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Estimating the potential of “Energy Towers” in a GIS environment

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1. Introduction

“Energy Towers” is the name of a technology which was developed at the Technion - Israel Institute of Technology, to produce electricity in arid lands, taking its predicament - a lot of hot and dry air - and turning it into an asset.

The aim of this special project is to estimate the net power production and the cost it would take, when placing the “Energy Tower” on different sites around the globe. This evaluation will allow the selection and ranking of sites, where a construction of an “Energy Tower” power plant may be introduced as an alternative energy source, both renewable and environmentally clean.

2. The thermodynamic principle

The phenomenon of a downward wind shear caused by cloud rain has been well known for centuries. The first to suggest the use of this phenomenon for producing electricity was Philip Carlson (1975). The Energy Towers technology is an attempt to contain the process inside a tall and large diameter hollow shaft with an open top

and openings around the bottom, more or less as suggested by Philip Carlson. At the top of the Tower the rain is replaced with a continuous spray of water, which partially evaporates and therefore cools the air from its dry bulb temperature to close to its wet bulb temperature (see figure 1). The cooled, heavier air falls then down and comes out at the bottom. Along the way through the Tower’s base openings the airflow passes turbines and generators that produce electricity. The process continues endlessly as more dry and warm air is sucked in from the top. A part of the produced power is used to pump the water from a water source to the Tower’s base, and then to the top of the Tower to be sprayed across the diameter of the shaft.

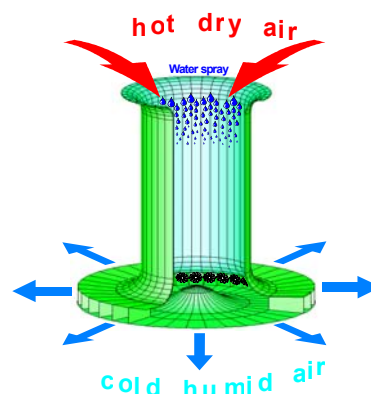


Figure 1: The Energy Tower principle

3. The model parameters

The power production of an Energy Tower depends on various factors, among them are the Tower dimensions (height and diameter), the topographic location of the Towers site, the “quality” of the supplied upper air (mainly temperature and humidity) and surface air conditions. For the purpose of this project, the power calculations are made for a base line design Tower of 1200 m height and 400 m diameter, under four significant parameters. The parameters are the height of the Tower site above the nearest water source, the distance between the Tower site and the nearest water source, the dry bulb and wet bulb temperatures of the air at the top of the Tower, (at 1200 m above ground level). The first two parameters will determine the share of generated power that will be re-directed towards pumping of water. The dry and wet-bulb temperatures are required for the estimation of the initial air cooling due to water evaporation at the top of the Tower.

4. The analytical model for the estimated power production

The net deliverable power N [MW] of the Energy Tower is calculated for every site (pixel on the geographical grid) and on every time step (four times per day). Obviously these circumstances impose a simplified model that would enable a fairly good power evaluation in a short run-time. The most suitable model chosen

for that purpose was therefore the analytical model that expresses very closely the Tower net power by the following equation:

$$N = A_c \eta_t \left(\frac{2}{3} E_{net} \right)^{3/2} \frac{1}{\sqrt{F \rho}}$$

Where:

A_c is the cross-sectional area of the main shaft [m²], η_t is the efficiency of the turbine transmission generator aggregate [-], ρ is the average air density [kg/m³], F is the energy loss coefficient [-], and E_{net} is the net mechanical specific energy [Pa], which can be computed as the sum of the excess static pressure of a cooled air column minus the pumping energy required for spraying a certain amount of water per cubic meter of air.

This formula is a result of an analysis showing that the term $2/3 * E_{net}$ in parenthesis gives the theoretical maximum possible deliverable power and that $1/3 * E_{net}$ is devoted to energy losses.

The net mechanical specific energy E_{net} increases more or less in proportion to the Towers height and the extent of the average air cooling, which is the difference in the pressure between the ambient hot dry air column and the humid colder air column flowing inside the Tower.

The formula was confirmed analytically, by wind tunnels, 21m model test, and half a dozen different numerical solutions of flow equations including turbulence terms. The effects of different intricacies are

finally expressed in the actual values formed for E_{net} , F and ρ .

5. The algorithm for the potential assessment

In order to estimate the potential of a specific site a sequence of calculation and decisions are to be taken. The algorithm's major steps are as following:

- Step I: Processing a Digital Elevation Model (DEM) in order to obtain two of the model parameters: the height and distance between the site and water source. The applied data set is the GTOPO30 produced by the U.S Geological Survey's (USGS) available at the EROS Data Center. The elevations in GTOPO30 data set are regularly spaced at 30-arc seconds ($\approx 1\text{km}$). This grided data is computed on a Geographic Information System (GIS) resulting two rasters of the resolution 0.16 long/lat degree, which describe the two parameters mentioned above. Within the span of one pixel ($\approx 20 \times 20\text{km}$) the most appropriate location for placing an Energy Tower may be the lowest area section of $3 \times 3\text{ km}$. This significant consideration will set the pixel values of the height raster.

- Step II: Processing upper air parameters for the evaluation of the wet-bulb temperature at the top of the Tower. The data set utilized for this purpose is the ERA15 Re-Analysis Project retrieved

from the MARS, data storage and retrieval system developed and used by the European Center for Medium-Range Weather Forecasts (ECMWF). The ERA15 archive contains all relevant weather parameters, beginning from December 1978 to February 1994. The model temporal resolution is 6 hours and spatial resolution of 1.125 long/lat degree. Eventually three upper air parameters are being retrieved: the geopotential [m^2/s^2], the dry bulb temperature [K] and the relative humidity [%], at five pressure levels: 1000, 925, 850, 775 and 700 [hPa]. The parameter's value at the Tower top is evaluated through a linear interpolation between the pressure levels. On hand of the resulting values and according to an algorithm using perfect gas relation the wet-bulb temperature is iteratively calculated.

- Step III: Running an analytical model for the calculation of the Tower net power production at every site and time step during the period of 10 years. This part of processing is also applied on a GIS system. On hand of the results a sample statistics, such as averages and variances may be evaluated for the Energy Tower performance. A further step includes an economical assessment for the price of electricity, taking into consideration social and economical condition regarding the site.

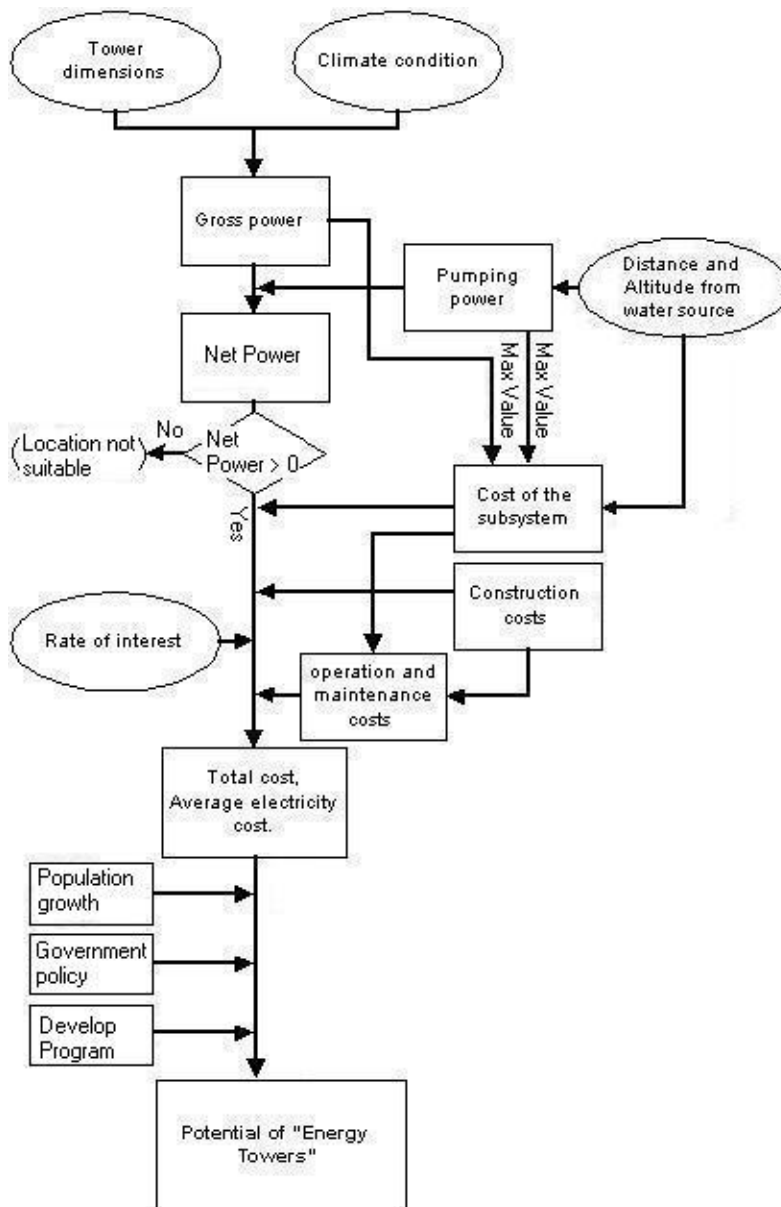


Fig 2: A flow chart for the Algorithm

6. First results

At this point of the project a run-test was accomplished which comprehend steps I, II and partly step III. Practically the frame of work achieved is the processing of the sets of raw data and the application of the

analytical model following the value of net deliverable power production.

The area that was covered for the run-test is the Middle East. Figures 3-6 show the resulting model parameters and the corresponding power production for a picked time point.

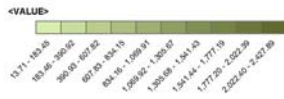
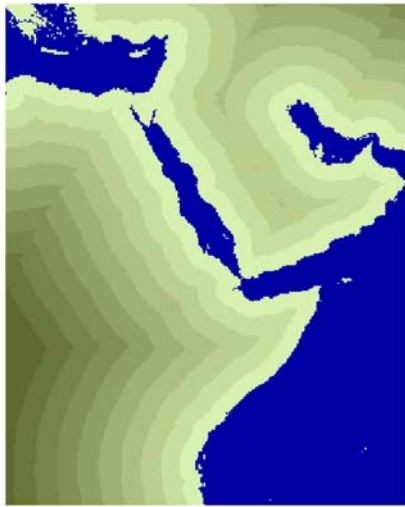


Figure 3: Distance of the site from water source [km]

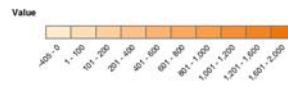
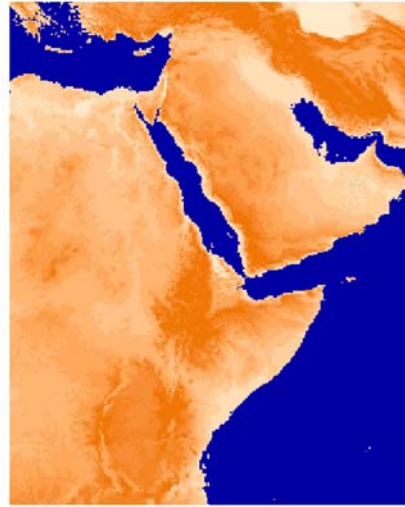


Figure 4: Height of the site above water source [m]

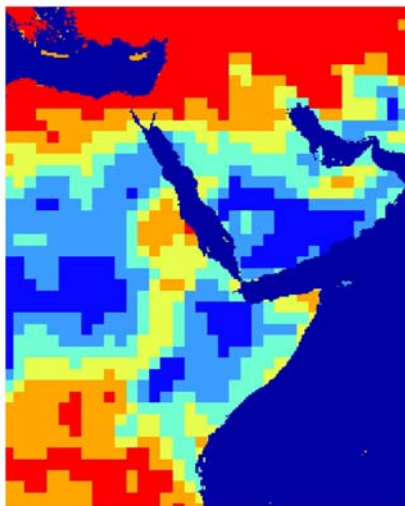


Figure 5: Cooling of the air at the top of the Tower [K]

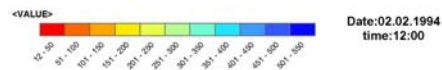
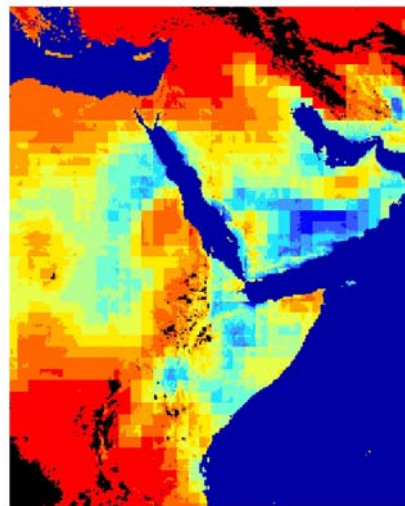


Figure 6: Net power production of the Tower [MW]

7. Future work

In the near future the pattern of the run test will be applied to the continent of Australia over a time period of one year. This analysis will provide a daily and seasonally variation of the power. Later, based on the resulting data, step III will be concluded with its statistical analysis and the economic analysis.

Finally, the special project will attempt an evaluation of the Energy Towers global potential based on 15 years sampling duration.

A more accurate computation of the net deliverable power will require the air temperature and humidity in several heights along the Tower, optimization of different geometrical parameters of the Tower, optimization of the rate of water spray, droplet size optimization, water salinity etc.

8. References

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