High-Rise Tubes for Solar Chimneys

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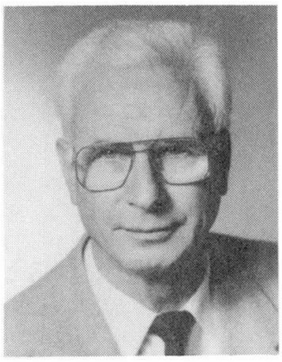

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Summary

The solar chimney combines three well-known technologies - the greenhouse, the chimney, and the turbine - in a novel way. Incident solar radiation heats the air under a large transparent collector roof. The temperature difference causes a pressure drop over the height of the chimney resulting in an upwind which is converted into mechanical energy by turbines and then into electricity via conventional generators (Fig. 1). In order to achieve competitive electricity cost, the height of the chimney should be in the order of 1.000 m.

1. Introduction

This solar energy system has many technological and physical advantages:

- Global radiation, including diffuse radiation when the sky is overcast, can be exploited.
- The natural storage medium - the ground - guarantees operation at a constant rate until well into the hours of darkness (and throughout the night with large-scale installations). If in addition black water-filled tubes are placed on the ground underneath the roof (Fig. 2), a continuous 24 hours electricity production can be achieved (Fig. 3).
- There are no moving parts, nor are there parts that require intensive maintenance aside from the turbine and the generator. Not even water is required.

Its simple, low-cost design and materials (glass, concrete, steel) make solar chimney systems applicable to less industrialised countries. Labour represents a high portion of the installation costs. This would stimulate the local labour market, while at the same time helping to keep overall costs down.

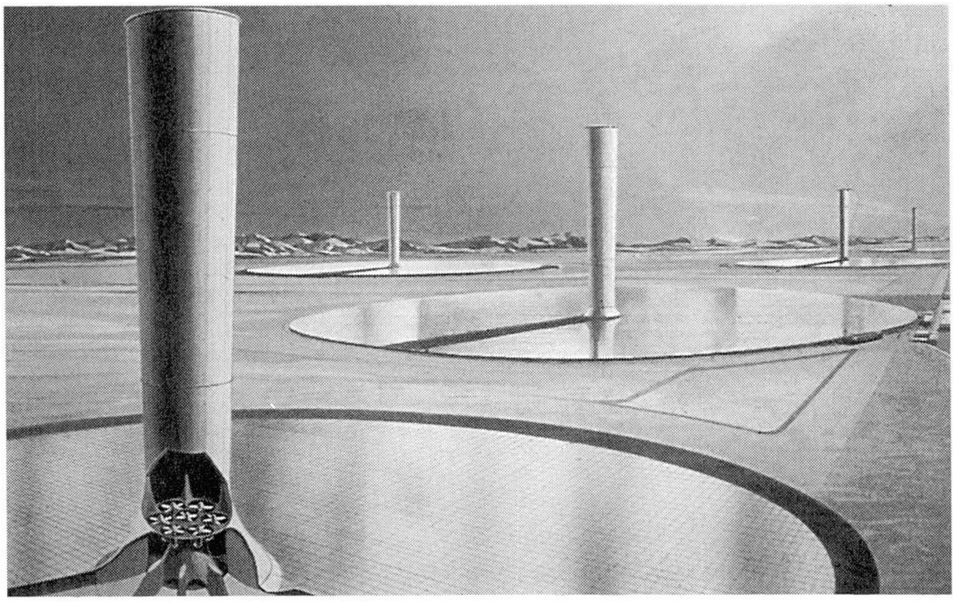

Fig. 1 Drawing of several large (100 - 200 MW) solar chimneys in a desert.

There is in fact no optimum physical size for solar chimneys. The same output may result from a large chimney with a small collector roof area and vice versa. Thus, to decide the optimum dimensions of chimney height against collector radius, the specific construction costs of these items must be known. If glass is cheap but concrete expensive, a large collector and low chimney is preferable, and vice versa. Broadly, to achieve a maximum output of (30) 200 MW at an irradiance of 1.000 W/m^2, the roof must have a diameter of (2.200) 4.000 m if the chimney has a height of (750) 1.500 m. If black water-filled tubes are placed on the soil underneath the roof (Fig. 2) for a continuous 200 MW full load 24 hours electricity production the diameter of the roof must be increased to 7.200 m. Now this solar chimney from a solar radiation of 2.300 kWh/m^{2}a extracts about 1.500 GWh/a, in fact a power plant!

The collector roof, responsible for almost 50 % of the total cost must be as economical as possible. For that the glass panels are placed on suspended stress ribbons made from steel slats, spaced 1 m. They are supported by underslung girders resting on steel tubular columns 9/9 m^2. Tests on a prototype solar chimney in Manzanares/Spain have shown that this is a most efficient and durable structure (Fig. 4 and 5).

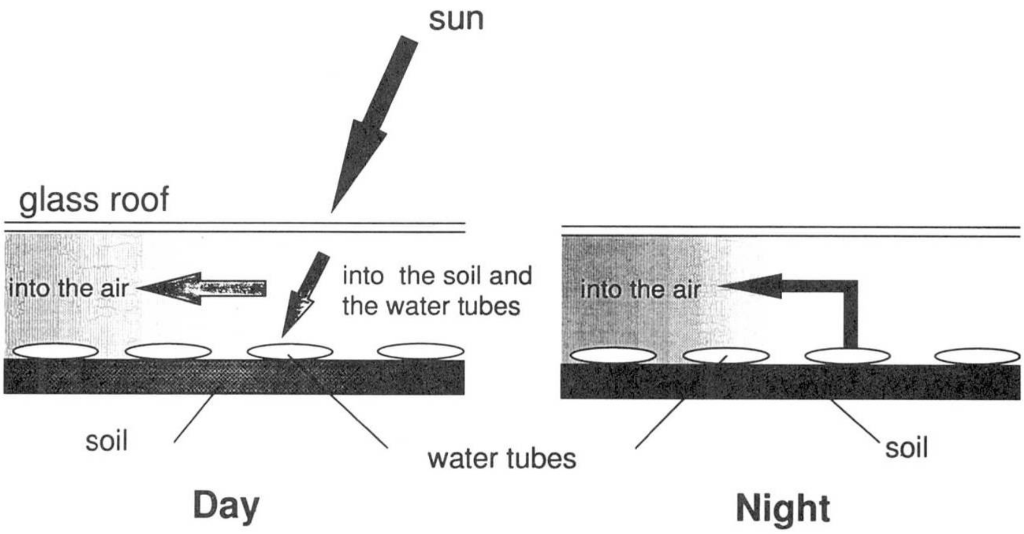

Fig. 2 Principle of heat storage underneath the roof using water-filled black tubes.

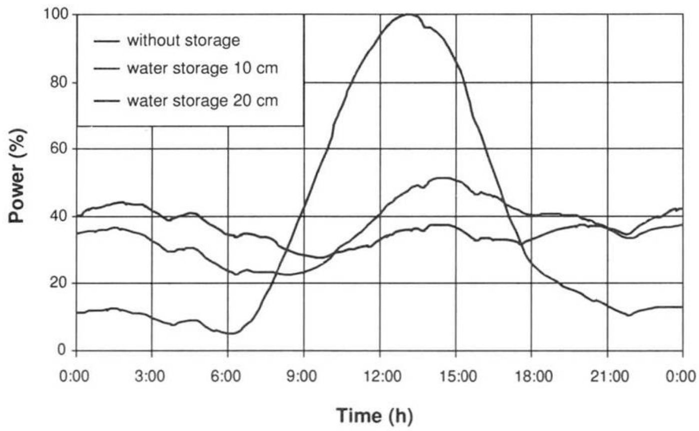

Fig. 3 Electricity output during 24 h as a function of the thickness of the water layer.

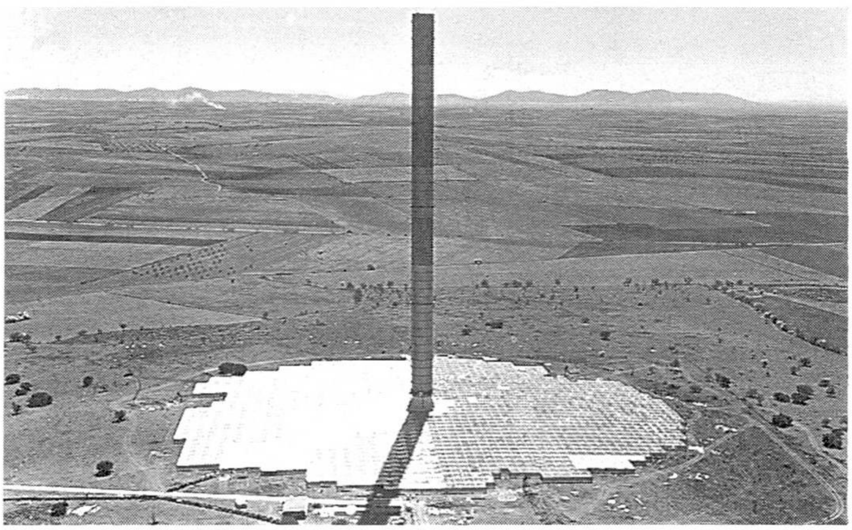

Fig. 4 The solar chimney in Manzanares/Spain.

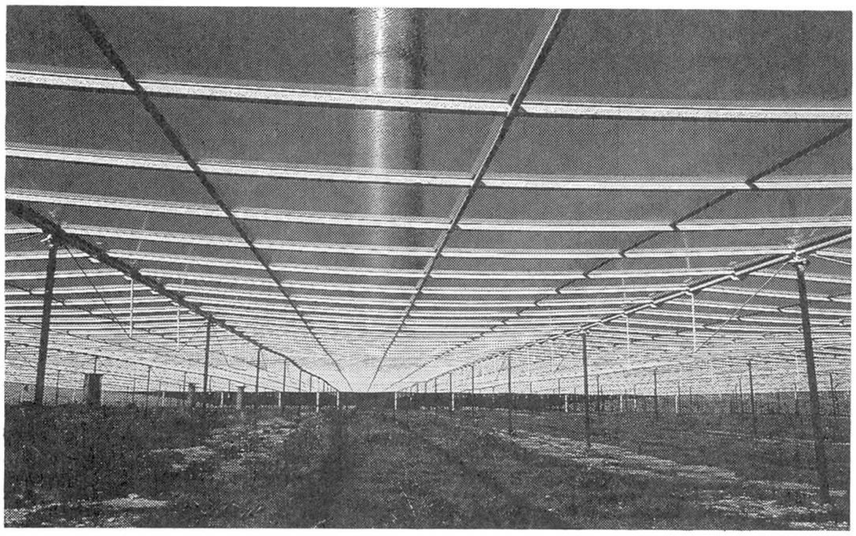

Fig. 5 The glass collector roof of a solar chimney.

The turbines are basically more closely related to the pressure-induced water turbines than to the velocity-induced natural wind power plants. Either several horizontal axis engines are placed around the chimney base or - the cheaper solution - one large, say 200 MW turbine with a vertical axis is placed in the chimney's diameter (Fig. 6).

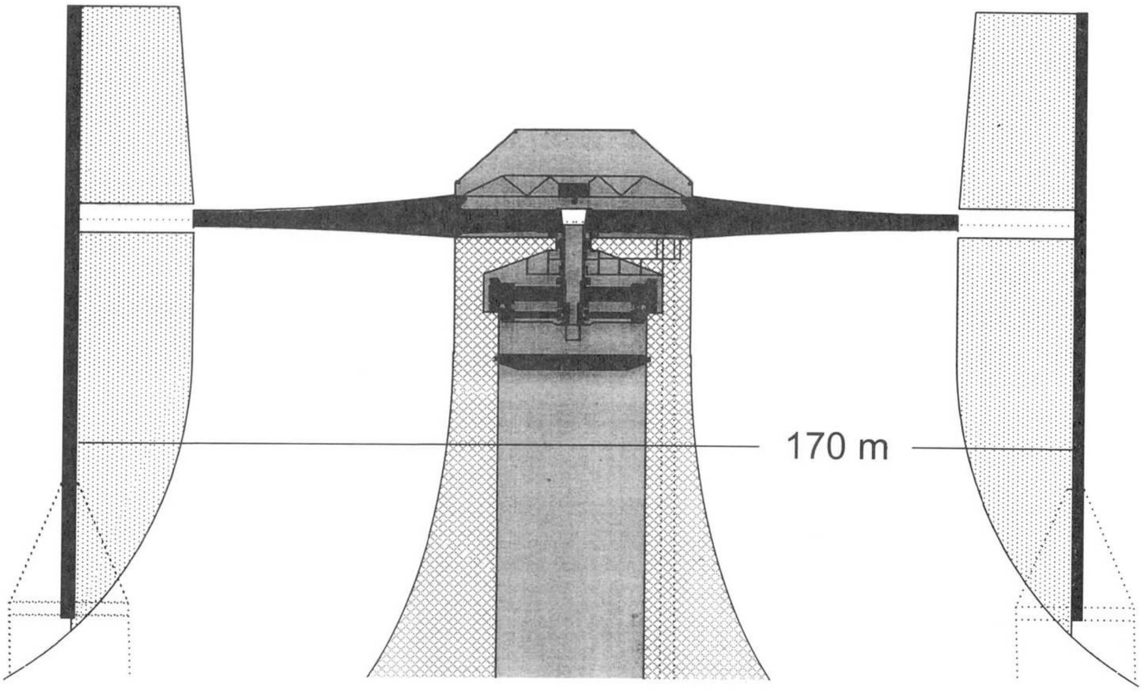

Fig. 6 200 MW vertical axis in the shaft of the solar chimney.

For the chimney itself the possible construction methods and the materials such as covered steel framework with cable nets, membranes, trapezoidal metal sheet etc. were compared to discover that for all the desert countries in question the reinforced concrete tube promises the

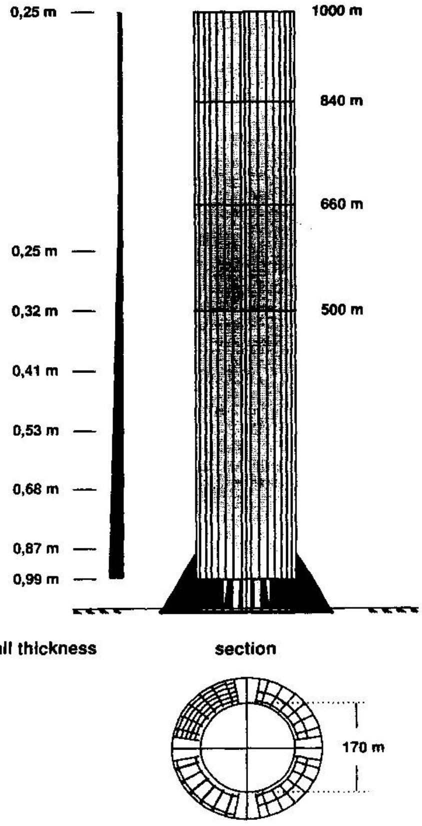

Fig. 7 Wall thickness of a chimney 1.000 m high and 170 m in diameter

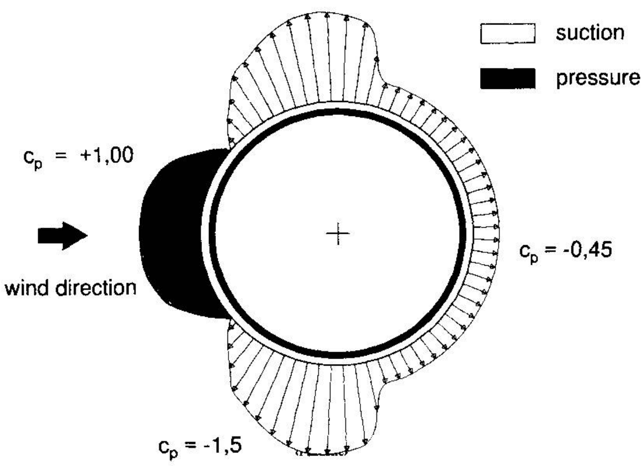

Fig. 8 Typical pressure distribution around the circumference of a cylindrical tube

longest life-span at the most favourable costs. Technologically speaking they are nothing but cylindrical natural draught cooling towers with - as shown in Fig. 7 as an example - a diameter of 170 m and height of 1.000 m. The wall thickness decreases from 99 cm just above the support on radial walls to 25 cm halfway up, then remaining constant all the way to the top. Such thin-walled tubes will oval due to the wind suction especially at the flanks (Fig. 8). This tremendously increases the meridional compressive and tensile stresses if compared with the linear bending stresses of a cantilevering beam (Fig. 9, top left). The resulting loss in stiffness due to cracking of the reinforced concrete and the danger of buckling limit the height of natural draught cooling towers to about 200 m. But this ovalling can be efficiently counteracted by stiffening spoked wheels, which have the same effect as diaphragms, hardly affecting the upwind. If the spokes are made of vertical steel slats stressed between a compression ring along the chimney's wall and a hub ring, such a spoked wheel is prestressed by its own weight, thus resulting in tension- and compression-resistant spokes (Fig. 10). It is seen from Fig. 9 that the meridional stresses in the chimney wall, shown in the diagrams across the diameter and the height, do ondulate tremendously without any spoked wheels. But one spoked wheel at the top and another one or even three more further below reduce the meridional stresses to an extent that tension disappears completely, succumb by the tube's dead load. Considering thatthe absolute volume under these stress diagrams is somehow proportional to the consumption of concrete and reinforcing steel, one finds that these spoked wheels, make such high towers for solar chimneys feasible.

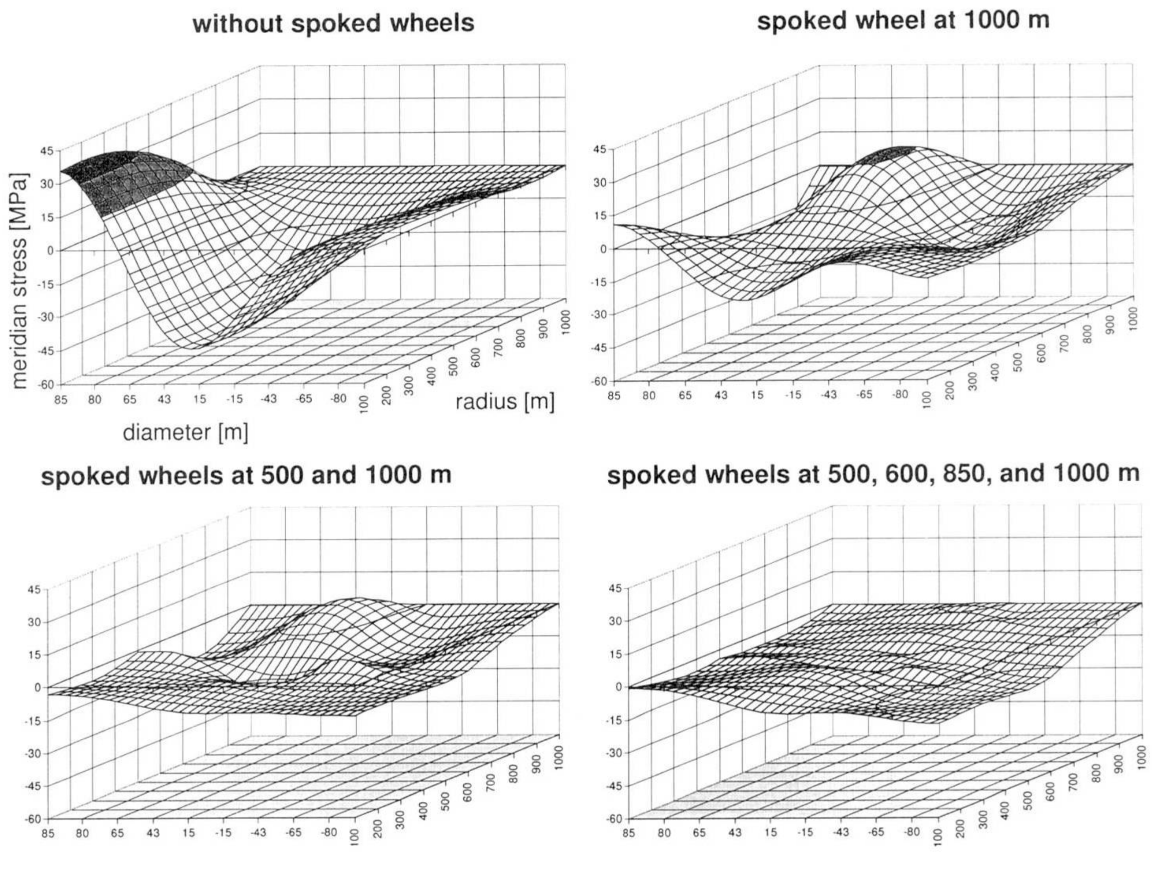

Fig. 9 Meridional stresses in the chimney according to fig. 7, around its periphery and along its height depending on the number of stiffening spoked wheels.

Thus, with the support of construction companies, turbine manufacturers and the glass industry a rather exact cost estimate for a 200 MW solar chimney could be compiled. Two big German utilities determined the electricity producing costs compared to coal- and combined cycle power plants based on equal and usual methods (Fig. 11).

This clearly shows that calculated purely under commercial aspects with a gross interest rate o' 11 % and a construction period of 4 years during which the investment costs increase already by 30 % (!) electricity from solar chimneys is just 20 % more expensive than that from coal.

In case of the solar chimney the interest on the investment governs the price of electricity, whereas in the case of fossil fuel power plants mainly the fuel costs are the deciding factor.

Merely reducing the interest rate to 8 % would make electricity from solar chimneys competitive today (Fig. 12).

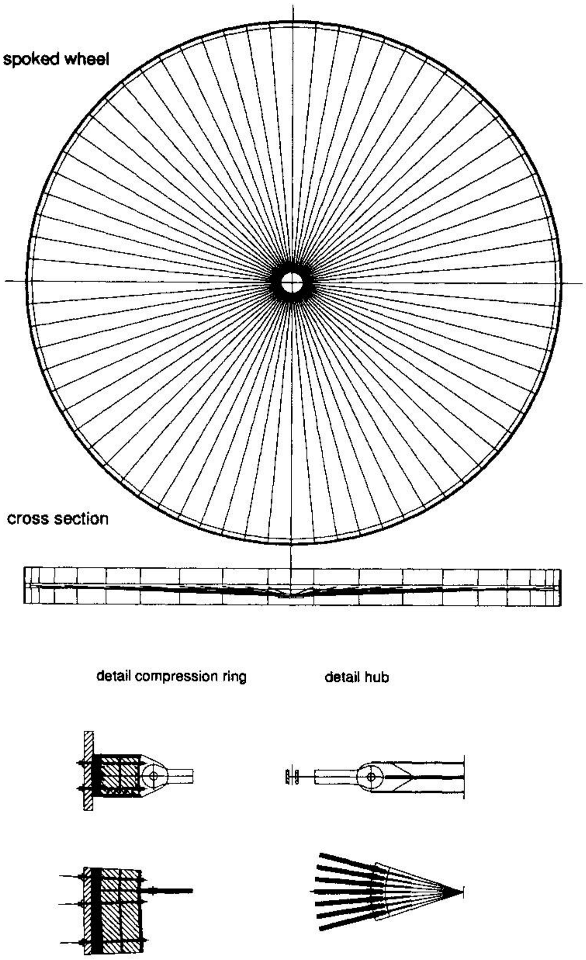

Fig. 10 Spoked wheels, the spokes are made of vertical steel slats.

Proportion of	Solar Chimney Pf/kWh	Coal Pf/kWh	2 x CC Pf/kWh
Investment	11,32	3,89	2,12
Fuel	0,00	3,87	6,57
Personnel	0,10	0,78	0,31
Repair	0,52	0,92	0,83
Insurance	0,01	0,27	0,12
Other running costs	0,00	1,16	0,03
Tax	2,10	0,69	0,37
Total	**14,05**	**11,58**	**10,35**

Commissioning in 2001
Power: 400 MW
Running hours: 7445 h/a
Yearly energy: 2978 GWh

Own investment 1/3 at 13,5%
External investment 2/3 at 8%
Total interest rate: 10,67%
Tax rate: 30%

Fig. 11 Electricity producing costs per kWh (1 Pf = 0.01 DM) from solar chimney, coal and combined cycle power plants according to the present business managerial calculation.

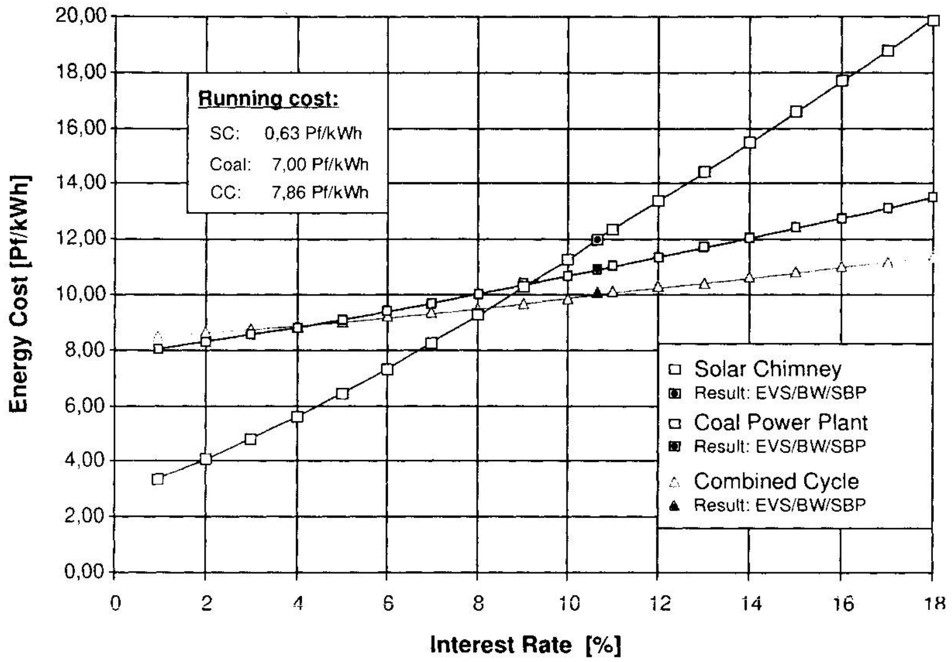

Fig. 12 Electricity producing costs from solar chimney, coal and combined cycle power plants depending on the interest rate.

The presently still higher costs of solar electricity are balanced by several advantages:

- No ecological damage and no consumption of resources, not even for the construction, because a solar chimney predominantly consists of glass and cement which is sand plus self-made energy, a really sustainable power plant.
- The (high) investment costs are almost exclusively due to labour costs. This creates jobs, and
- a high net product for the country with increased tax income and reduced social costs (= human dignity, social harmony), and in addition
- no costly imports of coal, oil, gas which is especially beneficial for the developing countries releasing means for their development.

We have no choice but to do something for the energy consent, the environment and above all for the billions of underprivileged people in the Third World. But we should not offer them hand-outs, a multiple of which we deceitfully regain by imposing a high interest rate on their debt. Instead we should opt for global job sharing. If we buy solar energy from Third World countries, they can afford our products. A global energy market with an essential solar contribution beyond hydropower is no utopian dream!

If we really want to we can do it!

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