit	Current	2025	2050	2025	2050	2025	2050
Resources	Coal, brown, in ground	resource	kg	1,04E-03	1,92E-04	6,18E-05	1,74E-04	6,18E-05	1,62E-04	6,14E-05
	Coal, hard, unspecified, in ground	resource	kg	4,38E-03	2,84E-03	2,34E-03	3,66E-03	2,84E-03	3,60E-03	2,71E-03
	Gas, natural, in ground	resource	Nm3	4,17E-03	3,34E-03	3,00E-03	2,02E-03	1,66E-03	1,88E-03	1,54E-03
	Oil, crude, in ground	resource	kg	2,61E-03	2,22E-03	2,01E-03	1,70E-03	1,38E-03	1,71E-03	1,37E-03
	Uranium, in ground	resource	kg	5,92E-08	3,28E-08	3,15E-08	3,34E-08	2,89E-08	3,18E-08	2,73E-08
	Freshwater (lake, river, groundwater)	resource	m3	3,36E-04	3,45E-04	3,24E-04	5,62E-04	5,42E-04	7,03E-04	6,83E-04
	Occupation, agricultural and forestal area	resource	m2a	8,75E-04	6,61E-04	5,59E-04	5,87E-04	4,71E-04	5,64E-04	4,62E-04
	Occupation, built up area incl. mineral extraction and dump sites	resource	m2a	1,70E-02	1,49E-02	1,48E-02	9,76E-03	9,72E-03	5,48E-03	5,45E-03
Extended List	Transformation, from arable, unspecified	resource	m2	4,50E-04	4,36E-04	3,81E-04	1,88E-04	1,65E-04	1,55E-04	1,35E-04
List for External	Transformation, from arable, intensive	resource	m2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Cost Assessment	Transformation, from forest, unspecified	resource	m2	9,65E-06	6,62E-06	5,69E-06	6,81E-06	5,61E-06	6,76E-06	5,61E-06
	Transformation, from pasture and meadow, unspecified	resource	m2	5,36E-07	3,55E-07	3,00E-07	7,55E-07	6,33E-07	8,38E-07	7,07E-07
	Transformation, from pasture and meadow, extensive	resource	m2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Transformation, from pasture and meadow, intensive	resource	m2	1,70E-08	1,23E-08	1,08E-08	8,19E-09	7,15E-09	8,96E-10	7,38E-10
	Transformation, from shrub land, sclerophyllous	resource	m2	3,38E-07	2,24E-07	1,89E-07	5,01E-07	4,19E-07	5,59E-07	4,71E-07
	Transformation, from unknown	resource	m2	7,47E-06	1,24E-05	1,04E-05	9,38E-06	7,24E-06	7,92E-06	6,13E-06
Emissions to air	Ammonia	air	kg	1,43E-05	7,08E-06	6,05E-06	7,96E-06	6,79E-06	7,61E-06	6,48E-06
	Arsenic	air	kg	3,39E-09	2,21E-09	1,90E-09	2,73E-09	1,56E-09	1,80E-09	7,33E-10
	Cadmium	air	kg	1,50E-09	9,07E-10	7,80E-10	1,10E-09	7,70E-10	8,27E-10	4,75E-10
	Carbon dioxide, fossil	air	kg	1,96E-02	1,47E-02	1,21E-02	1,49E-02	1,27E-02	1,45E-02	1,28E-02
	Carbon monoxide, fossil	air	kg	1,38E-04	9,34E-05	7,74E-05	8,53E-05	6,41E-05	7,95E-05	6,18E-05
	Carbon-14	air	kBq	1,04E-04	6,34E-05	6,10E-05	6,48E-05	7,11E-05	6,14E-05	6,69E-05
	Chromium	air	kg	1,38E-07	8,66E-08	7,27E-08	1,41E-07	1,16E-07	1,31E-07	1,08E-07
	Chromium VI	air	kg	3,19E-09	1,95E-09	1,62E-09	3,32E-09	2,72E-09	3,11E-09	2,54E-09
	Dinitrogen monoxide	air	kg	4,72E-05	2,33E-05	2,04E-05	2,58E-05	2,25E-05	2,43E-05	2,14E-05
	Iodine-129	air	kBq	1,02E-07	5,31E-08	5,12E-08	5,60E-08	4,83E-08	5,33E-08	4,56E-08
	Lead	air	kg	1,30E-07	9,09E-08	7,68E-08	4,77E-08	1,95E-08	3,83E-08	1,61E-08
	Methane, fossil	air	kg	4,92E-05	3,66E-05	3,11E-05	3,11E-05	2,66E-05	2,97E-05	2,73E-05
	Mercury	air	kg	4,54E-09	3,22E-09	2,65E-09	2,40E-09	1,88E-09	1,39E-09	1,08E-09
	Nickel	air	kg	2,57E-08	1,41E-08	1,20E-08	1,62E-08	1,20E-08	1,34E-08	9,64E-09
	Nitrogen oxides	air	kg	8,39E-05	5,76E-05	5,12E-05	6,12E-05	4,98E-05	6,22E-05	5,03E-05
	NMVOC total	air	kg	1,90E-05	1,71E-05	1,52E-05	1,13E-05	9,22E-06	1,09E-05	8,77E-06
	thereof:			0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Benzene	air	kg	1,76E-06	2,03E-06	1,90E-06	7,75E-08	6,31E-08	7,62E-08	6,14E-08
	Benzo(a)pyrene	air	kg	2,55E-10	1,43E-10	1,28E-10	7,61E-10	4,32E-10	7,75E-10	4,60E-10
	Formaldehyde	air	kg	4,71E-08	5,59E-08	4,80E-08	8,67E-08	7,36E-08	9,59E-08	8,14E-08
	PAH	air	kg	5,78E-09	4,38E-09	3,88E-09	3,13E-08	2,42E-08	3,42E-08	2,65E-08
	PM10	air	kg	2,79E-05	1,30E-05	1,09E-05	2,50E-05	2,05E-05	2,30E-05	1,92E-05
	PM2.5	air	kg	1,01E-05	6,65E-06	5,73E-06	9,79E-06	7,54E-06	9,77E-06	7,97E-06
	PCDD/F (measured as I-TEQ)	air	kg	3,77E-14	2,67E-14	2,20E-14	1,69E-14	7,52E-15	6,99E-15	5,26E-15
	Radon-222	air	kBq	1,88E+00	1,02E+00	9,83E-01	1,08E+00	9,31E-01	1,02E+00	8,78E-01
	Sulfur dioxide	air	kg	5,12E-05	3,15E-05	2,73E-05	3,20E-05	2,32E-05	2,95E-05	2,16E-05
Extended List	Global Warming Potential (non-biogenic)	air	kg CO2-eq.	3,44E-02	2,20E-02	1,84E-02	2,28E-02	1,79E-02	2,15E-02	1,68E-02
List for External	Global Warming Potential (biogenic)	air	kg CO2-eq.	-3,05E-05	-1,19E-07	1,64E-06	4,74E-05	4,12E-05	3,99E-05	3,43E-05
Cost Assessment	Aerosols, radioactive, unspecified	air	kBq	2,37E-08	1,06E-08	1,25E-08	1,19E-08	9,63E-09	1,14E-08	1,01E-08
	Hydrogen-3, Tritium	air	kBq	5,80E-04	2,83E-04	2,73E-04	3,05E-04	2,08E-04	2,91E-04	1,97E-04
	Iodine-131	air	kBq	5,75E-06	3,90E-07	3,50E-07	4,33E-07	3,91E-07	4,30E-07	3,89E-07
	Iodine-133	air	kBq	2,08E-10	1,59E-10	1,37E-10	1,35E-10	1,16E-10	1,24E-10	1,06E-10
	Iodine-135	air	kBq	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Krypton-85	air	kBq	4,53E-05	3,04E-06	2,68E-06	3,34E-06	3,36E-06	3,29E-06	3,30E-06
	Krypton-85m	air	kBq	3,21E-06	1,94E-06	1,67E-06	1,65E-06	1,42E-06	1,52E-06	1,30E-06
	Noble gases, radioactive, unspecified	air	kBq	9,84E-01	5,11E-01	4,93E-01	5,39E-01	4,65E-01	5,13E-01	4,39E-01
	Sulfur hexafluoride	air	kg	1,16E-08	5,21E-09	4,35E-09	3,64E-09	3,07E-09	1,61E-09	1,30E-09
	Thorium-230	air	kBq	5,50E-08	3,03E-08	2,89E-08	3,17E-08	2,74E-08	3,01E-08	2,57E-08
	Uranium-234	air	kBq	1,68E-07	9,15E-08	8,77E-08	9,61E-08	8,30E-08	9,13E-08	7,82E-08
	Uranium-235	air	kBq	7,82E-09	4,17E-09	3,99E-09	4,39E-09	3,77E-09	4,17E-09	3,54E-09
	Uranium-238	air	kBq	2,91E-07	1,33E-07	1,23E-07	2,17E-07	1,75E-07	2,05E-07	1,59E-07
Emissions to Water	Ammonium, ion	water	kg	8,07E-08	5,53E-08	4,96E-08	5,13E-08	4,30E-08	4,97E-08	3,98E-08
	Arsenic, ion	water	kg	4,76E-08	3,12E-08	2,57E-08	4,47E-08	3,63E-08	4,58E-08	3,70E-08
	Cadmium, ion	water	kg	3,38E-08	2,23E-08	1,84E-08	2,28E-08	1,88E-08	2,37E-08	1,96E-08
	Carbon-14	water	kBq	3,99E-05	2,12E-05	2,05E-05	2,23E-05	2,03E-05	2,12E-05	1,91E-05
	Cesium-137	water	kBq	1,92E-05	9,99E-06	9,64E-06	1,05E-05	9,07E-06	1,00E-05	8,56E-06
	Chromium, ion	water	kg	3,27E-09	2,44E-09	2,04E-09	2,87E-09	2,36E-09	2,84E-09	2,33E-09
	Chromium VI	water	kg	7,11E-07	5,04E-07	4,17E-07	5,19E-07	4,24E-07	4,32E-07	3,51E-07
	COD	water	kg	1,26E-04	1,03E-04	9,10E-05	7,22E-05	5,79E-05	7,21E-05	5,75E-05
	Copper, ion	water	kg	2,84E-07	1,94E-07	1,63E-07	2,59E-07	2,15E-07	3,44E-07	2,86E-07
	Lead	water	kg	8,16E-08	5,46E-08	4,53E-08	7,19E-08	5,99E-08	8,08E-08	6,76E-08
	Mercury	water	kg	4,01E-09	2,77E-09	2,28E-09	2,88E-09	2,36E-09	2,98E-09	2,45E-09
	Nickel, ion	water	kg	1,08E-06	7,34E-07	6,11E-07	9,38E-07	7,77E-07	9,12E-07	7,54E-07
	Nitrate	water	kg	8,43E-07	5,04E-07	4,41E-07	5,19E-07	4,42E-07	2,39E-07	1,96E-07
	Oils, unspecified	water	kg	1,01E-05	6,56E-06	5,63E-06	8,69E-06	7,08E-06	8,78E-06	7,11E-06
	PAH	water	kg	3,26E-09	2,02E-09	1,69E-09	3,33E-09	2,73E-09	3,16E-09	2,57E-09
	Phosphate	water	kg	3,27E-06	2,19E-06	1,80E-06	2,64E-06	2,15E-06	2,73E-06	2,22E-06
Extended List	Hydrogen-3, Tritium	water	kBq	4,37E-02	2,35E-02	2,27E-02	2,48E-02	2,26E-02	2,35E-02	2,13E-02
List for External	Iodine-131	water	kBq	5,20E-09	3,20E-09	3,00E-09	3,38E-09	1,78E-09	3,20E-09	1,66E-09
Cost Assessment	Iodine-133	water	kBq	2,82E-10	2,15E-10	1,85E-10	1,82E-10	1,57E-10	1,67E-10	1,43E-10
	Krypton-85	water	kBq	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Thorium-230	water	kBq	3,59E-05	1,96E-05	1,89E-05	2,07E-05	1,79E-05	1,96E-05	1,69E-05
	Uranium-234	water	kBq	3,17E-07	1,74E-07	1,67E-07	1,83E-07	1,59E-07	1,74E-07	1,50E-07
	Uranium-235	water	kBq	5,22E-07	2,86E-07	2,74E-07	3,00E-07	2,60E-07	2,86E-07	2,45E-07
	Uranium-238	water	kBq	1,13E-06	6,27E-07	5,59E-07	7,81E-07	6,27E-07	7,41E-07	5,87E-07
Emissions to Soil	Arsenic	soil	kg	2,72E-11	1,76E-11	1,54E-11	2,35E-11	1,92E-11	2,37E-11	1,95E-11
	Cadmium	soil	kg	1,82E-11	1,07E-11	1,01E-11	1,14E-11	9,53E-12	1,13E-11	9,99E-12
	Chromium	soil	kg	8,71E-10	5,26E-10	4,68E-10	5,63E-10	4,68E-10	5,43E-10	4,56E-10
	Chromium VI	soil	kg	1,14E-09	9,76E-10	8,34E-10	1,74E-09	1,35E-09	1,77E-09	1,39E-09
	Lead	soil	kg	1,91E-10	1,15E-10	1,05E-10	1,09E-10	9,29E-11	1,09E-10	9,48E-11
	Mercury	soil	kg	5,11E-13	3,53E-13	3,05E-13	2,62E-13	2,24E-13	1,21E-13	1,03E-13
	Oils, unspecified	soil	kg	6,99E-06	4,44E-06	3,88E-06	6,83E-06	5,54E-06	6,88E-06	5,54E-06

Table 7.8: Emissions' list of the modelled solar thermal power plants (weighted results, mean of case A (Spain) and case B (Algeria), including HVDC transmission to Germany)

	Parameter (per kWh,el)				**Pessimistic**		**realistic-optimistic**		**very optimistic**	
		Path	**Unit**	**Current**	**2025**	**2050**	**2025**	**2050**	**2025**	**2050**
Resources	Coal, brown, in ground	resource	kg	9,12E-04	1,91E-04	8,08E-05	1,76E-04	8,08E-05	1,66E-04	8,05E-05
	Coal, hard, unspecified, in ground	resource	kg	3,81E-03	2,50E-03	2,08E-03	3,20E-03	2,50E-03	3,15E-03	2,39E-03
	Gas, natural, in ground	resource	Nm3	3,56E-03	2,85E-03	2,56E-03	1,73E-03	1,43E-03	1,61E-03	1,33E-03
	Oil, crude, in ground	resource	kg	2,26E-03	1,93E-03	1,75E-03	1,48E-03	1,21E-03	1,49E-03	1,20E-03
	Uranium, in ground	resource	kg	5,17E-08	2,93E-08	2,81E-08	2,98E-08	2,60E-08	2,84E-08	2,46E-08
	Freshwater (lake, river, groundwater)	resource	m3	2,88E-04	2,96E-04	2,78E-04	4,80E-04	4,62E-04	6,00E-04	5,83E-04
	Occupation, agricultural and forestal area	resource	m2a	7,49E-04	5,67E-04	4,80E-04	5,05E-04	4,06E-04	4,85E-04	3,99E-04
	Occupation, built up area incl. mineral extraction and dump sites	resource	m2a	1,44E-02	1,26E-02	1,26E-02	8,29E-03	8,26E-03	4,66E-03	4,63E-03
Extended List	Transformation, from arable, unspecified	resource	m2	3,82E-04	3,70E-04	3,24E-04	1,60E-04	1,40E-04	1,31E-04	1,15E-04
List for External	Transformation, from arable, intensive	resource	m2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Cost Assessment	Transformation, from forest, unspecified	resource	m2	8,30E-06	5,73E-06	4,94E-06	5,88E-06	4,86E-06	5,84E-06	4,86E-06
	Transformation, from pasture and meadow, unspecified	resource	m2	4,65E-07	3,11E-07	2,65E-07	6,50E-07	5,47E-07	7,21E-07	6,10E-07
	Transformation, from pasture and meadow, extensive	resource	m2	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Transformation, from pasture and meadow, intensive	resource	m2	1,44E-08	1,04E-08	9,18E-09	6,96E-09	6,09E-09	7,72E-10	6,37E-10
	Transformation, from shrub land, sclerophyllous	resource	m2	2,97E-07	2,00E-07	1,70E-07	4,35E-07	3,66E-07	4,85E-07	4,10E-07
	Transformation, from unknown	resource	m2	6,49E-06	1,07E-05	8,94E-06	8,12E-06	6,29E-06	6,87E-06	5,35E-06
Emissions to air	Ammonia	air	kg	1,21E-05	6,03E-06	5,16E-06	6,78E-06	5,78E-06	6,48E-06	5,52E-06
	Arsenic	air	kg	3,04E-09	2,04E-09	1,77E-09	2,47E-09	1,49E-09	1,68E-09	7,81E-10
	Cadmium	air	kg	1,33E-09	8,23E-10	7,15E-10	9,91E-10	7,07E-10	7,55E-10	4,57E-10
	Carbon dioxide, fossil	air	kg	1,69E-02	1,28E-02	1,06E-02	1,29E-02	1,11E-02	1,26E-02	1,12E-02
	Carbon monoxide, fossil	air	kg	1,19E-04	8,12E-05	6,76E-05	7,43E-05	5,63E-05	6,94E-05	5,44E-05
	Carbon-14	air	kBq	9,05E-05	5,62E-05	5,41E-05	5,74E-05	6,28E-05	5,46E-05	5,92E-05
	Chromium	air	kg	1,23E-07	7,91E-08	6,73E-08	1,25E-07	1,04E-07	1,17E-07	9,76E-08
	Chromium VI	air	kg	2,73E-09	1,68E-09	1,39E-09	2,84E-09	2,33E-09	2,66E-09	2,18E-09
	Dinitrogen monoxide	air	kg	4,23E-05	2,21E-05	1,95E-05	2,42E-05	2,13E-05	2,29E-05	2,04E-05
	Iodine-129	air	kBq	8,93E-08	4,74E-08	4,59E-08	5,00E-08	4,34E-08	4,76E-08	4,11E-08
	Lead	air	kg	1,12E-07	7,87E-08	6,68E-08	4,21E-08	1,81E-08	3,41E-08	1,52E-08
	Methane, fossil	air	kg	4,23E-05	3,16E-05	2,69E-05	2,69E-05	2,30E-05	2,57E-05	2,37E-05
	Mercury	air	kg	3,85E-09	2,73E-09	2,25E-09	2,04E-09	1,59E-09	1,18E-09	9,18E-10
	Nickel	air	kg	2,26E-08	1,27E-08	1,09E-08	1,45E-08	1,09E-08	1,21E-08	8,90E-09
	Nitrogen oxides	air	kg	7,22E-05	4,99E-05	4,44E-05	5,30E-05	4,33E-05	5,38E-05	4,36E-05
	NMVOC total	air	kg	1,64E-05	1,47E-05	1,32E-05	9,84E-06	8,07E-06	9,51E-06	7,68E-06
	thereof:			0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Benzene	air	kg	1,49E-06	1,72E-06	1,62E-06	6,77E-08	5,55E-08	6,66E-08	5,40E-08
	Benzo(a)pyrene	air	kg	2,62E-10	1,67E-10	1,54E-10	6,92E-10	4,12E-10	7,04E-10	4,36E-10
	Formaldehyde	air	kg	4,05E-08	4,80E-08	4,12E-08	7,41E-08	6,30E-08	8,19E-08	6,96E-08
	PAH	air	kg	5,82E-09	4,63E-09	4,21E-09	2,75E-08	2,14E-08	2,99E-08	2,34E-08
	PM10	air	kg	2,42E-05	1,15E-05	9,75E-06	2,17E-05	1,79E-05	2,00E-05	1,68E-05
	PM2.5	air	kg	8,79E-06	5,90E-06	5,12E-06	8,57E-06	6,65E-06	8,55E-06	7,02E-06
	PCDD/F (measured as I-TEQ)	air	kg	3,21E-14	2,27E-14	1,87E-14	1,44E-14	6,44E-15	5,99E-15	4,52E-15
	Radon-222	air	kBq	1,64E+00	9,12E-01	8,78E-01	9,57E-01	8,33E-01	9,12E-01	7,88E-01
	Sulfur dioxide	air	kg	4,45E-05	2,78E-05	2,42E-05	2,82E-05	2,07E-05	2,61E-05	1,93E-05
Extended List	Global Warming Potential (non-biogenic)	air	kg CO2-eq.	2,96E-02	1,90E-02	1,59E-02	1,97E-02	1,55E-02	1,86E-02	1,46E-02
List for External	Global Warming Potential (biogenic)	air	kg CO2-eq.	-2,51E-05	7,86E-07	2,28E-06	4,11E-05	3,59E-05	3,48E-05	3,00E-05
Cost Assessment	Aerosols, radioactive, unspecified	air	kBq	2,06E-08	9,46E-09	1,11E-08	1,06E-08	8,66E-09	1,02E-08	9,05E-09
	Hydrogen-3, Tritium	air	kBq	5,07E-04	2,54E-04	2,46E-04	2,73E-04	1,91E-04	2,61E-04	1,81E-04
	Iodine-131	air	kBq	4,98E-06	4,27E-07	3,93E-07	4,64E-07	4,28E-07	4,60E-07	4,26E-07
	Iodine-133	air	kBq	1,81E-10	1,40E-10	1,21E-10	1,19E-10	1,03E-10	1,10E-10	9,49E-11
	Iodine-135	air	kBq	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Krypton-85	air	kBq	3,90E-05	3,08E-06	2,77E-06	3,33E-06	3,34E-06	3,28E-06	3,29E-06
	Krypton-85m	air	kBq	2,77E-06	1,69E-06	1,47E-06	1,45E-06	1,26E-06	1,34E-06	1,15E-06
	Noble gases, radioactive, unspecified	air	kBq	8,59E-01	4,57E-01	4,42E-01	4,81E-01	4,18E-01	4,59E-01	3,96E-01
	Sulfur hexafluoride	air	kg	9,84E-09	4,42E-09	3,69E-09	3,09E-09	2,61E-09	1,37E-09	1,10E-09
	Thorium-230	air	kBq	4,81E-08	2,71E-08	2,60E-08	2,83E-08	2,47E-08	2,70E-08	2,33E-08
	Uranium-234	air	kBq	1,46E-07	8,15E-08	7,83E-08	8,54E-08	7,43E-08	8,13E-08	7,02E-08
	Uranium-235	air	kBq	6,65E-09	3,54E-09	3,40E-09	3,74E-09	3,21E-09	3,54E-09	3,01E-09
	Uranium-238	air	kBq	2,56E-07	1,22E-07	1,14E-07	1,94E-07	1,58E-07	1,83E-07	1,45E-07
Emissions to Water	Ammonium, ion	water	kg	6,95E-08	4,80E-08	4,31E-08	4,46E-08	3,75E-08	4,32E-08	3,48E-08
	Arsenic, ion	water	kg	4,14E-08	2,74E-08	2,27E-08	3,89E-08	3,18E-08	3,98E-08	3,23E-08
	Cadmium, ion	water	kg	2,92E-08	1,94E-08	1,61E-08	1,98E-08	1,64E-08	2,06E-08	1,71E-08
	Carbon-14	water	kBq	3,49E-05	1,90E-05	1,84E-05	1,99E-05	1,82E-05	1,90E-05	1,72E-05
	Cesium-137	water	kBq	1,68E-05	8,95E-06	8,65E-06	9,42E-06	8,17E-06	8,98E-06	7,74E-06
	Chromium, ion	water	kg	2,78E-09	2,08E-09	1,73E-09	2,45E-09	2,01E-09	2,42E-09	1,99E-09
	Chromium VI	water	kg	6,18E-07	4,42E-07	3,68E-07	4,55E-07	3,74E-07	3,81E-07	3,12E-07
	COD	water	kg	1,09E-04	8,90E-05	7,87E-05	6,28E-05	5,05E-05	6,27E-05	5,03E-05
	Copper, ion	water	kg	2,45E-07	1,68E-07	1,42E-07	2,23E-07	1,86E-07	2,96E-07	2,46E-07
	Lead	water	kg	7,02E-08	4,73E-08	3,94E-08	6,20E-08	5,18E-08	6,96E-08	5,84E-08
	Mercury	water	kg	3,41E-09	2,36E-09	1,94E-09	2,44E-09	2,01E-09	2,53E-09	2,08E-09
	Nickel, ion	water	kg	9,51E-07	6,54E-07	5,50E-07	8,27E-07	6,90E-07	8,05E-07	6,71E-07
	Nitrate	water	kg	7,20E-07	4,32E-07	3,78E-07	4,44E-07	3,79E-07	2,07E-07	1,70E-07
	Oils, unspecified	water	kg	8,75E-06	5,76E-06	4,97E-06	7,56E-06	6,20E-06	7,64E-06	6,22E-06
	PAH	water	kg	2,78E-09	1,73E-09	1,45E-09	2,85E-09	2,33E-09	2,70E-09	2,20E-09
	Phosphate	water	kg	2,83E-06	1,90E-06	1,58E-06	2,29E-06	1,87E-06	2,36E-06	1,93E-06
Extended List	Hydrogen-3, Tritium	water	kBq	3,81E-02	2,09E-02	2,02E-02	2,20E-02	2,01E-02	2,09E-02	1,90E-02
List for External	Iodine-131	water	kBq	4,42E-09	2,72E-09	2,55E-09	2,88E-09	1,51E-09	2,72E-09	1,42E-09
Cost Assessment	Iodine-133	water	kBq	2,44E-10	1,87E-10	1,62E-10	1,59E-10	1,38E-10	1,47E-10	1,26E-10
	Krypton-85	water	kBq	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Thorium-230	water	kBq	3,15E-05	1,76E-05	1,70E-05	1,85E-05	1,61E-05	1,76E-05	1,53E-05
	Uranium-234	water	kBq	2,79E-07	1,57E-07	1,51E-07	1,65E-07	1,44E-07	1,57E-07	1,36E-07
	Uranium-235	water	kBq	4,58E-07	2,57E-07	2,47E-07	2,69E-07	2,35E-07	2,57E-07	2,22E-07
	Uranium-238	water	kBq	9,84E-07	5,57E-07	4,99E-07	6,88E-07	5,57E-07	6,54E-07	5,22E-07
Emissions to Soil	Arsenic	soil	kg	2,35E-11	1,54E-11	1,35E-11	2,04E-11	1,68E-11	2,06E-11	1,70E-11
	Cadmium	soil	kg	1,55E-11	9,07E-12	8,58E-12	9,69E-12	8,09E-12	9,63E-12	8,49E-12
	Chromium	soil	kg	7,39E-10	4,47E-10	3,97E-10	4,78E-10	3,97E-10	4,61E-10	3,87E-10
	Chromium VI	soil	kg	9,64E-10	8,29E-10	7,09E-10	1,48E-09	1,15E-09	1,51E-09	1,18E-09
	Lead	soil	kg	1,67E-10	1,02E-10	9,36E-11	9,75E-11	8,35E-11	9,69E-11	8,51E-11
	Mercury	soil	kg	4,35E-13	3,00E-13	2,59E-13	2,23E-13	1,91E-13	1,03E-13	8,79E-14
	Oils, unspecified	soil	kg	6,08E-06	3,91E-06	3,43E-06	5,93E-06	4,84E-06	5,98E-06	4,84E-06

7.2 Summarising tables for RS IIa

The following tables summarise the technical data, the cost data, as well as the LCI data for the purposes of RS IIa-requirements. In case of different technologies within one scenario the single results are weighted according to the factors presented in Figure 4.2.

Table 7.9: Summary of solar thermal power plant's technical data for 2007, 2025, and 2050

Parameter		**2007*)**	**2025**	**2050**
Net electrical power at el. peak load				
"Very optimistic"	MW_{el}	37	200	400
"Optimistic-realistic"	MW_{el}	37	200	400
"Pessimistic"	MW_{el}	37	200	400
Electrical efficiency at el. peak load				
"Very optimistic"	%	14.9	8.2	8.2
"Optimistic-realistic"	%	14.9	16	16
"Pessimistic"	%	14.9	16.2	16.2
Technical life time				
"Very optimistic"	y	30	35	40
"Optimistic-realistic"	y	30	35	40
"Pessimistic"	y	30	35	40
Solar share				
"Very optimistic"	%	85	100	100
"Optimistic-realistic"	%	85	100	100
"Pessimistic"	%	85	100	100

*) Data for current technology refer to Table 2.3.

Table 7.10: Summary of solar thermal power plant’s cost data for 2007, 2025, and 2050

Parameter		**2007*)**	**2025**	**2050**
Specific investment costs				
"Very optimistic"	€/kW$_{el}$	5,302	3.522	2,458
"Optimistic-realistic"	€/kW$_{el}$	5,302	3.722	2,770
"Pessimistic"	€/kW$_{el}$	5,302	4,301	3,343
Guarding costs				
"Very optimistic"	Mio. €	0	0	0
"Optimistic-realistic"	Mio. €	0	0	0
"Pessimistic"	Mio. €	0	0	0
Specific demolition costs (greenfield)				
"Very optimistic"	€/kW$_{el}$	53	35	25
"Optimistic-realistic"	€/kW$_{el}$	53	37	28
"Pessimistic"	€/kW$_{el}$	53	43	33
Fixed costs of operation				
"Very optimistic"	€/kW$_{el}$,y	381	106	74
"Optimistic-realistic"	€/kW$_{el}$,y	381	112	83
"Pessimistic"	€/kW$_{el}$,y	381	129	100
Other variable costs				
"Very optimistic"	€/MWh$_{el}$	0	0	0
"Optimistic-realistic"	€/MWh$_{el}$	0	0	0
"Pessimistic"	€/MWh$_{el}$	0	0	0

*) Data for current technology refer to Table 2.3.