Life Cycle Assessment of Solar Chimneys

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Abstract

Climate change is increasingly becoming a significant issue globally and the use of solar thermal technology is one approach in managing the world's environment. There is now greater use of renewable energy sources in order to minimize the depletion of energy resources while providing an environmentally-friendly energy source that has minimal impact on the environment. It is thus important to be able to assess the environmental impact of different types of solar thermal technologies in order to have an understanding of the actual impact of solar thermal on the environment. Most solar thermal technologies need to use water in the production process to produce electricity. The most viable place to produce solar energy is in extremely hot climates like deserts where there is not much water to choose from. Most of the time water comes from sources that are far away and becomes expensive to transport the water to the solar plant sites. There is one solar thermal technology that does not require water to produce electricity. It is called Solar Chimney or Solar updraft tower. This paper will assess the environmental impact of Solar Chimneys across its life cycle using the Life Cycle Assessment approach (LCA). The contribution of this paper is providing further understanding of the environmental impact of solar chimneys across its life cycle particularly as new technologies in solar technology continue to be developed.

Keywords:

Solar Chimney, Solar upward draft tower, Hybrid power plant, Life Cycle, Solar Technology

1 INTRODUCTION

In most parts of the world, there is a growing awareness from companies, organizations and even political movements know that some alternative energy sources could have an important role to play in the reduction of global warming and green house gas emissions.

Recent studies have shown that Solar and Wind technologies are the most feasible green energy that can be produced over a long period of time. The most feasible areas to produce solar energy are in extremely hot areas like deserts in Africa and the Middle East which has low water reserves in those feasible areas. The need for water in these technologies has become critically important to obtain it cheaply and effectively.

Electricity generation in solar power plants require and consume water. Photovoltaic (PV) consumes water only for cleaning mirrors and surfaces and solar chimneys does not have a water demand to generate electricity. The amount of water used per megawatt hour (MWh) of electricity produced is called *water intensity*. The water intensity of electricity from a concentrating solar power (CSP) plant with wet cooling generally is higher than that of fossil fuel facilities with wet cooling. Although concentrated solar power (CSP) cooling technologies are generally the same as those used in traditional thermoelectric facilities, the CSP uses the least amount of water as shown below in Table 1. There are a few options that are available that don't use water in the production process.

Technology	G/MWhr
Estimate for Ivanpah solar-thermal (air cooled)	16
Solar photovoltaic (with panel washing)	30
Solar parabolic trough (air cooled)	78
Combined Cycle Gas (evaporated)	200
Coal (evaporative)	500
Solar power tower (evaporative)	600
Solar parabolic trough (evaporative)	800

Table1: Water Consumption by Power Generation

Source: Estimate for Ivanpah based on calculations from public data; other data from "Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation," Report to Congress, U.S. Department of Energy. Accessed 7/26/10.

We have learned in the past to make use of three green technologies to do certain tasks, we use solar energy to heat water and to make greenhouses to grow food, we also have made use of chimney suction ventilation systems to cool buildings and windmills to ground grains and pump water. There is one green energy technology that uses a hybrid approach and does not require water to produce electricity; it is called a solar chimney also known as solar updraft tower. It is a hybrid plant which combines three of the above proven green technologies chimney effect, greenhouse effect and wind turbines. Air is heated by sunshine and contained in a very large greenhouse-like structure around the base of a tall tower; the resulting convection causes air to rise up the updraft tower. This airflow drives turbines, which produce electricity.

2. METHODOLOGY

Life cycle analysis (LCA) accounts for all impacts that a particular product might have from the extraction and supply of the raw materials through production and usage to when it is finally disposed of as waste (ISO14041/1998). Hybrid-Approach completes the generally used Process Chain Analysis by a model based on economic Input-Output-Tables (Marheinekeet al. 1999). Methodology allows a quick and easy estimation of the elementary flows of up-and downstream processes and commodity flows which are neglected and not included in the Process Chain Analysis.

3 DESIGN

Solar Chimney is a hybrid green technology that uses two of the main alternative energies wind a solar to generate electricity. It combines three elements; glass roof collector, chimney, and wind turbine which each element has been used for centuries to create energy. This combination of elements to generate electricity was already described in 1931 by Gunther (Gunther 1931).

The power out is dependent on 2 main factors the collector area and chimney height. A larger area collects and warms a greater volume of air to flow up the chimney; collector areas as large as 7 kilometres (4.3 mi) in diameter have been discussed. A larger chimney height increases the pressure difference via the stack effect; chimneys as tall as 1,000 metres (3,281 ft) have been discussed.

With technology improving, the technology on the chimney has improved by installing a telescopic collapsible features can enable the chimney to decrease or increase the chimneys height in order to prevent storm damage.

Heat is stored inside the collector area. A saltwater thermal sink in the collector could 'flatten' the diurnal variation in energy output, while airflow humidification in the collector and condensation in the updraft could increase the energy flux of the system.

Turbines can be installed in a ring around the base of the tower, with a horizontal axis..

Carbon dioxide is emitted only negligibly as part of operations. Manufacturing and construction require substantial power, particularly to produce cement. Net energy payback is estimated to be 2–3 years.

These Solar Chimneys take up a large amount of area, deserts and other low usage sites are more likely to be used.

A small tower may be a better option for remote regions and developing countries. With the low-tech approach would allow local resources and labour to be used for construction and maintenance

The EnviroMission design consists of a giant, round greenhouse like structure, under which air becomes trapped and gets very hot around 160 degrees Fahrenheit. The hot air naturally rises, and would rush toward the tall tower in the centre, passing through 32 turbines, whose turning blades would run generators and create electricity. Heat can also be stored inside the collector area greenhouse or inside tubes filled with water to be used to warm the air later and increase energy storage as needed. Turbines can be installed in a ring around the base of solar updraft towers, with a horizontal axis, as planned for the Arizona project, or—as in the prototype in Spain—a single vertical axis turbine can be installed inside the chimney.

Typically carbon dioxide is emitted only negligibly while operating, but is emitted more significantly during manufacture of its construction materials, particularly cement. Net energy payback is estimated to be 2–3 years. A solar updraft tower power station would consume a significant area of land if it were designed to generate as much electricity as is produced by modern power stations using conventional technology. Construction is optimized in hot regions with large amounts of very low-value land, such as deserts, or otherwise degraded land. A small-scale solar updraft tower may be an attractive option for remote regions in developing countries. The relatively low-tech approach could allow local resources and labor to be used for its construction and maintenance.

Hybrid

Solar updraft towers can be combined with other technologies to increase output. Solar thermal collectors or photovoltaic can be arranged inside the collector greenhouse. This could further be combined with agriculture

4. FUNCTIONING

The solar chimney functioning principle is shown in the above figure 1. Solar radiation hits the glass roof collector which heats up the air and the ground below which forms a solar air collector. In the middle of the roof is a vertical tower with large air inlets at its base. At the base and the solar air collectors is airtight. As the air under the solar air collectors gets hotter it rises above the cold air and pushes in to the inlets and rises up the tower. A suction is created by the tower vacuuming in more hot air into to the tower from the solar air collectors, and cold air gets sucked in from the outer parameter which creates enough force to get the wind turbines to move in the tower which is converted in to electricity by using conventional generators. A 24/7 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. These tubes are filled only once, no further water is needed. This result in solar radiation causes a constant updraft in the tower.

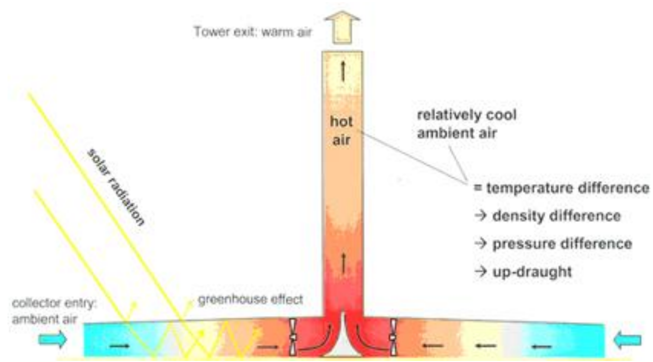


Figure 1. Solar Chimney Functioning

5. TECHNOLOGY

5.1. The collector

In a simple air collector the hot air is produced by the green house effect. The area is covered with glass or plastic filming about two to six meters collector increases with the height of the chimney base, so the air can be pushed vertically to reduce the friction loss. The covering helps to store short and long wave radiation from the ground. The ground under the roof heats up and transfers the heats the air flowing from outside the surrounding area to the chimney.

5.2. The energy storage

Black tubes are filled up with water only once in the entire life cycle of the plant and are laid side by side on the soil under the roof collector. Which means no evaporation takes place. The volume of water in the tubes corresponds to the power output that is desired (5cm to 20cm of water per tube).

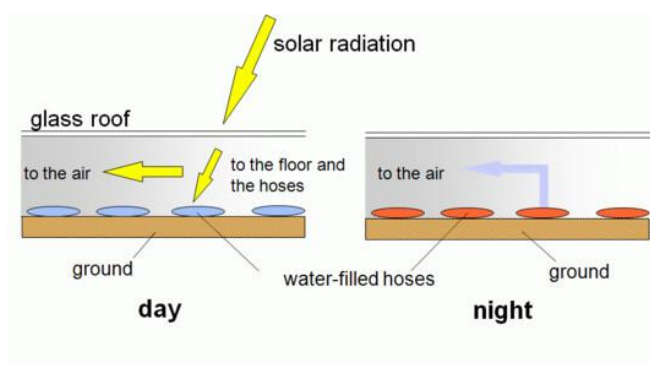


Figure 2: Day and night energy storage

The heat transfer between the black tubes and the water is greater than the ground surface and the deeper soils even at low water speed in the tubes, and heat capacity of water (4.2 kJ/kg) is much higher than that of soil (0.75 - 0.85 kJ/kg) the water inside the tubes stores a part of the solar heat and releases it during the night, when the air in the collector cools down therefore creating a 24 hour production period.

5.3. The chimney

The chimney is the 'heart' of the plant. It is the plants thermal engine. It is a tube that creates pressure with low friction loss because of its smooth surface. The updraft of heated air in the collector is proportional to the air temperature rise in the DTcoll in the collector and the volume of the chimney. In a large solar chimney the collector raises the temperature by about 35k. This causes an updraft velocity in the chimney of about 15m/s. It is now possible for an operating solar chimney plant. A 1000 meter chimney can be built with no hassles. Solar chimneys are easy to construct.

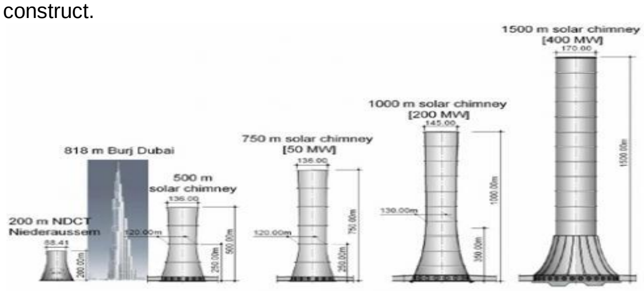


Figure 3: Heights of Solar Chimneys' and power outputs

As you can see from figure 3 and table 2 the solar Chimneys will be the biggest tower type structures to exist to man. Also the bigger you make the chimney the more power output would exists. For a 1,000 metre high chimney will produce 200 mega watts of power and 1,500m could produce 400 mega watts of power.

Table 2. Typical dimensions and electricity output Capacity MW 5 30 100 200

Capacity MW	5	30	100	200
tower height m	550	750	1000	1000
tower diameter m	45	70	110	120
collector diameter m	1250	2900	4300	7000
electricity output A GWh/a	14	99	320	680

A at a site with an annual global solar radiation of 2300 kWh/(m²a)
Typical dimensions for selected solar

Chimneys are not difficult to build 1,000 metres high. There are already plans to build 2,000 metre skyscrapers. A large diameter hollow cylinder, not slender and are subject to a few demands. There are a few ways to build the chimneys. The best are free standing in reinforced concrete. The guyed tubes, their skin is made of corrugated metal sheets, as well as cable-net design with cladding are also possible. All the structural designs already exists and does not need any new technology in order to construct them

5.4. The turbines

Figure 4 : Turbine

The turbines use mechanical output in the form of rotational energy in the form of rotational energy which is powered by the air currently in the chimney. Turbines in a solar chimney do not work on staged velocity. Like a free running wind energy converter. It works like using cased pressure staged wind generator. This takes static pressure and converts it into rotational energy using a cased turbine. The power output of a cased pressure turbine is about eight times greater than that of a speed stepped open air turbine. The air speeds before and after the turbine is about the same. The output is achieved by the product of the volume and the fall in pressure at the turbine. By achieving this output the maximum energy yield the aim of the turbine regulation system is to maximize this product under all operating conditions. The blade speed is adjusted during operation to regulate power output according the changing airspeed and airflow. The blades need to be parallel to the airflow and allow air to flow through undisturbed and no drop in air pressure in order to produce electricity. These are the optimum blade settings. The electricity produced is maximised if the pressure drops at the turbine is about two thirds of the total pressure is available.

6. Life Cycle Assessment

Life Cycle Assessment (LCA) is a useful tool to asses the environmental impact of a product, process or service and together can be very useful to the comparison of similar products. Life Cycle Assessment can be very helpful to engineers and researchers. The application of the LCA methodology, can lead to techniques that minimize the magnitude of pollution, conserve fuels and ecological systems, develop and utilize cleaner technologies and maximize recycling Although LCA is a relatively new method it has been accepted by industries worldwide. LCA methodology is applied in the products eco-design, development of new techniques to improve products, as the global trend is towards to the environmental issues. The Life Cycle assessment can be used in all sorts of industries.
Environmental life cycle assessment is a method for the analysis of environmental effects of economic products. It covers a wide range of environmental themes and takes the total production chain 'from cradle to grave' into account. Life Cycle Assessment is to provide a holistic picture of the environmental impacts of a given system, while being relevant both at a global scale, i.e., for global impact categories such as climate change, and at a smaller scale, i.e., for regional impact categories. Among those, the LCA approach, which considers the whole product life cycle, is recommended by the European Union and UNEP. The EU communication on Integrated Product Policy states that "All products cause environmental degradation in some way, whether from their manufacturing, use or disposal. Integrated Product Policy (IPP) seeks to minimise these impacts by looking at all phases of a product's life cycle and taking action where it is most effective".

The stages of Solar Tower Power Plant's LCA from construction to recycling of its parts are the ones presented below:

- Raw materials excavation
- Materials processing
- Construction of the parts of Solar Power Tower Plant
- Transportation and assembly of the parts
- Operation of the Solar Tower Power Plant
- Decommissioning-Recycling
- Products disposal

The main operation of the system of Solar Power Tower is the exploitation of solar radiation and its conversion, firstly in thermal and continuously to electrical energy. In all the life cycle stages there are inputs and outputs. The inputs are energy, water and materials, while in outputs there are air and liquid emissions, solid wastes and the product, in this case electric power. In the operational stage the energy input is direct solar radiation that prostrates systems' sun-tracking mirrors. The functional unit of the analysis is set to be 1MWel and the operational life of the system is 30 years. The construction period is 3 years.

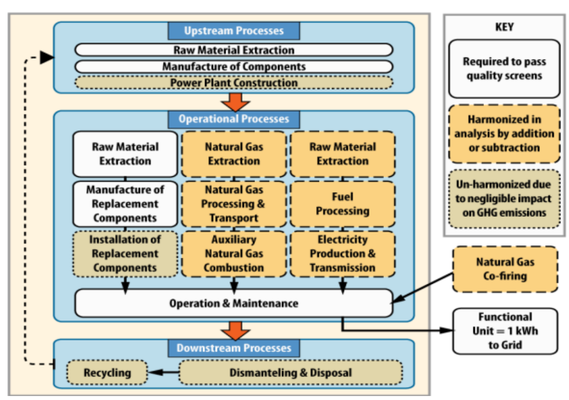


Fig. 5 – Life Cycle Stages

In the analysis done, there are several assumptions made. For instance, during the operation period no replacement of any element of the Solar Tower Power Plant is taking place (fig.1). Additionally,no hazardous gaseous or liquid emissions are released during operation of the solar power tower plant. In present study plant under study, there is no heat storage, thus no salt usage. In the case where there was heat storage no additional emissions occur; if a salt spill occurs, the salt will freeze before significant contamination of the soil occurs. Salt is picked up with a shovel and can be recycled if necessary [05].

The Solar Tower Power Plant has a nominal capacity of 1 MW and covers land and area of 4.07×10^6 m^2, of which 7000 m^2 [14] is the area covered by the heliostats.

The required materials for the construction of the plant are listed in table 1 and fig. 6[14].

Table 3 – Construction Materials

Materials	Tns
Aluminum (0.29%)	32
Concrete (16.9%)	1850
Copper (64.34%)	7050
Chromium (12.5%)	1375
Glass (0.62%)	68
Plastic (0.1%)	11.5
Steel (5%)	545
Insulation (0.25%)	27.5
Total	**10959**

The energy used in the production of 1 ton of each material and its distribution is presented in Table 3. It is assumed that the materials are being transported from a region 100Km far from the plants' location with 200, 40tns diesel trucks. The diesel usage and the emissions from the trucks for 1tKm distance are presented in table

Table 2 – Energy usage for material production

Coal (MJ/tone)	
Aluminum	1980
Concrete	360
Copper	13914
Chromium	51480
Glass	-
Plastic	7596
Steel	33840
Insulation	5464.14
Crude Oil (MJ/tone)	
Aluminum	1.84884
Concrete	0.266676
Copper	27.9456
Chromium	66.456
Glass	67.6
Plastic	45.582
Steel	23.3874
Insulation	39930
Natural Gas (MJ/tone)	
Aluminum	9205
Concrete	633.145
Copper	20265
Chromium	42700
Glass	154.4
Plastic	2660
Steel	11760
Insulation	72480
Total	
Aluminum	11186.84884
Concrete	993.411676
Copper	34206.9456
Chromium	94246.456
Glass	222
Plastic	10301.582
Steel	45623.3874
Insulation	117874.14

It is observed that the 1 ton of insulation has the highest energy requirements for its production (Table 4). On the other hand insulation has a small share of the construction materials. The total energy consumption for the production of the total amount of materials used in the plant is presented in Table 4 and fig. 7. Figure 8 presents the share of the coal, crude oil and natural gas. The diesel oil contribution to the development of the power plant is minimum compare to other fossils.

Table 4 – Diesel oil use and emissions of a 40ton truck

Input	Output		Distance
Diesel fuel	**CH4**	**.0000197 K**	**1 tKm**
0.348 Kg	**CO**	**0.00114 Kg**	
	CO2	**1.1 Kg**	
	NOx	**0.00992 Kg**	
	SO2	**0.000209 Kg**	

Truck 40 tones

Table 5 – Total energy use for the material production of the Power Plant

	MJ/Plant
Aluminum (0.09%)	357979.1629
Concrete (0.46%)	1837811.601

Copper (60.11%)	241158966.5
Chromium (32.3%)	129588877
Glass (0.004%)	15096
Plastic (0.03%)	118468.193
Steel (6.2%)	24864746.13
Insulation (0.8%)	3241538.85
Total	**401183483.4**

Figure 6 – Total energy use for the material production of the Power Plant

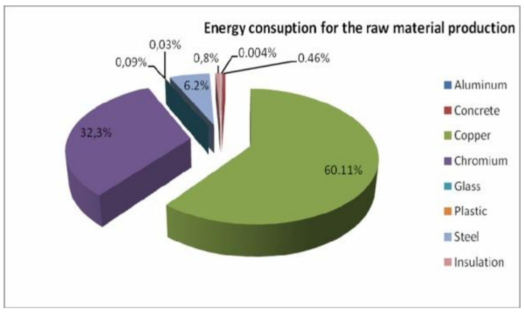
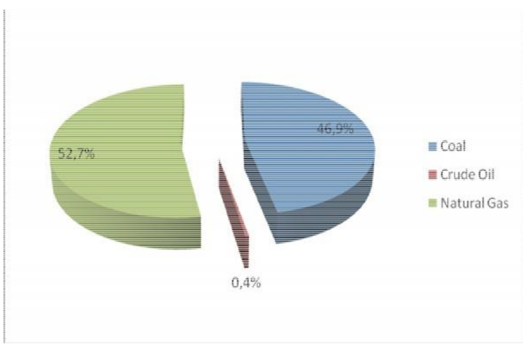


Fig. 7 - Total Energy Distribution



3. **Impact Assessment**

3.1 Impact Categories Selection and Determination

In the present study are assessed the impacts that contribute to the following:

- Greenhouse Effect
- Stratospheric Ozone Depletion
- Acidification
- Eutrophication
- Carcinogenesis
- Winter Smog
- Summer Smog
- Heavy Metals

Classification

In the classification process emissions are associated with impacts categories. In this study emissions are proportioned to all impacts categories. Emissions are considered that they contribute 100% to all impacts categories.

Characterization

In the characterization process emissions are quantified. Each emission is converted to equivalent units for each impact using Eco-Indicator's characterization factor. The equivalent quantities for every impact category are presented in table 6

Table 6 – Equivalent Quantities of Impact Categories

	Equivalent Quantities (Kg)
Greenhouse Effect (CO_2)	6.82E+06
Acidification (SO_2)	8.51E+03
Eutrophication(air) (PO_4)	1.42E+03
Eutrophication(water) (PO_4)	1.154034552
Stratospheric Ozone Depletion (CFC-11)	2.57E-02
Carcinogenesis (B(a)P)	4.82E-02
Winter Smog (SPM)	8.43E+02
Summer Smog (C_2H_4)	1.82E+01
Solid Waste	1.07E+02
Heavy Metals(air) (Pb)	5.76E-01

Normalization

Normalization follows characterization, and is the process which associates each impact with the region The normalization Values of the analysis are.

Table 7- Normalization Values of the Analysis

	Normalization Values
Greenhouse Effect	5.06E+02
Acidification	7.55E+01
Eutrophication(air)	3.73E+01
Eutrophication(water	3.02E-02
Stratospheric Ozone Depletion	3.18E-02
Carcinogenesis	5.11E+00
Winter Smog	8.94E+00
Summer Smog	9.25E-01
Solid Waste	0.00E+00
Heavy Metals(air)	1.02E+01
Heavy Metals(water)	1.89E+00

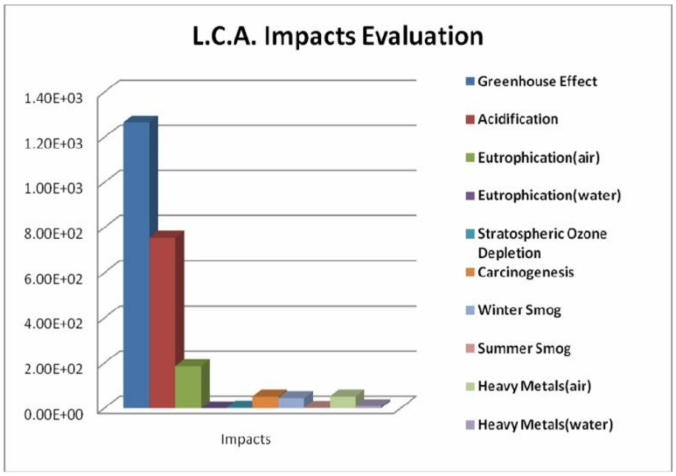
Evaluation

Evaluation is the final step of this L.C.A. study, where all impacts are associated between them and the significance of each impact category is assessed.

Table 8 – Evaluation Values of the Analysis

	Impact Valuation Values
Greenhouse Effect	1.27E+03

Acidification	7.55E+02
Eutrophication(air)	1.86E+02
Eutrophication(water)	1.51E-01
Stratospheric Ozone Depletion	3.18E+00
Carcinogenesis	5.11E+01
Winter Smog	4.47E+01
Summer Smog	2.31E+00
Solid Waste	0.00E+00
Heavy Metals(air)	5.12E+01
Heavy Metals(water)	9.46E+00



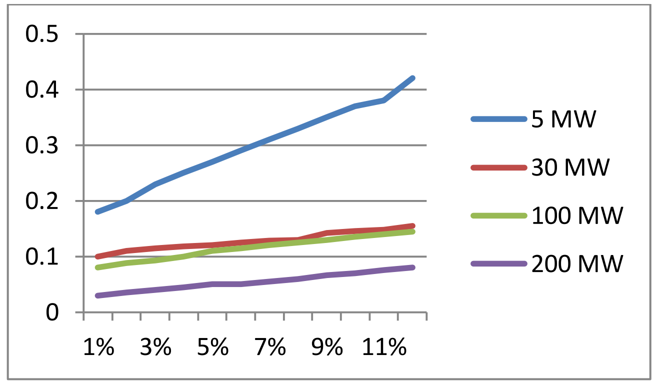
7. Economy

Based on certain cost factors and electricity output from table 4 investment costs can be calculated. Using simulation runs on annual energy outputs electricity costs can also be calculated using an interest rate of 6% and a deprivation time of 30 years in table 5. As you can see from table 5 that the smaller the plant the more expensive it gets. Leading to LEC 0.07 €/kWh for a 200 MW plant in the given example at an interest rate of 6 %.

Table 9. Investment cost and LEC

Capacity	**MW**	**5**	**30**	**100**	**200**
Tower	Mio. €	19	49	156	170
Collector	Mio. €	10	48	107	261
Turbine	Mio. €	8	32	75	133
Engineering tests, misc.	Mio. €	5	15	40	42
Total	**Mio. €**	**42**	**145**	**378**	**606**
annuity on investment	€/a	2.7	10.2	27.1	43.7
annual operation & maintenance cost	€/a	0.2	0.6	1.7	2.8
levelized electricity cost	**B €/kWh**	**0.21**	**0.11**	**0.09**	**0,07**
A. cost for unskilled labour assumed to be 5 €/h B. at an interest rate of 6 % and a depreciation time of 30 years					

A variation of the financial parameters interest rate and depreciation time is shown in Fig. 8. The upper boundary was calculated for a depreciation time of 20 years, the lower boundary for 40 years.



The gap between the two electricity costs closes with increasing fossil fuel costs. After 20 years, electricity generation costs are identical. Then both plants are paid for in this example, no more annuities have to be paid. From this point in time on the solar tower produces electricity at low cost, as only operation and maintenance costs have to be paid. In contrast to that, electricity generation costs of the coal fired plant are still comparatively high, as they are governed by fuel costs.

In countries with very low wages investment costs, and therefore mostly electricity generation costs of the solar tower, will be further reduced. This holds especially true as the collector, which alone amounts to roughly one half of the overall solar tower investment costs, is a low-tech component and can be built anywhere with unskilled labour.

8. Advantages and disadvantages

8.1. Advantages

- Solar chimney power stations are particularly suitable for generating electricity in deserts and sun-rich wasteland.
- It provides electricity 24 hour a day from solar energy alone
- No fuel is needed. It needs no cooling water and is suitable in extreme drying regions
- It is particularly reliable and a little trouble-prone compared with other power plants
- The materials concrete, glass and steel necessary for the building of solar chimney power stations are everywhere in sufficient quantities.
- No ecological harm and no consumption of resources

8.2. Disadvantages

- Some estimates say that the cost of generating electricity from a solar chimney is five times more than from a gas turbine. Although fuel is not required, solar chimneys have a very high capital cost [2].
- The structure itself is massive and requires a lot of engineering expertise and materials to construct [2].

9. Summary and Conclusion

Conclusions

The dominant impact category in the construction and operation of a Power Tower plant is the Greenhouse effect, followed by the acidification and air eutrophication. The dominant air emission that affects the GH effect is CO_2, while in Acidification is the NO_x [14]. Thus, in order to design a more sustainable and environmental friendly power plant, there must be interfering in that life cycle process that has the maximum contribution to the generation of these emissions. Copper and Chromium are the dominant materials used in the construction of the power tower plant. Additionally, the coal consumption represents the 46,9% of the overall energy consumption. The 54,6% of the energy used in the chromium production came from the coal combustion, while the total amount of copper required for the power plant requires the highest consumption of energy and almost 40% of it came from coal combustion. Among the utilized solids fuels in the production of the materials coal produces the majority of CO_2 and NO_x emissions.
According the above coal usage minimization is the first and

achievable in short terms, step in the minimization of the environmental impact. The energy gap that will rise from the coal minimization can easily be replaced by natural gas. Natural gas, compare to coal has significant less CO_2 and NO_x emissions. Another route is the usage of Nuclear power, although from the perspective of LCA it is not a sustainable solution, if we consider the nuclear waste production and their final disposal impact. Last but not least renewable energy can be utilized in the production of these materials, renewable for renewable. This is the best scenario, although it is not directly implemented.

Compare to other electricity production methods, GSP plants are the most sustainable of all, taking into consideration their whole life cycle (fig. 4). On the other hand they can be further “evolved”. Besides the research in the field of operational stage, there must be a research in the material usage. The minimization or replacement of copper for instance, with another less pollutant material.

References

[1]http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html

[2] Subcontractor report, “ Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts”, October 2003,

NREL/SR-550-34440

[3] Hans Muller – Steinhagen, Franz Trieb, “Concentrating solar power - A review of the technology”, Quarterly of the Royal Academy of Engineering Ingenia 18, February/March 2004

[4] Energy Efficiency and Renewable Energy, “Concentrating Solar Power: Energy from Mirrors” DOE/GO-102001-1147 FS 128, March 2001

[5] EPRI Project Manager, E.A. DeMeo, “Renewable Energy Technology Characterizations”, TR- 109496, Final Report, December 1997

[6] Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996. Report ISBN 3-9804901-0-6.

[7] SOLAR DISH ENGINE (www.solarpaces.org)

[8] Washom, B., “Parabolic Dish Stirling Module Development and Test Results”, Paper No. 849516, Proceedings of the IECEC, San Francisco, CA (1984).

[9] Parabolic Trough Solar Collector Systems Made More Energy Efficient,http://www.sciencedaily.com/releases/2007/05/070515174832.htm]

[10] Concentrating Solar Power Program, Office of Solar Energy Technologies Power Towers, “Proving the technical feasibility and cost potential of generating large-scale electric power from the sun when it is needed, day or night”, National Renewable Energy Laboratory a DOE national laboratory, DOE/GO-10098-468, September 1998, revised August 2000

[11] Scott Jones, “Concentrating Solar Power: The ‘Other’Solar…A Systems Perspective”, Sandia National Laboratories, October 19, 2004

[12] Concentrating Solar Power Now, Deutsches Zentrum für Luft und Raumfahrt e.V., German Aerospace Center,.

[13] http://www.unep.org/

[14] U.S. Department of Energy, “Energy Technology Characterizations Handbook, Environmental Polution and Control Factors”, March 1983, Third Edition,DOE/EP – 0093, Dist. Categoory UC - 11