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A model for estimating the potential of "Energy Towers" in a GIS environment

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1. Introduction

"Energy Tower" is a new proposed technology aimed to produce electrical energy by means of cooling large masses of hot and dry air and producing a down-draft in a large shaft. Assessment of the ET potential may shed light on the outlook of this technology as an alternative source for producing renewable electric energy.

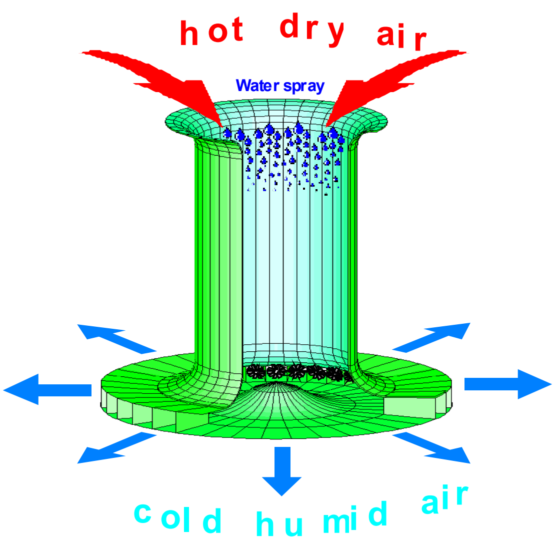

Figure 1: Illustration of an ET

The principal concept of an ET is to cool hot and dry air by a fine spray of water. The cooled and denser air flows downward within a tall (1200 m) and large diameter (400 m) shaft of a Tower. At the bottom outlet the high velocity airflow actuates turbines to generate electricity (Figure 1). The water required for the air cooling may be fresh or salty. The water discharge is pumped and conveyed from the water source (lake or sea) by a pumping system

Preliminary, very rough estimates show that the worldwide supply of hot and dry air by the Hadley Cell Circulation is in order of 2 10^{16}- 4 10^{16} kWh per year. The efficiency of turning this heat into mechanical work and electricity is about 1%. Thus the potential of electricity production is in the order of 30 times the present global electricity production.

A cost comparison (Table 1) shows that it is economically competive with electricity production from coal gas and nuclear energy.

Table 1 - Characteristic electricity production costs (¢/kWh) by major electricity suppliers, for years 2005-2010 (1996 US dollars) (75% load factor, 30 years) [IEA, 1998]

Technology	Cost extreme range		Representative average costs	
	5% discount rate	10% discount rate	5% discount rate	10% discount rate
Nuclear	2.47-5.75	3.90-7.96	3.31	5.05
Coal	2.48-5.64	3.74-7.61	4.07	4.99
Gas	2.33-7.91	2.36-8.44	3.98	4.47
Energy Towers	1.68-3.93	2.51-6.42	2.47	3.88

The only competitive sources of electricity in terms of cost are large hydro-electric projects and eventually some extraordinary sites for wind power production. None of the solar energy technologies come even close to the projected costs. Another outstanding advantage of the Energy Tower is that it works 24 hours a day.

The aim of this special project is to estimate the net power and the production cost, 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. 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.

The main problem is to obtain the necessary mapping is the computation time. The computation time of a one point case at a detailed tree dimensional model takes about 5 days on a powerful parallel computer. In order to obtain the mapping of a huge number of points in time and space we must reduce to a small fraction of seconds. Towards this end we have devised the simplified ETP model (Energy Tower Production model). The model uses two groups of input variables, climatic and topographic: the climatic parameters include the air properties at the tower's top: temperature [K], relative humidity [%], and air pressure [hPa] (all at ~1300 m above ground), and the topographic variables include site elevation [m] and distance [km] between the site and the nearest water source. The outputs of the ETP model are net power production [MW], gross power [MW], pumping power [MW] and water discharge [ton/s].

We are in the process of testing this model and gradually improving it. Different examples will be mentioned in the following report.

3. Methods

The first application of the model for the Energy Tower's potential estimation was made for the Australian continent. The major steps of the model are as following:

I. Setup of a climate and topographic dataset

The first step is the processing of raw Topographic and Climatic data sources, to set up an input dataset for the ETP model. This dataset includes the two topographic parameters (distance and height above sea level) and the three main climatic parameters (Temperature, Relative humidity and air pressure at the Tower's top), all at a temporal resolution of 6 hr and a spatial resolution of 0.2 deg. The entire dataset was integrated into a GIS in the format of Lat/Lon grid layers of *231x180* cells, where cell size is approximately 20x20[km^2] (0.2x0.2[deg]).

The topographic data source is the Digital Elevation Model GTOPO30 produced by the U.S Geological Survey [USGS, 2003], where elevations are regularly spaced at 30-arc seconds (≈1km). The data set is used for the calculation of the two topographic variables: The height of site above sea level (Fig. 2) and the Euclidean distance from site to the nearest water source (Fig. 3).

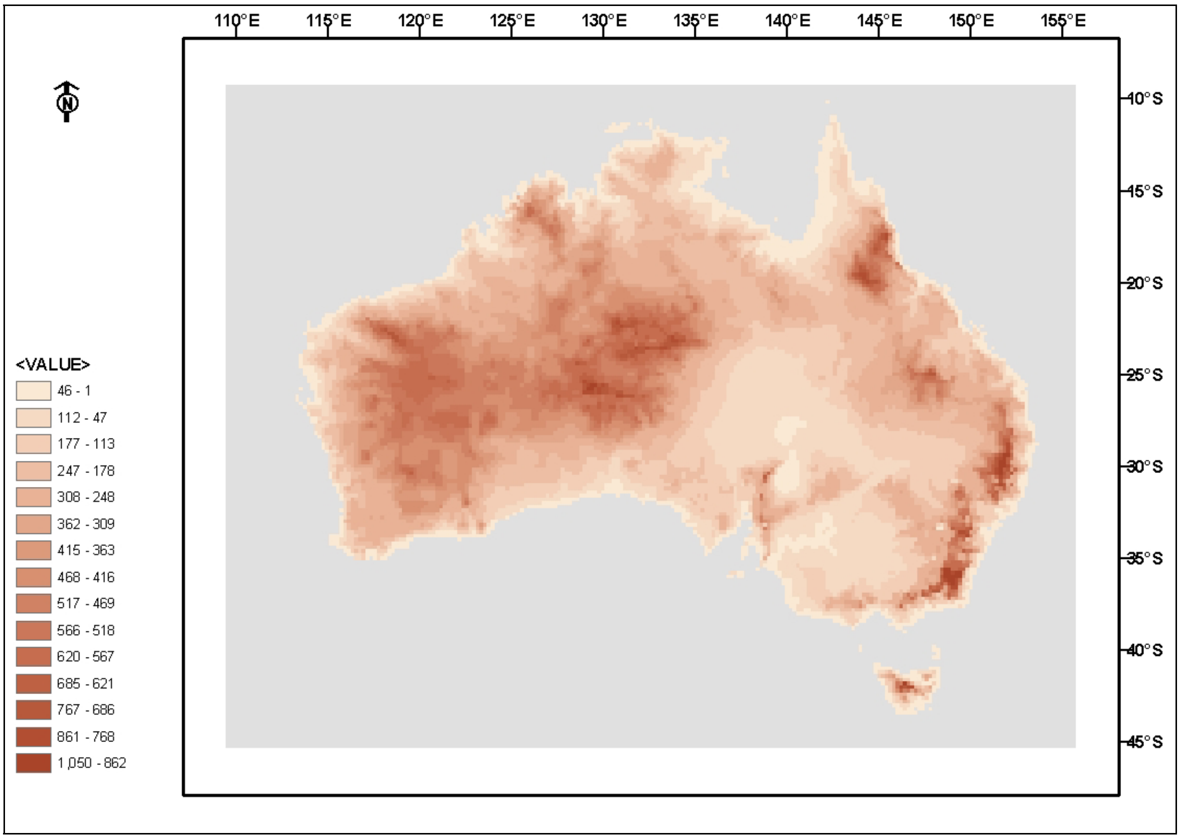

Fig 2: Minimum height difference between the Tower's site and Water Source [m]

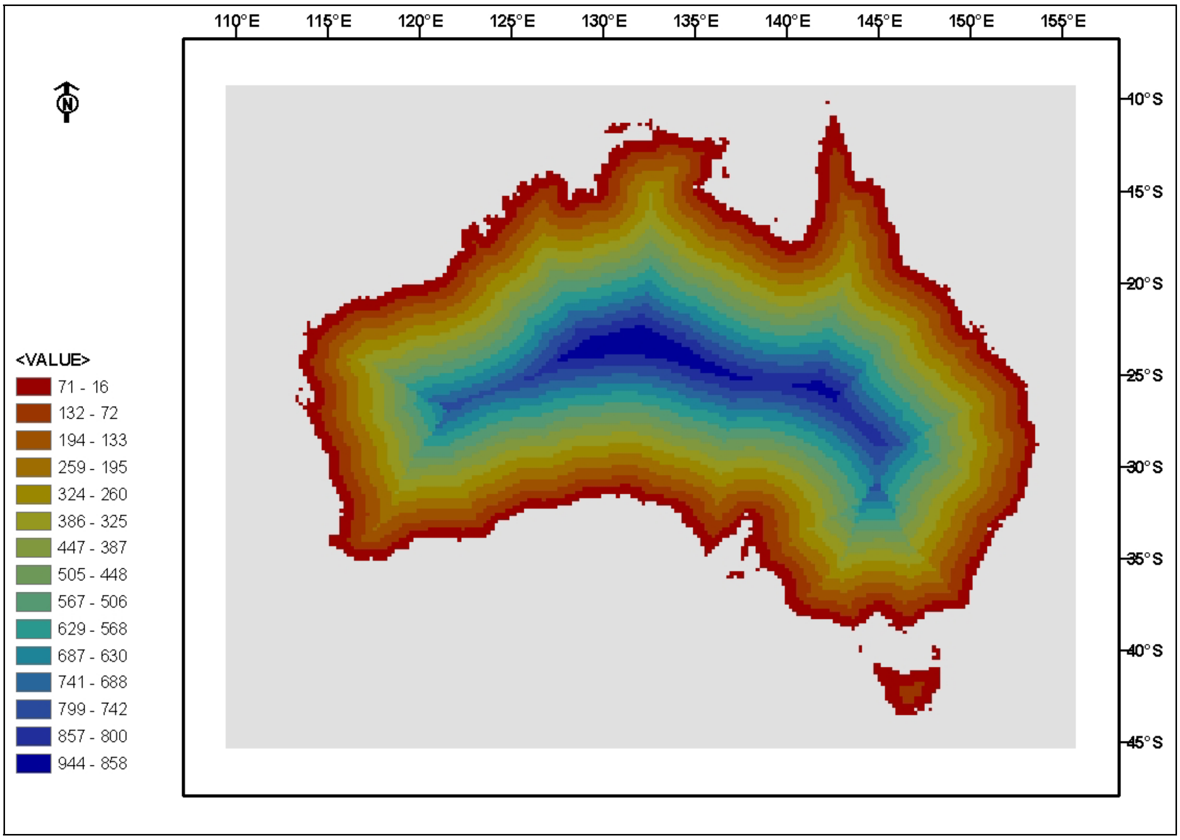

Fig 3: The distances between the Tower's site and water source [km]

The data source for the upper air parameters is the ERA15 Re-Analysis Project retrieved from the MARS-data Storage and Retrieval System, developed by the European Center for Medium-Range Weather Forecasts [ECMWF, 2003]. The ERA15 archive specifies numerous weather parameters from December 1978 to February 1994. Three upper air parameters were retrieved: the geopotential [m^2/s^2], the dry bulb temperature [K] and the relative humidity [%], at five air pressure levels: 1000, 925, 850, 775 and 700 [hPa] every six hours during the year 1993. The ERA-15 atmospheric model is at a spatial resolution of 1.125 long/lat degree. Cell-specific elevation data served to calculate the climatic parameters, temperature, humidity and pressure at the tower top, using a linear interpolation between air pressure levels. The outputs of this process are maps of climatic parameters at the same resolution as the elevation data, namely 20 [km^2] (Fig. 4 illustrates the temperature at Tower's top for the entire continent).

II. Application of the ETP model and evaluation of the power potential

The next step of the Energy Tower potential assessment was to calculate the power outputs for the entire input dataset. The

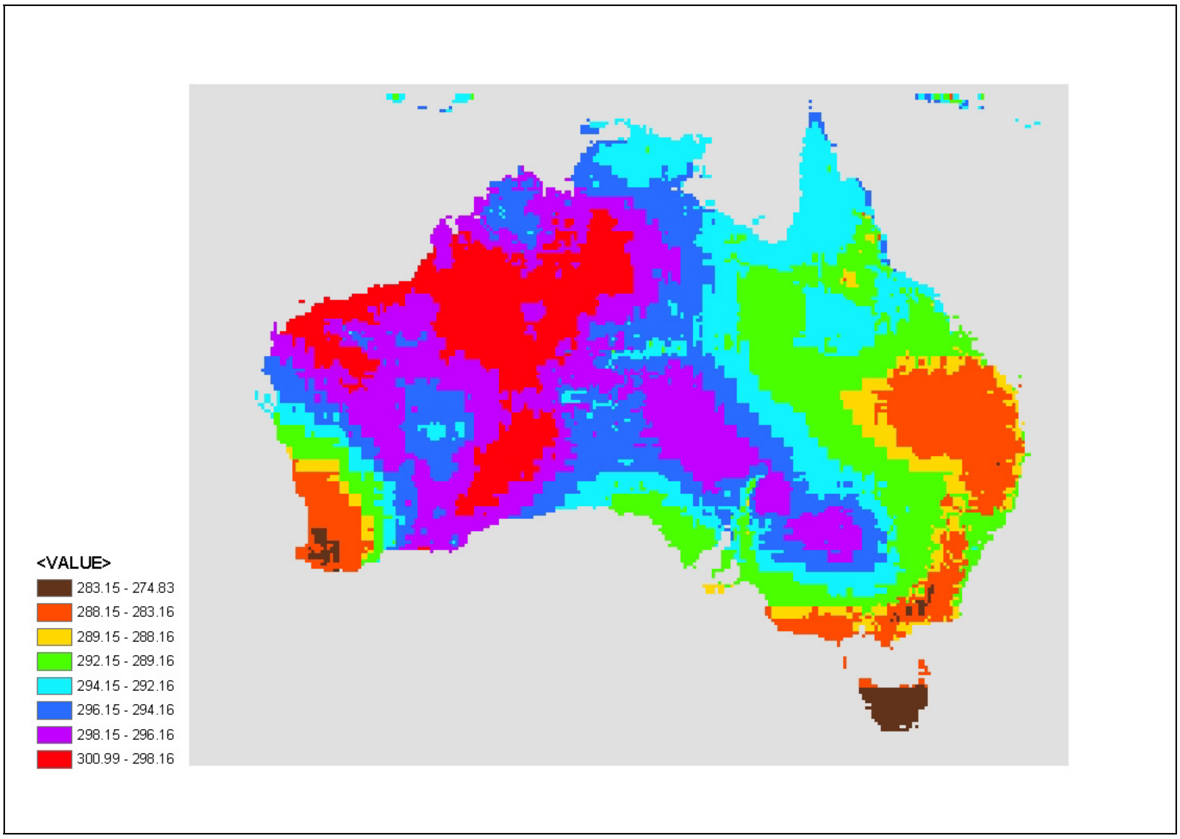

Fig 4: Air Temperature at the Tower's top at the resolution of the processed data, 0.2deg [^oK]

output of this step are time-series of data and maps of Gross Power, Pumping Power, and Net Power for Australia (4 sets per day for one year). Monthly average, seasonal average and annual average, as well as data and maps of the variability statistics of these parameters were then constructed.

III. Evaluation of the electricity cost

The third and last step is the estimation of the energy cost. This step relies much on previous work for estimating the costs of ET's sub systems [Zaslavsky, 1999]. The electricity cost evaluation included the following steps:

1.) Evaluation of the total cost of an ET power plant was summarized with the equation:

$$C_{construction}[M\$] = 648 + 0.32 GP_{Installed} + 0.4 PP_{Installed} + 2.85 D$$

Where: 648[M$] is a fixed construction cost of the Tower, the spray system and the operational reservoir. The second term is the costs of the turbine and generators power system as a function of the installed gross power ($GP_{installed}$ [MW]). The next term expresses the costs of the pumping system as a function of the installed pumping power ($PP_{installed}$ [MW]), and the last term stands for the construction costs of the water conduit from the water source to the ET site as a function of the distance between them (D [km]).

2.) The evaluation of the annual net deliverable energy

3.) Calculation of the electricity production cost as a function of the above mentioned, construction cost and the annual net energy, for an assumed annual interest rate of 5% life time expectancy of 30 years and 0.49 cent per kWh operation and maintenance cots.

4. Results

The time serials maps of Tower's power outputs were processed with GIS tools to calculate the steps II and III. The results of the analysis are represented by the mapping of the annual average net power (Fig. 5) and the electricity cost (Fig. 6).

The pattern of the average annual net power reveals two separate areas that would yield the highest net power, areas A and D In these areas the average net power of an Energy Tower is estimated to be above 350[MW]. Areas E and F were sampled because of their proximity to population centers and area G was sampled as an example for a strictly unsuitable locations.

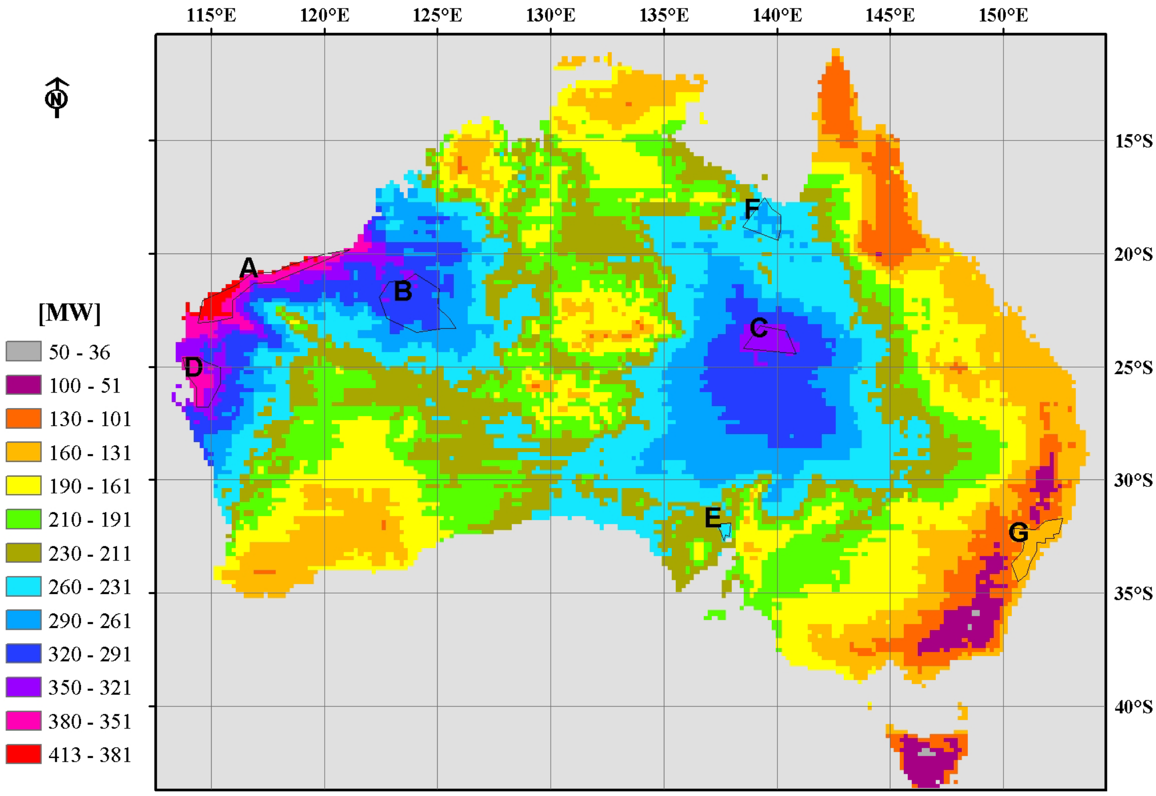

Fig 5: Annual average Net Power of the "Energy Tower" for 1993 [MW]

Table 2: Summary of the parameters and ET outputs of zones A-G

Area of interest	Avg. Distance	Avg. height	Annual avg. temperature	Annual avg. humidity	Annual avg. Gross power	Annual avg. Net power	Std. of the net power
	Topography		Climate conditions at the ET's top		ETP model outputs		
	[km]	[m]	[C]	[%]	[MW]	[MW]	[%]
A	50	67	19.2	39.0	654	377	44.3
B	416	316	18.4	39.0	623	306	51.0
C	684	107	17.9	38.6	626	324	46.5
D	66	68	16.4	40.7	618	355	54.0
E	95	24	11.6	53.0	419	236	60.0
F	117	60	19.2	53.4	470	261	57.2
G	85	94	9.8	66.0	275	142	62.9

Table 2 presents various model outputs for areas of interest A-G. Comparison of areas A to D explains the contribution of the topographic and climatic parameters to the resulting net power. For example the gross power production of areas A and B make a ~5% difference due to climate conditions. As for the net power this difference rises up to ~20% mainly because of the topographic differentiations. On the contrary, area D which holds the lowest gross power shows up in the net power for the same reason. Another important feature documented in the Table 2 is the standard deviation of the net power production, indicating the reliability of electricity supply. The research results show that area A stands out not only for high net power but also for low variations in power production, promising a relatively stable generation of electricity.

The evaluation of the electricity cost range from 2.7 [¢/kWh] up to 26 [¢/kWh]. The pattern of the electricity cost shows the impact of the conduct construction cost, causing a constant increase in costs with distance-from-sea. Note, for example a comparison of two specific sites, one located in area A, 50[km] away from sea shore and the other in area E directly on coastline. The average net power production of both sites differ in ~32%, yet because of conduct cost and power fluctuations, the sites have the same economic potential (the evaluated electricity production cost is ~3.75 [cent/kWh]).

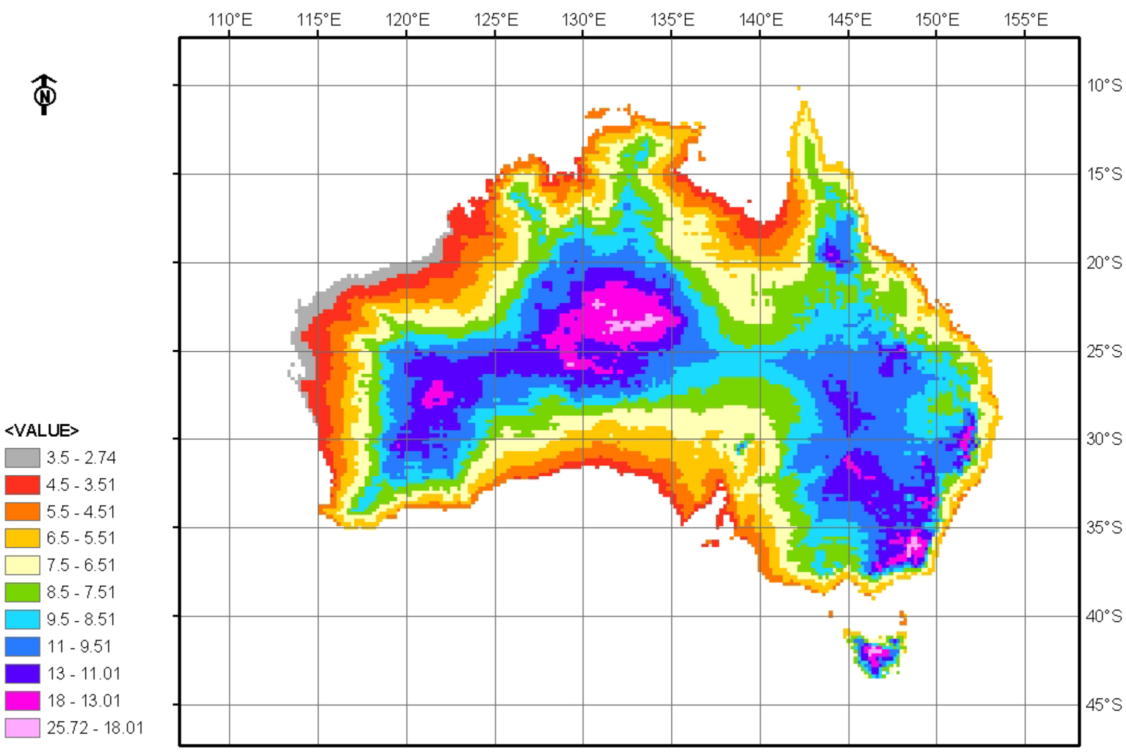

Fig 6: Electricity Cost projected with interest rate of 5% and 30 years life expectancy [¢/kWh]

5. Conclusions

The Model for estimating the potential of Energy Towers enables the assessment of upper air and topographic conditions, and formulates a simplified ETP model for the Tower's outputs. Consequently the developed model's tools facilitate the evaluation of the power and cost potential of an Energy Tower over extensive region.

First application of the model was done for the Australian continent. Analysis of the results indicates that the sites of high net power production occur along a narrow and relatively plane strip of the continent's west coast. In this area, the average net power of an Energy Tower is estimated to be above 350[MW] with variations of ±150-204[MW] around the average. The average water discharge for the Tower's operation is 15.5-17.8[tons/s]. This area holds also the highest economic potential, since the cost of electricity is the lowest and below 3.5[¢/kWh]. The obvious disadvantage of this area is its distance from the largest population centers and electricity consumers. Areas closer to population centers indicated average net power of 236[MW] and electricity cost that ranges between 3.5-4.5[¢/kWh].

6. Future work

In the near future we intend to expend the processed range of time and area. Therefore, the model will be applied for 15 year and for different areas such as California-Mexico, North Africa, India-Pakistan etc.

A more accurate computation of the net deliverable power will require the air temperature humidity and air pressure in several heights along the Tower and at ground level. Other intended improvements of the ETP model include the influences of atmospheric winds, optimization of water spray rate, droplet size, water salinity etc.

7. Acknowledgements

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8. References

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