SPECIAL PROJECT INTERIM REPORT

Interim Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2007
Project Title:	Evaluation of the Global Potential of Energy Towers SPDEGPET
Computer Project Account:	SPDEGPET
Principal Investigator(s):	Dr. Gregor Czisch
Affiliation:	IEE-RE, Universität Kassel
Name of ECMWF scientist(s) collaborating to the project (if applicable)	……………………………………………………………… ………………………………………………………………
Start date of the project:	2001
Expected end date:	2012

Computer resources allocated/used for the current year and the previous one
(if applicable)
Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	100	0	100	0
Data storage capacity	(Gbytes)	10	0	10	0

Summary of project objectives

(10 lines max)

The goal of this study is to incorporate the important parameters that affect the power production of an Energy Tower into a model capable of calculating the "Energy Tower potential" for an entire world region across a whole year. Here, we evaluate two aspects of the potential of Energy Tower, the net power production and the energy production cost.

Summary of problems encountered (if any)

(20 lines max)

Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

See following pages

Evaluation of the potential of electricity Production by using technology of "Energy Towers"

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1. Introduction

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

The principal concept of an Energy Tower (ET hereafter) is to cool hot and dry air by evaporation of a fine water spray. 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 1.1). 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 and conveyance. The ET technology employs solar energy indirectly and therefore promises the production of electric energy day & night, without the need to construct solar collectors.

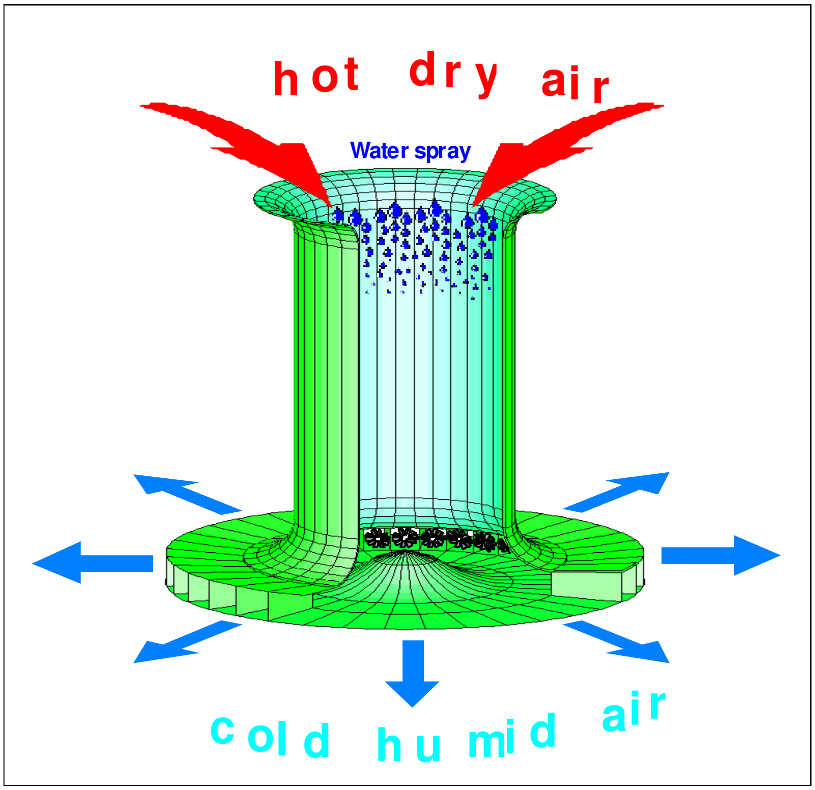

Figure 1.1: Illustration of an ET

The power production of an Energy Tower depends on several factors. The Tower's gross power is determined mainly by the properties of the surrounding air, mainly its temperature, humidity, and pressure. Hotter and dryer air will result in a higher temperature-difference between the air inside and outside the Tower, and therefore increase the gross power production of the Tower. The Tower's net power is the gross power minus the power re-directed to pumping of water from the water source up to the Tower's top spraying system.

Naturally, air characteristics vary in space and time; therefore Energy Tower's gross power production fluctuates diurnally and seasonally. Moreover, the Tower's net power is also dependant upon site location and elevation relative to the water source. Consequently, the Energy Tower's performance would vary greatly in different locations. Thus, a critical preliminary step in the planning of a commercial application is the mapping of the expected potential of an Energy Tower across a whole region. This kind of analysis would enable the ranking and locating of promising sites. The goal of the present study is to incorporate the important parameters that affect the power production of an Energy Tower into a model capable of calculating the "Energy Tower potential" for an entire region across a whole year. Here, we evaluate three main aspects of the potential of Energy Tower, the net power production and the energy production cost and possible production of sea water desalination assuming we use 20% of the produced electricity for this purpose.

2. The Model for the Evaluation of the Energy Tower Potential

2.1 The Energy Tower's Production model (ETP)

In order to estimate net power production of an ET for an entire region for a whole year, a model should calculate net power production for each location, several times per day, 365 days a year. Obviously, this requires the formulation of a highly simplified model capable of producing fairly accurate estimates in a short run-time. Towards this end, we devised the model called ETP (Energy Tower Production) model. Basically, the ETP model gives an analytical expression for the major process occurring in the ET. The ETP model results were compared with a one dimensional flow model, which in turn had to be compared for validity with a the most accurate three dimensional computational fluid dynamics model which took five days computations of 5 parallel computers. This is per one tower at one point in time and a set of climatic parameters at least 5 elevations. Instead to simplify, the ETP model uses two groups of input variables, meteorological and topographic. The meteorological parameters include the air properties at the tower's top only: temperature [K], relative humidity [%], and air pressure [hPa] (all at ~1300 m above ground). The topographic variables include site elevation [m] and distance [km] between the site and the nearest water source. The models outputs are net power production [MW], gross power [MW], pumping power [MW] and water discharge [ton/s]. The ETP model formulates four energy terms expressed in pressure units (energy per unit volume): The energy gain due to air-cooling (E_C [Pa]), which is defined as the excess of static pressure due to cooled air column inside the ET. The drag effect energy (E_r [Pa]) exerted on the air by the un-evaporated water droplets falling along the tower at a constant velocity. The pumping energy (E_p [Pa]) expressed as a function of the total pumping head and the total energy losses of the airflow (E_{loss} [Pa]). The energy losses in the ET are due to friction and turbulence of the flow and mainly due to local energy losses at the ET's inlet and outlet, where the air flow is turning by 90 degrees. Coefficients for the energy losses were studied previously by an axi-symetric numerical model and were compared to results of an ET's laboratory model in a wind tunnel (Mezhibovski 1999). Here we assumed the total energy losses to be proportional to the air's kinetic energy with an empiric constant F=0.8. The calculation of the energy gain due to air cooling and drag effect (E_C and E_r) are based on the approximation of two air temperature profiles inside and outside the ET. Next, the model solves the four energy terms (E_C, E_r, E_p and E_{loss}) for the thermodynamic optimum. This yields the maximum net power using the following equation:

$$N_{opt}[W] = A_c \eta_t \left(\frac{2}{3} E_{net} \right)^{3/2} \frac{1}{\sqrt{F\rho}} \tag{2.1}$$

Where A_c is the cross-sectional area of the main shaft [m^2], η_t is the efficiency of the turbine transmission generator aggregate [-], ρ is the average air density [kg/m^3], F is the empiric energy loss coefficient [-], and E_{net} is the net mechanical energy per unit volume [Pa]. E_{net} is defined as the following sum:

$$E_{net}[Pa] = E_C + E_r - \frac{E_p}{\eta_p} \tag{2.2}$$

Where: η_p is the efficiency of the pumping system [-]. Equation (1) results from an analysis conducted in our lab, which shows that the term $2/3E_{net}$ in parenthesis gives the theoretical maximum possible deliverable power where the remaining $1/3E_{net}$ is energy losses (Zaslavsky et al , 2003, Zaslavsky & Guetta, 1999). Comparison of the ETP Model output results with those of the detailed one dimensional model (Gutman et al., 2003) indicated differences in the range of ±10%. However, the possible inaccuracy is small enough to provide the right relative ranking of different sites within a much smaller computation effort. Table 2.1 lists (a) the input parameters and (b) the state variables of the ETP model, with an example of possible values calculated for an ET of 1200[m] height and 400[m] diameter.

Table 2.1 - Input parameters (a) and state variables(b) of the ETP model with example values

	Input parameter	***Unit***	***Value***
1	Height of site above water source	[m]	80
2	Distance between site and water source	[km]	50
3	Air temperature at the top of the ET	[K]	283.15
4	Air relative humidity at the top of the ET	[%]	30
5	Air pressure at the top of the ET	[hPa]	820

	State variable	***Unit***	***Value***
1	Total pumping head	[m]	1445
2	Energy gain due to air cooling (E_C)	[Pa]	428.5
3	Energy gain due to the droplets drag effect (E_r)	[Pa]	27
4	pumping energy (E_p)	[Pa]	126.8
5	Net Energy (E_{net})	[Pa]	318
6	Energy losses (E_{loss})	[Pa]	102
7	Net power	[MW]	311.5
8	Gross power	[MW]	550
10	Air velocity at the ET's bottom	[m/s]	17.8
11	Water discharge	[ton/s]	14.2

2.2 Methods

We applied the ETP model to the entire Australian continent. The position of Australia across the Tropic of Capricorn, zone of descending dry air results in extensive arid and semi-arid regions in the continent. Evaluation of the Energy Tower potential involves a sequence of steps illustrated in Figure 2.1.

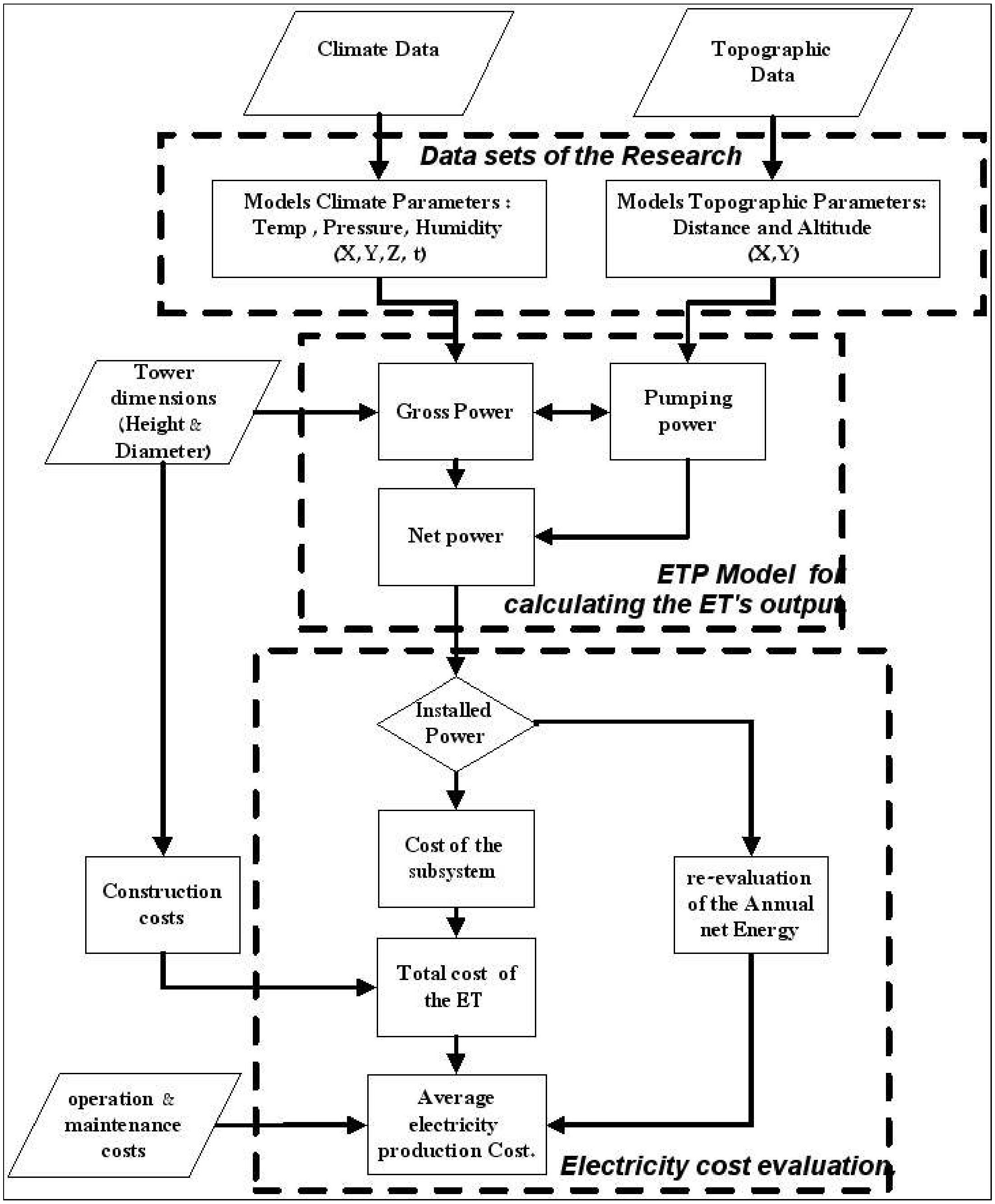

Figure 2.1 - Flow chart of the steps to evaluate the Energy Tower Potential

2.2.1 Setup of a meteorological and topographic dataset

A very thorough study of the computation procedure ETP was applied first in the Australian continent, part of which is brought in the following. The first step was the processing of raw Topographic and Meteorological 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 meteorological 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 (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 lowest location within a cell would be optimal for the ET operation, since it minimizes the pumping energy. Thus, each 20×20 km cell was assigned the minimum elevation value of the original 1 km DEM (Figure 2.2). The distance (*D*) to water source was calculated as the Euclidean distance between each cell and the nearest sea-cell.

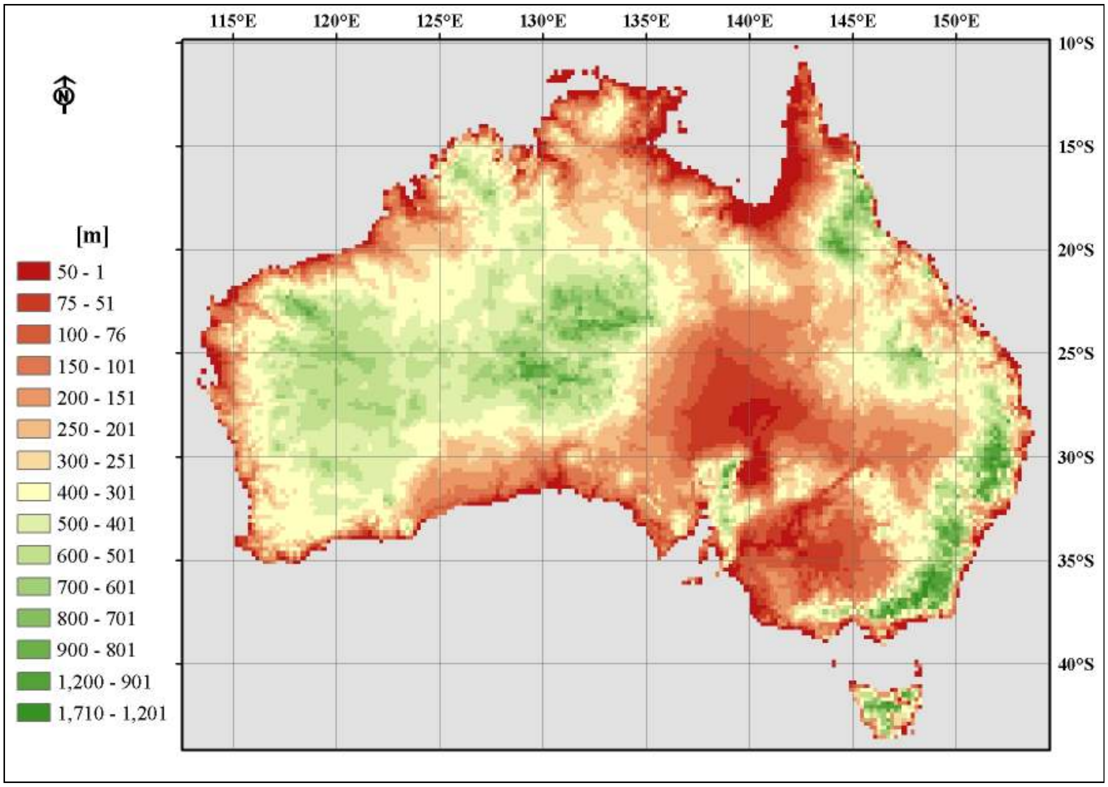

Figure 2.2 - Height difference between the Tower's site and Water Source [m]

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 geo-potential [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 meteorological parameters, temperature, humidity and pressure at the tower top, using a linear interpolation between air pressure levels. The output of this process is maps of meteorological parameters at the same resolution as the elevation data, namely 20x20 [km^2] (Figure 2.3 illustrates the temperature at Tower's top for the entire continent).

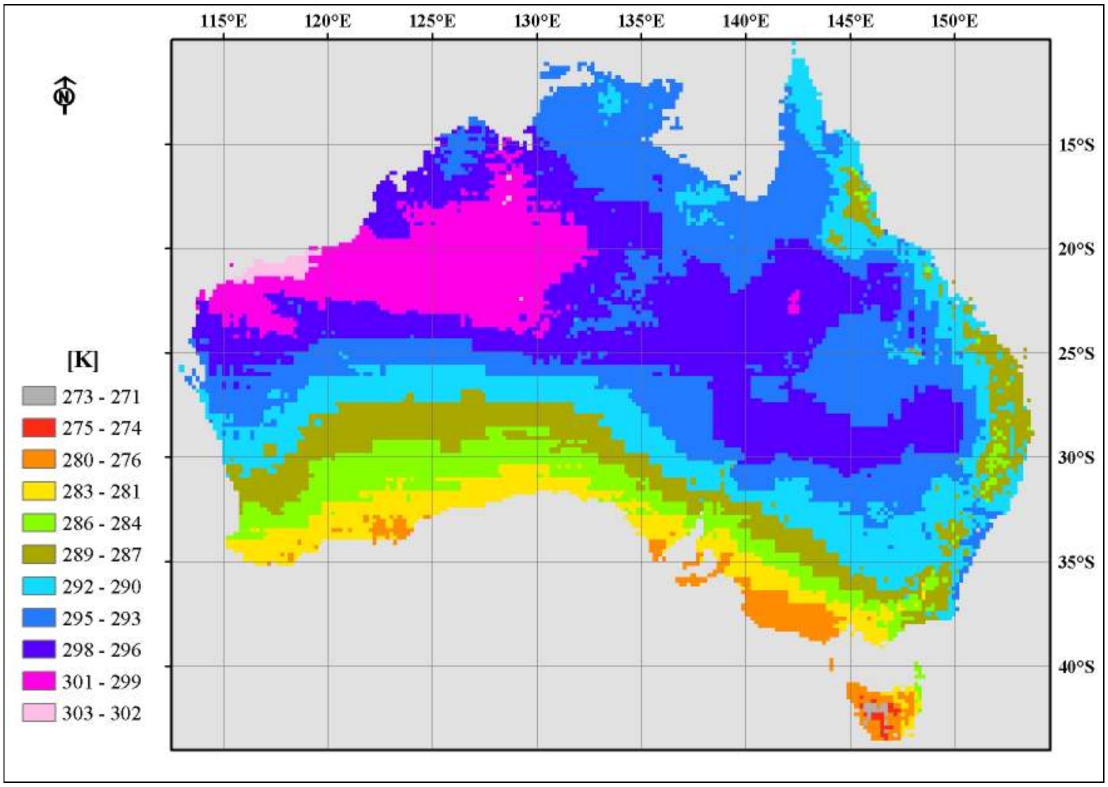

Figure 2.3 - Air Temperature at the Tower's top at the resolution of the processed data, 0.2deg [^{o}K]

2.2.2 Application of the ETP model and evaluation of the power potential

The next step of the Energy Tower potential assessment was to run the ETP model with the entire input dataset. Model output was time-series maps of Gross Power, Pumping Power, and Net Power for Australia (4 maps per day X 365). Monthly average, seasonal average and annual average maps, as well as maps of the variability of these parameters were then constructed.

2.2.3 Evaluation of the electricity cost

The third and last step is the estimation of the energy cost. This step is based on estimates of several parameters and considerations which are all detailed in Table 2.2.

Table 2.2 - Estimated costs of the Energy Tower's subsystems

Sub System	Unit description	Evaluated cost per unit [$/unit]	Number of units for construction
Tower Construction	Evaluated cost for the steel space frame construction (including chimney, diffuser and systems support).	2000 [$/ton]	191,300 [ton]
	Framework cover	13 [$/m^2]	3.355e+6 [m^2]
	Concrete foundation	165 [$/m^3]	140,500 [m^3]
Water Supply	Operational reservoir (1,000,000[m^3]) and water uptake structure	21.8[M$]	1 [per ET]
	Water conduit: 20% pipes (ϕ2600mm) & 80% concrete open canal (wall slope 1:4 and 4 m width)	0.2*5,500+0.8*1,000 [k$/km]	D [km]
	Water Pumping from water source up to the ET top	400[$/kW]	$PP_{installed}$ [kW]
Water Spray System	Including: 1,000,000 Sprayers, 20,000 m of water pipes (ϕ200-ϕ2000 mm), support beams and controllers.	38[M$]	1 [per ET]
Power Pack	An array of 100 Wind Turbine	124 [$/kW]	$GP_{installed}$ [kW]
	Generators	182 [$/kW]	$GP_{installed}$ [kW]
	Transmissions	10[$/kW]	$GP_{installed}$ [kW]
Brine disposal system	Brine reservoir (500,000[m^3]) Ground sealing and drainage of the ET surroundings	109 [M$]	1 [per ET]
	Brine disposal conduit (half the price of the Water conduit.	950[k$/km]	D [km]
Infrastructure	Land, Roads, fence, buildings etc.	30[M$]	1 [per ET]

The installed gross and pumping power is the machine capacity mounted at an ET site. Installing large capacities would enable large electricity production during rare events of favorable meteorological conditions (the hottest, driest day). On the other hand, providing the ET with capacities fitting to exceptional picks would imply higher construction cost. The optimal solution for this tradeoff depends on site-specific topography and power fluctuations, and thus varies from site to site. The variation of the total electricity cost as a function of the installed power at site located close to Port-Headland is illustrated in Figure 2.4. Here, the minimum electricity cost occurs where the installed power is 0.6 of the gross power's pick value. For the purpose of the present study, we applied a rule of thumb that sets the installed gross power at 0.7 of the sub-maximum gross power, defined as:

$$\mathrm{GP}_{\mathrm{installed}}[\mathrm{MW}] = 0.7(\mathrm{GP}_{\mathrm{avg}} + 3\mathrm{GP}_{\mathrm{std}}) \qquad (2.3)$$

Where $\mathrm{GP}_{\mathrm{avg}}$ is the average gross power [MW], $\mathrm{GP}_{\mathrm{std}}$ is the standard deviation of the gross power [MW] and 0.7 is the reduction coefficient.

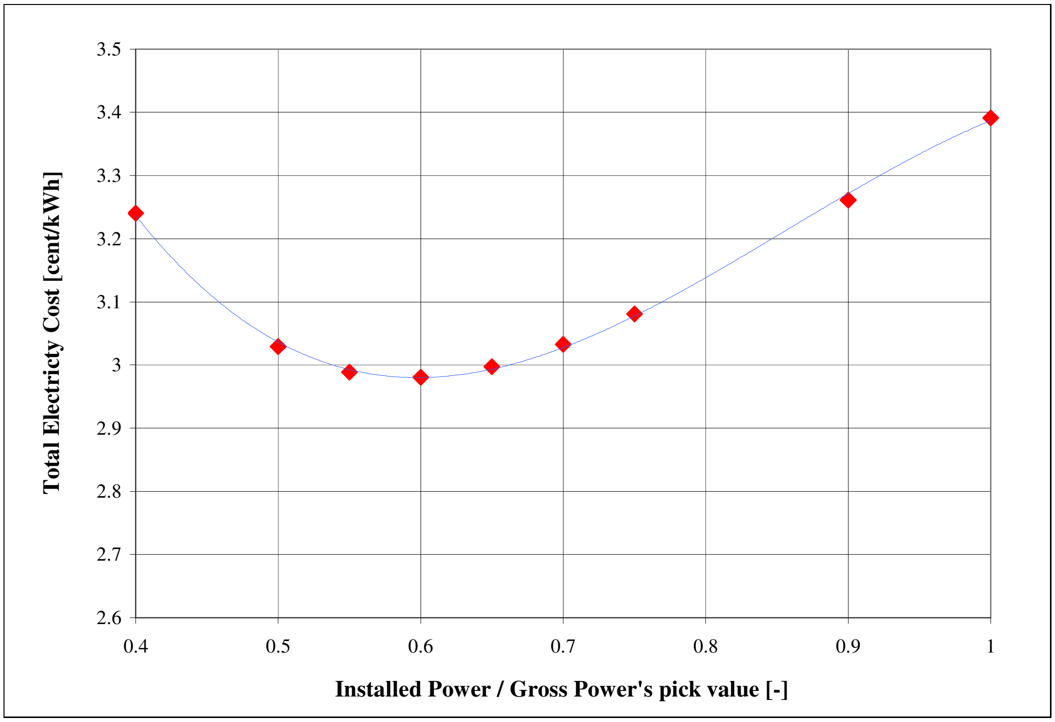

Figure 2.4 - Total electricity cost for different installed power ratios [¢/kWh]

Following the correction of the installed gross and pumping power the net annual electric energy (E_{year}) was then re-evaluated for the entire continent. Finally, the assessment of the electricity cost ($C_{electricity}$) consisted of the parameters expressed in equation (2.4)

$$C_{electricity} = \frac{\frac{i(1+i)^n}{(1+i)^n - 1} C_{construction} + C_{O\&M}}{E_{year}} \qquad (2.4)$$

Where: i=10% rate of interest, n=30 years life expectancy and $C_{O\&M}$=0.49[¢/kWh] operation and maintenance costs.

2.3 Detailed example of the results for the Australian continent

2.3.1 Gross power

The Gross power production of the ET is determined by the properties of the surrounding air. In the ETP model, these properties are represented by the temperature, humidity, and air pressure at the Tower's top. Not surprisingly, the pattern of the annual average gross power (Figure 2.5) indicates that areas of high gross power are found in regions that are dominated by a combination of high temperature and low humidity, namely the arid parts of the continent. Four areas of interest were characterized by high gross power, 620 - 694[MW] (marked as areas A, B, C and D in Figure 2.5).

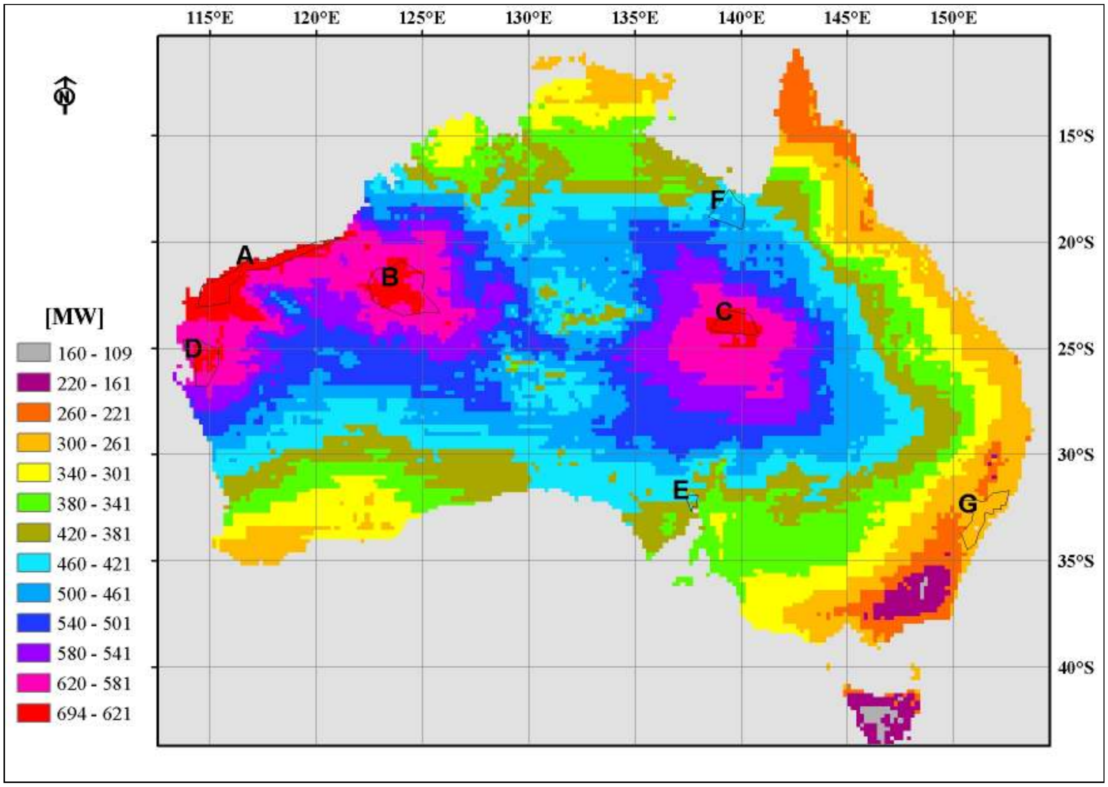

Figure 2.5- Annual average Gross Power of the "Energy Tower" for 1993 [MW]

The pumping power is calculated as a function of cell elevation, its distance from sea and water discharge. The first two parameters are determined by topography, while water discharge is determined by climate conditions (hot and dry air conditions result in increased evaporation, and thus require transport of more water).

2.3.2 Net power

Net power is the difference between the gross power and pumping power. The map of average annual net power (Figure 2.6) 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 of low net power production, 36-160[MW] are stretched along the continent's west coast.

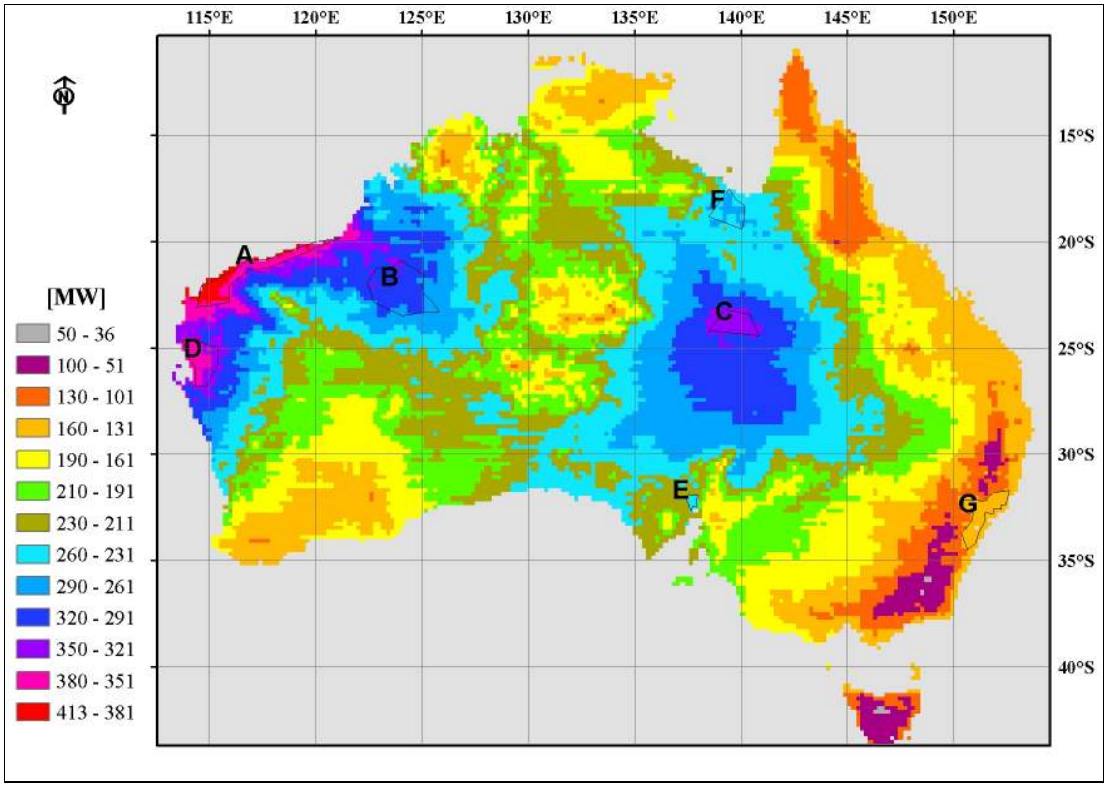

Figure 2.6 - Annual average Net Power of the "Energy Tower" for 1993 [MW]

Table 2.3 presents various model outputs for areas of interest A through G. Comparison of areas A to D explains the contribution of the topographic and meteorological parameters to the resulting net power. For example there is a ~5% difference between gross power production of areas A and B due to climate conditions. For the net power this difference rises up to ~20%, mainly because of topographic differences. In contrast, area D has a relatively low gross power but high net power for the same reason. Three additional areas of interest were delineated on the map, and their properties were investigated closely (Table 2.3). Areas E and F were explored because of their proximity to population centers and area G was explored as an example for an unsuitable location. Another important feature documented in the Table 2.3 is the standard deviation of the net power production, indicating the reliability of electricity supply. Our 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. There are several ways to adapt the slight daily power fluctuations to the demand curve, mainly by built-in pumped storage which is applicable near mountain ranges. There are also ways to adapt the seasonal power fluctuations to reduce the standard deviation, but these are beyond the scope of this work.

Table 2.3 - 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		**Properties of the air 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

Analysis of specific sites was performed as well. A single grid cell was selected in area A, close to Port Headland (Lat: 20.3S, Long: 119.5), located 44[km] south of the Indian Ocean. Net power production of an ET at this site is estimated to be on average 370[MW], where 95% of the time, net power will not drop below 137[MW]. The estimated net deliverable annual energy is summed up to 3.5 billion [kWh/year]. Assuming an annual consumption of 6000 [kWh/year] per capita, our calculations reveal that a single ET on site may serve a population of approximately half a million people.

2.3.3 Electricity cost

Electricity cost estimates (Figure 2.7) range from 4.5 [¢/kWh] up to 42 [¢/kWh]. This result reveals that at potential sites the costs of ET technology may be not only environmentally superior but also economically competitive to costs of fossil electricity sources (Table 2.4).

Table 2. - Characteristic electricity production costs [¢/kW] projected to 2005 with an interest rate of 10% (OECD, 1998).

Energy source	**Range of electricity cost [¢/kWh]**	**Average electricity cost [¢/kWh]**
Coal	3.74-7.61	4.99
Natural gas	2.36-8.44	4.47

The pattern of the electricity cost shows the impact of the conduit 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 differs by ~32%, yet because of conduit cost and power fluctuations, the sites have the same economic potential (the estimated electricity production cost is ~5.85 [cent/kWh]). These costs are based on a 10% interest rate, which is a conservative value (OECD 1998). If lower interest rates are available, then the relative advantage of ET over fossil sources increases further.

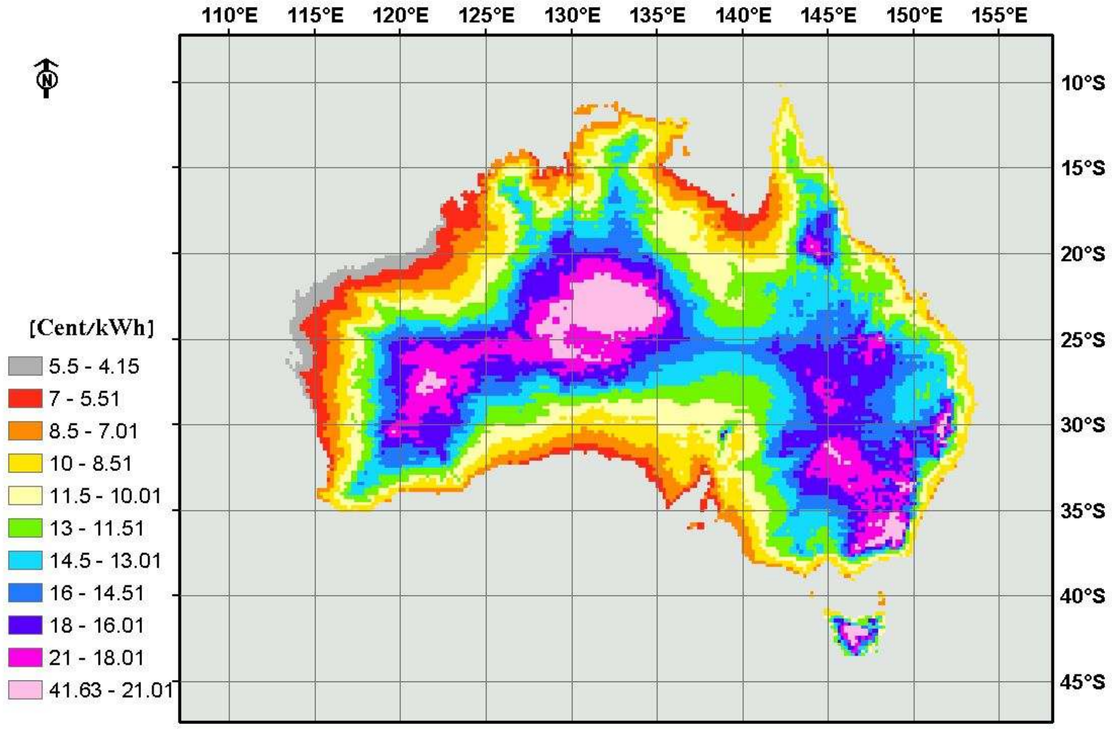

Figure 2.7 - Electricity Cost projected with interest rate of 10% and 30 years life expectancy [¢/kWh]

2.4 Conclusions

With the advent of GIS, Spatially explicit models are becoming indispensable tools for assessing the potential of new energy sources (Ariza-Lopez et al. 1997), offering important information for decision makers (Voivontas et al. 1998). Here, a set of tools was devised to assess the potential of an Energy Tower to supply environmentally clean and economically profitable electric energy. The computer-based assessment integrated site specific topographic parameters and time dependent air properties into a model producing time sequence maps of ET's power outputs. Implementation of the model resulted in the mapping of both power production and electricity cost for the entire continent of Australia. The ETP model running time was relatively short. Simulation of a whole year for the entire Australian continent took about one day, compared with an estimated running time of six months for the one dimensional model. This achievement allows the model to be further implemented on yet a larger scale, consisting several years of meteorological data and covering the whole globe. Analysis of the model outputs characterized specific regions of interest and provided overall ranking of sites in terms of net power production and energy cost. The results depicted vast regions in Australia where arid conditions imply high gross power from Energy Towers. However, part of these areas are characterized also by large distance from water source, and thus high pumping power, which in turn result in relatively low net power. Mapping of the net power and electricity cost indicated at least two regions in Australia (A and E) where the environmental conditions may support profitable Energy Towers. Region A (Port Headland area), characterized by favorable meteorological and topographic conditions, a single ET would supply constantly high net power (≈370 ± 160 MW), providing the electricity needs of ~0.5 million people, for an economically competitive costs (4.7 ¢KWh). In region E (Port Augusta area), characterized by less favorable environmental conditions (lower temperatures and higher humidity), net power would be lower (≈230 ± 140 MW). Yet, its proximity to populated areas and to water source makes of this region compatible to that of region A (7.3 ¢KWh).

3. Maps and Tables for the Evaluation of the global "Energy Towers" potential

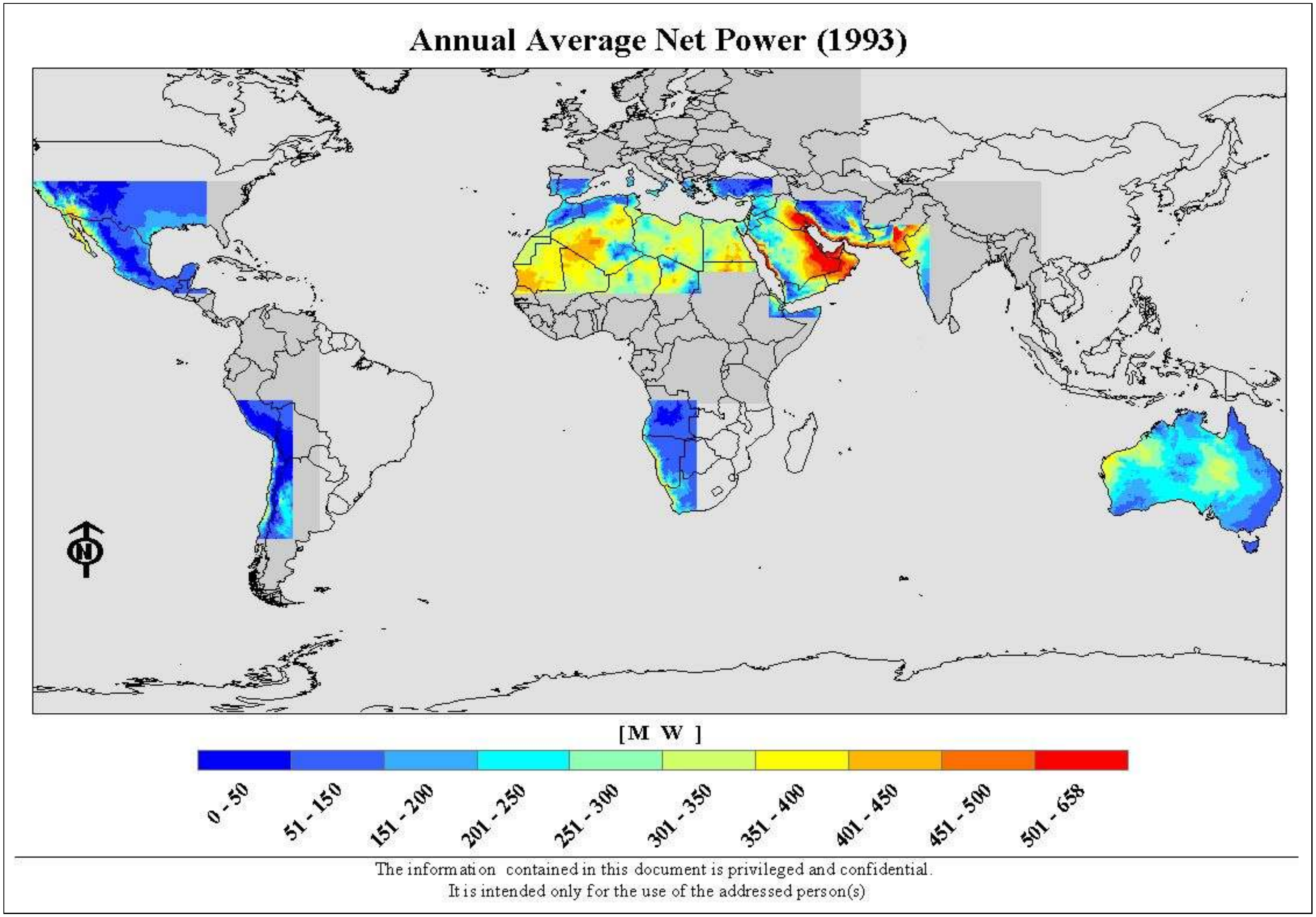

Figure 3.1- Evaluation of the annual average net power production of the "Energy Towers" for year 1993 on a global map

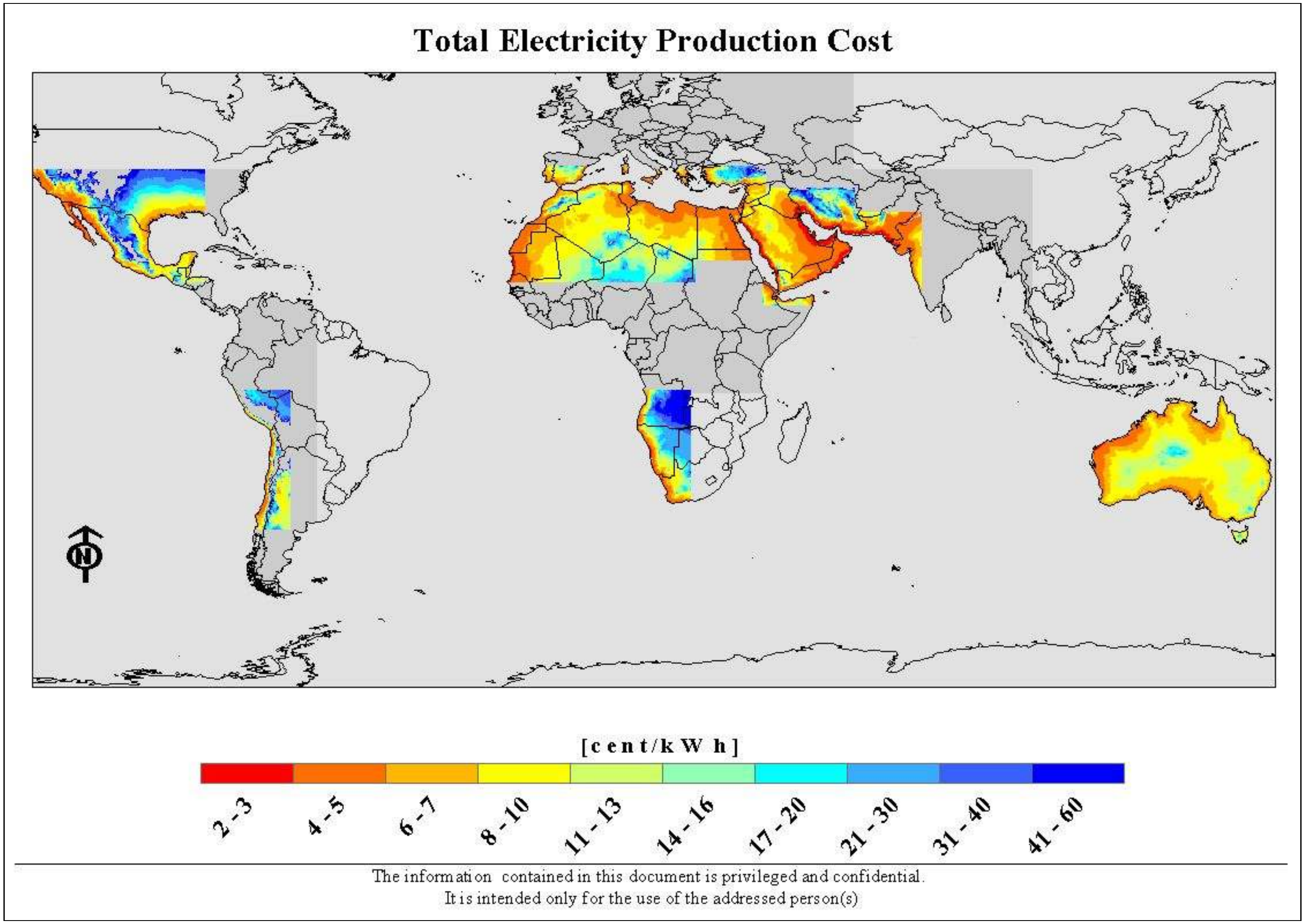

Figure 3.2 – Evaluation of the electricity production cost for year 1993 on a global map

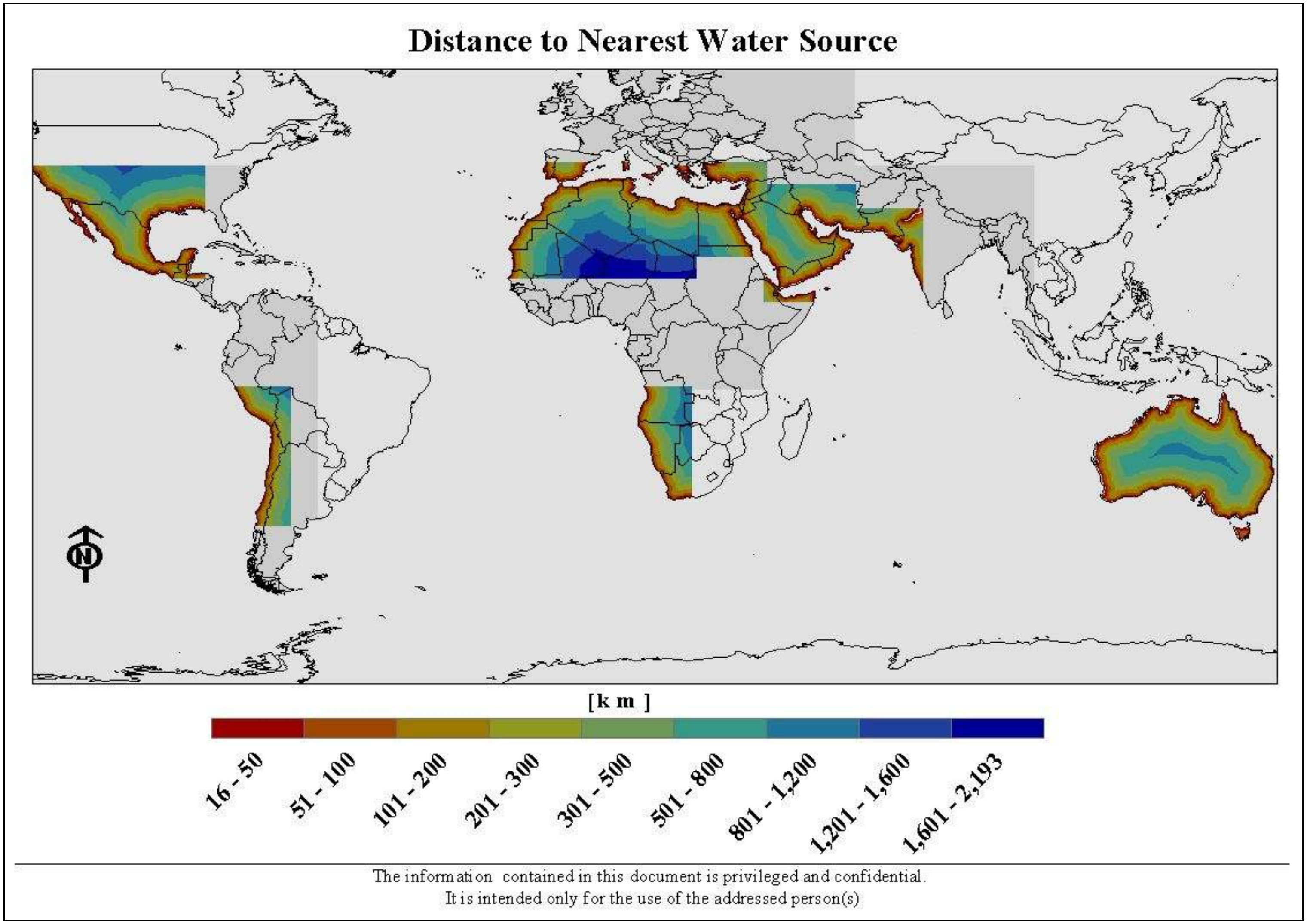

Figure 3.3- An illustration for the calculated distance between nearest water source and the potential sites

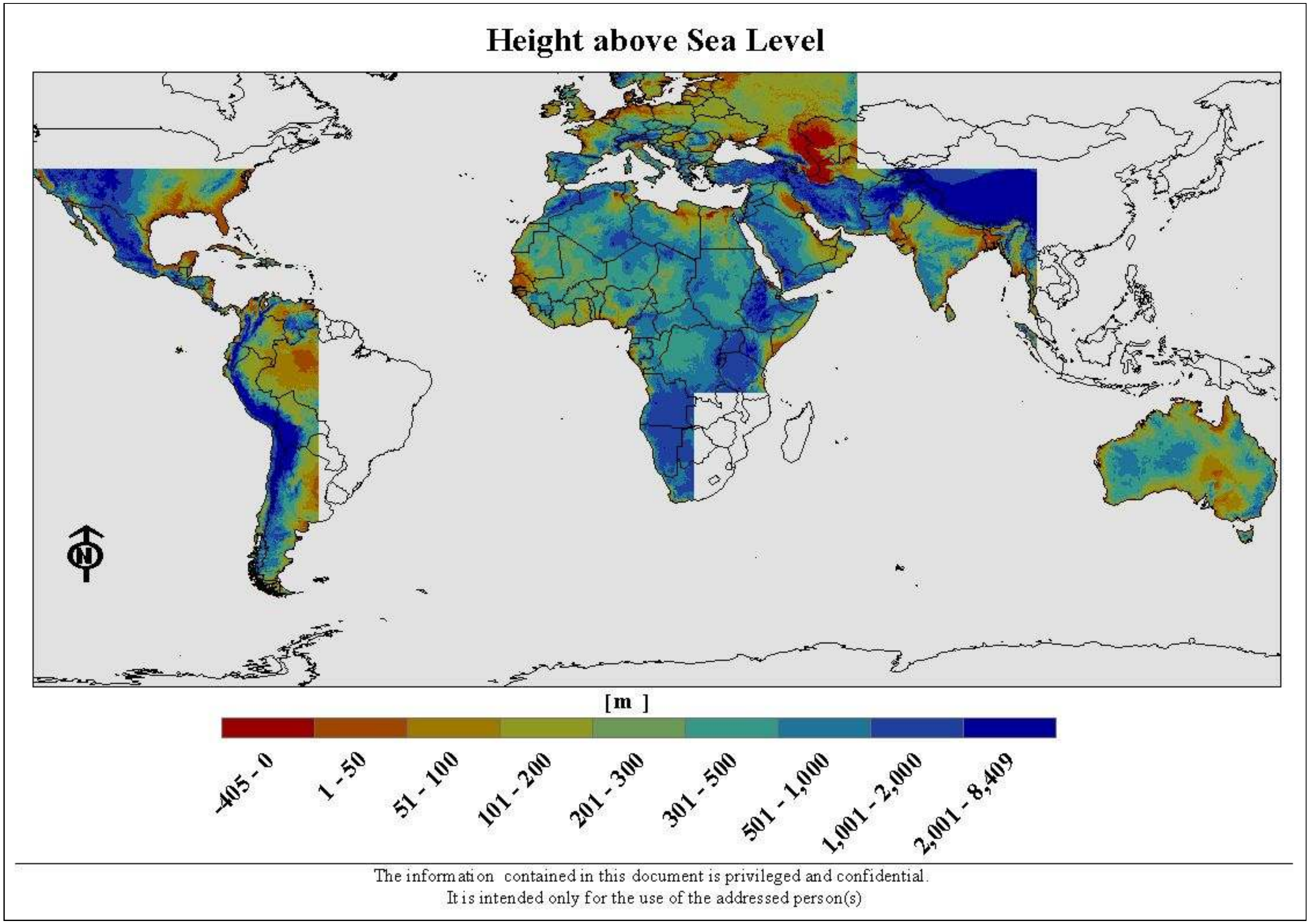

Figure 3.4- An illustration of the topographic height of the potential sites

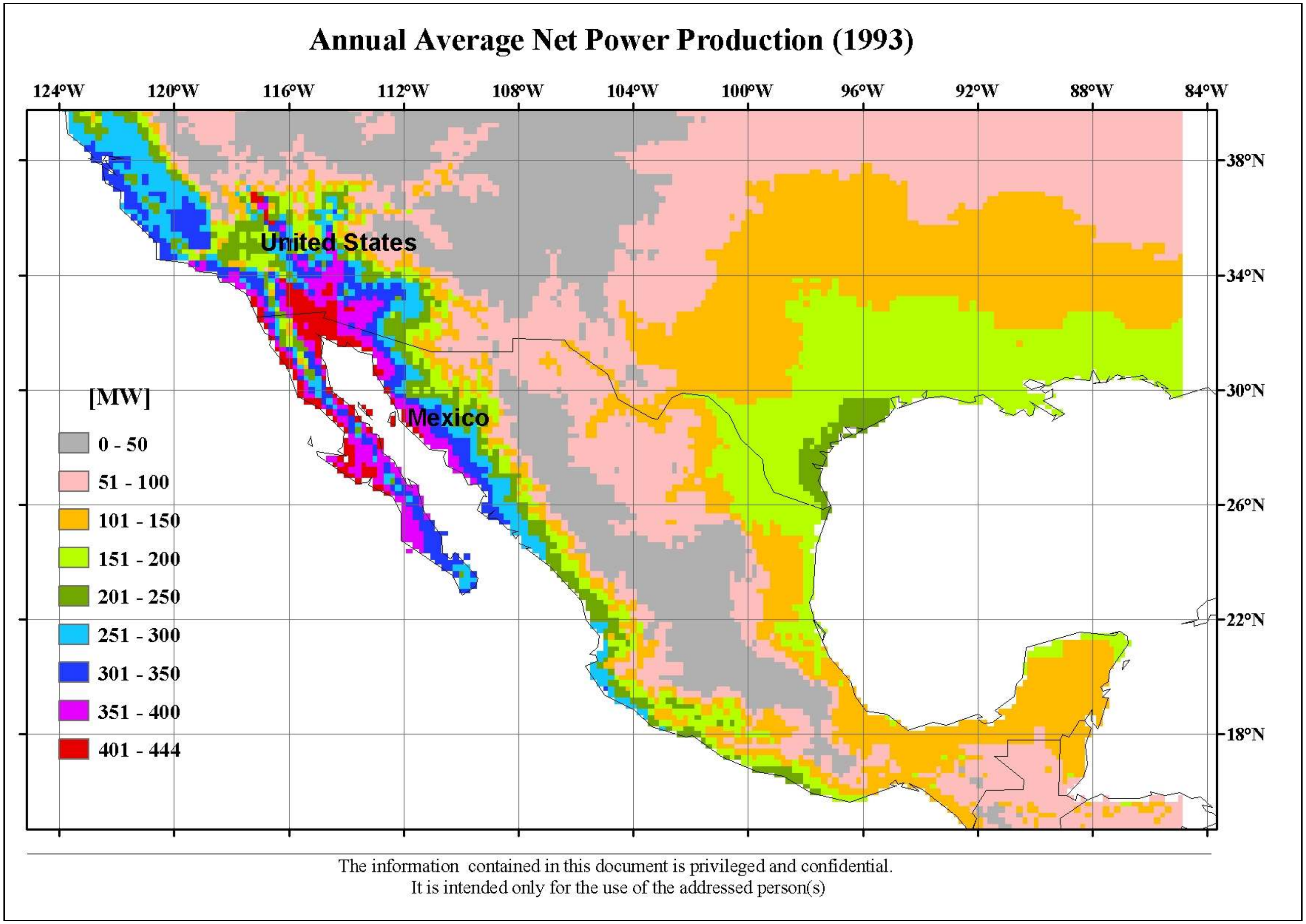
Annual Average Net Power Production (1993)

Figure 3.5- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for ***California and Mexico***

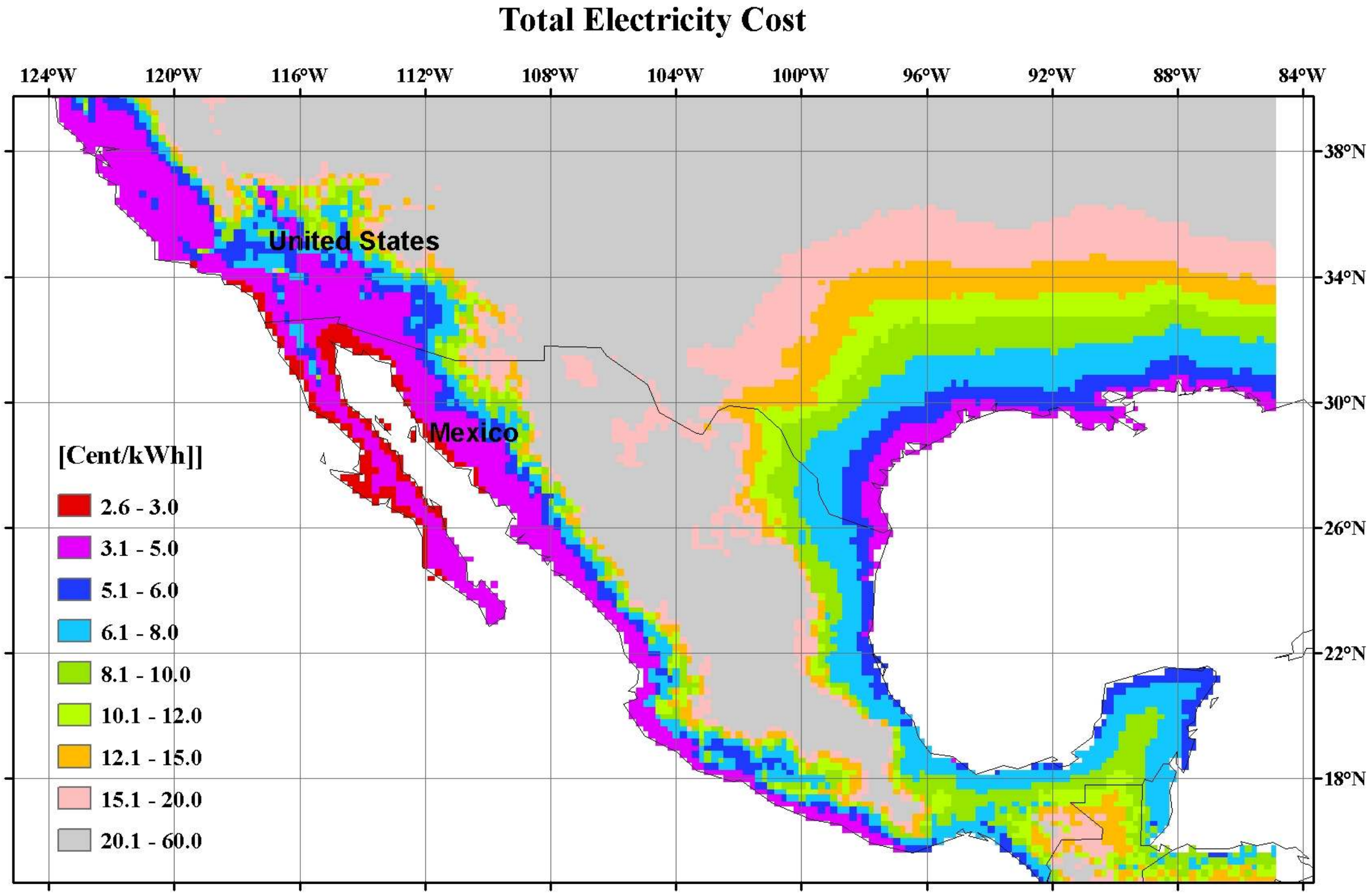

Figure 3.6- Evaluation of the electricity production cost (year 1993) for ***California and Mexico***

Table 3.1- Summary table for the evaluation of Energy Towers' potential in ***California-Mexico***

Range net power	**Average net power**	**Area in this region**	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Potential number of people at 6,000 kWh per year**
[MW]	**[MW]**	**[10^3 km^2]**	**[10^9kWh/year]**	**[-]**	**[millions]**
450-400	413	62.4	564	156	94
400-350	374	102	835	255	139
350-300	321	142.8	1005	357	167
300-250	276	170.4	1029	426	171
250-200	220	208	1003	520	167
TOTAL		**686**	**4435**	**1714**	**739**

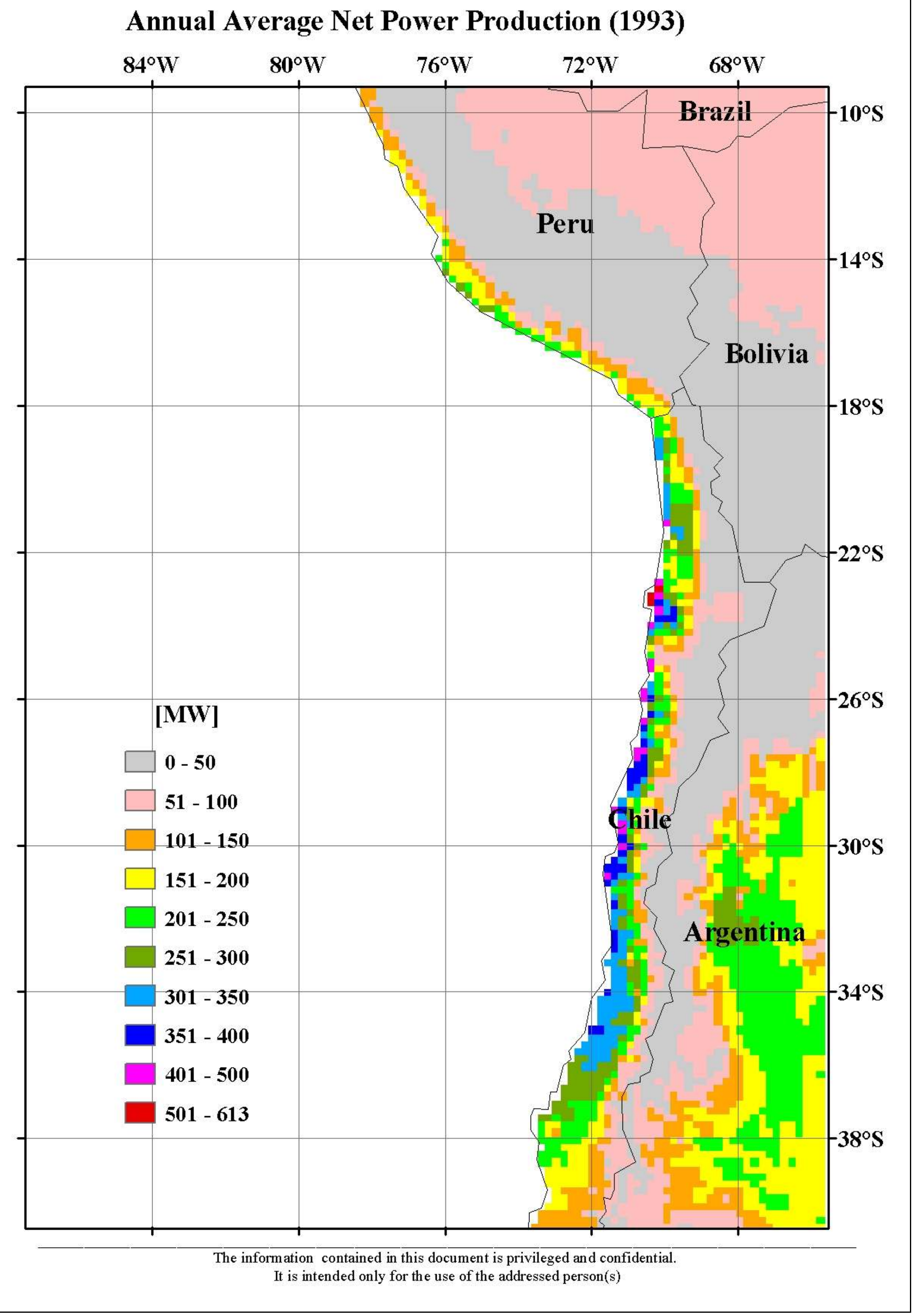

Figure 3.7- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for ***Chile-Peru***

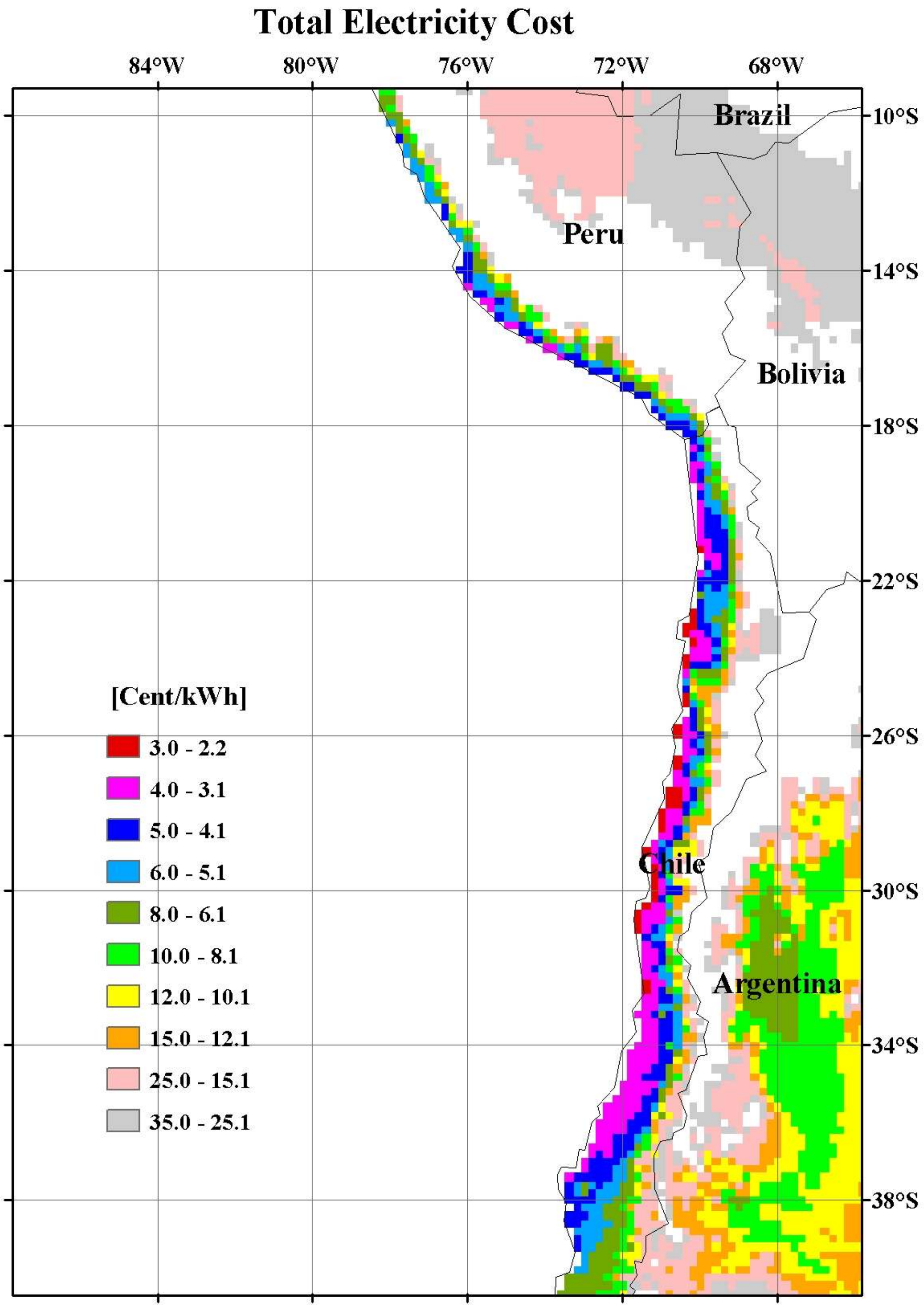

Figure 3.8- Evaluation of the electricity production cost (year 1993) for ***Chile-Peru***

Table 3.2- Summary table for the evaluation of Energy Towers' potential in ***Chile-Peru***

Range net power	**Average net power**	**Area in this region**	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Potential number of people at 6,000 kWh per year**
[MW]	**[MW]**	**[10^3 km^2]**	**[10^9kWh/year]**	**[-]**	**[millions]**
600-613	613	0.40	5.4	1	1
550-600	590	0.40	5.2	1	1
500-550	523	0.40	4.6	1	1
450-500	462	2.80	28.4	7	5
400-450	419	4.40	40.4	11	7
350-400	370	14.00	113.6	35	19
300-350	324	36.00	255.7	90	43
250-300	270	58.80	348.3	147	58
200-250	218	199.20	951.7	498	159
TOTAL		**316.40**	**1753.14**	**791.00**	**292.19**

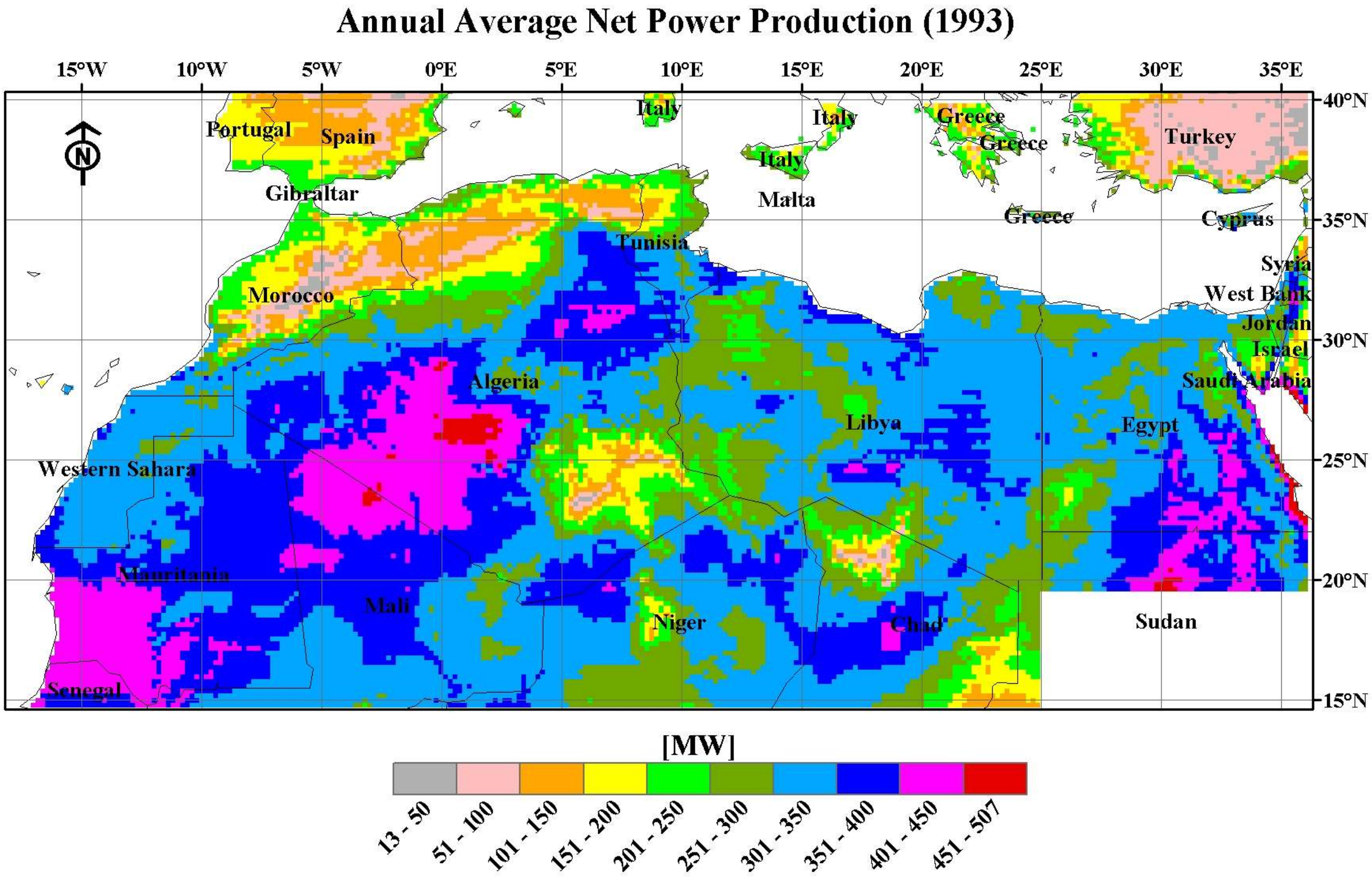

Figure 3.9- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for ***North Africa***

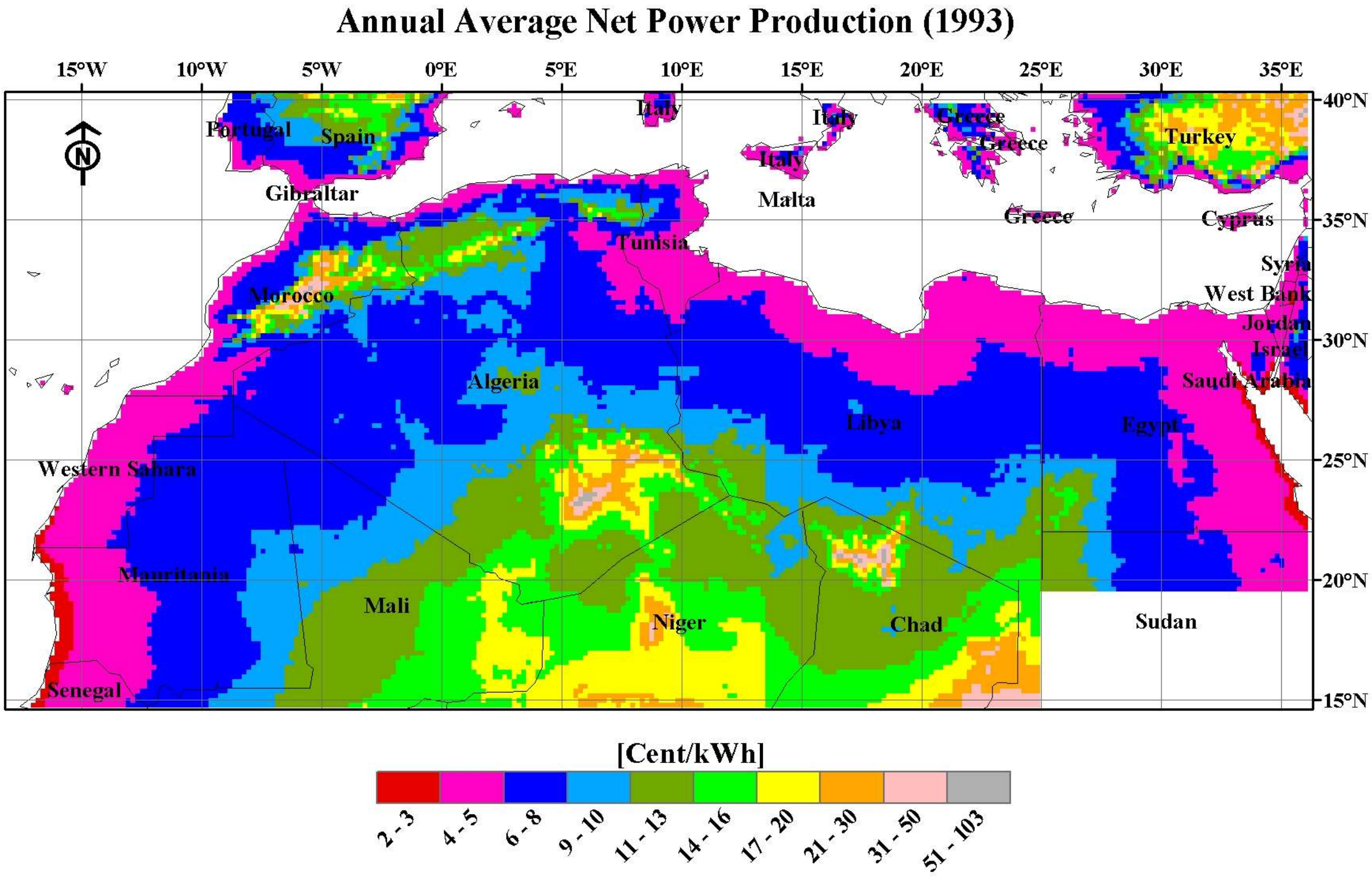

Figure 3.10- Evaluation of the electricity production cost (year 1993) for ***North Africa***

Table 3.3- Summary table for the evaluation of Energy Towers' potential in ***North Africa***

Range net power	**Average net power**	**Area in this region**	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Potential number of people at 6,000 kWh per year**
[MW]	**[MW]**	**[10^3 km^2]**	**[10^9kWh/year]**	**[-]**	**[millions]**
500-507	507	0.4	4	1	1
450-500	466	49.6	506	124	84
400-450	418	806.8	7381	2017	1230
350-400	372	2024.8	16480	5062	2747
300-350	326	3253.2	23234	8133	3872
250-300	280	1459.6	8941	3649	1490
200-250	226	631.2	3131	1578	522
TOTAL		**8226**	**59676**	**20564**	**9946**

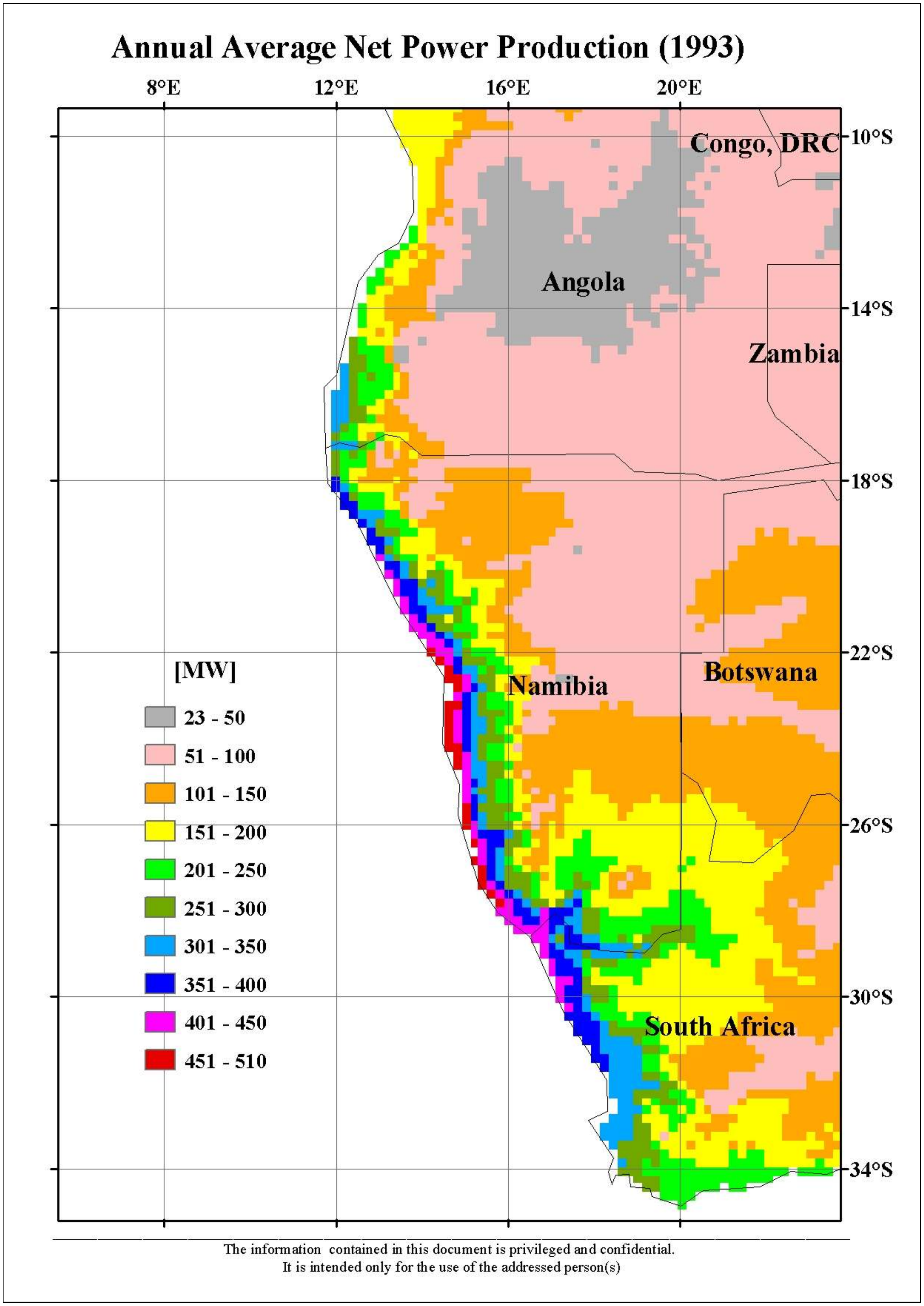

Figure 3.11- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for

South Africa (Namibia, South Africa & Angola)

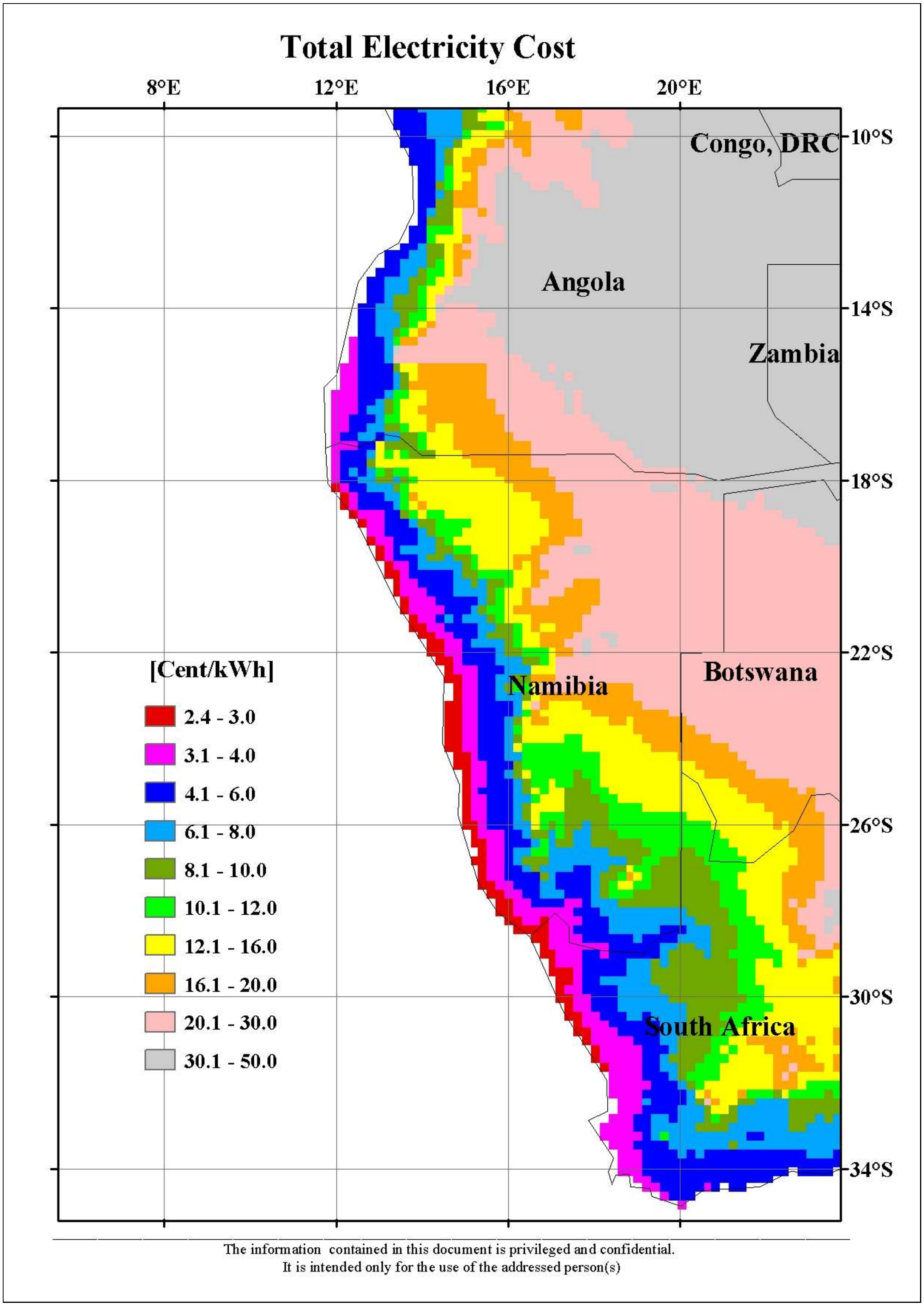

Figure 3.12- Evaluation of the electricity production cost (year 1993) for ***South Africa (Namibia, South Africa & Angola)***

Table 3.4- Summary table for the evaluation of Energy Towers' potential in ***South Africa (Namibia, South Africa & Angola)***

Range net power	**Average net power**	**Area in this region**	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Potential number of people at 6,000 kWh per year**
[MW]	**[MW]**	**[10^3 km^2]**	**[10^9kWh/year]**	**[-]**	**[millions]**
500-510	505	0.8	9	2	1
450-500	472	9.6	99	24	17
400-450	422	23.2	214	58	36
350-400	374	39.2	321	98	54
300-350	324	56.8	403	142	67
250-300	273	72.8	436	182	73
200-250	223	126	614	315	102
TOTAL		328	2097	821	350

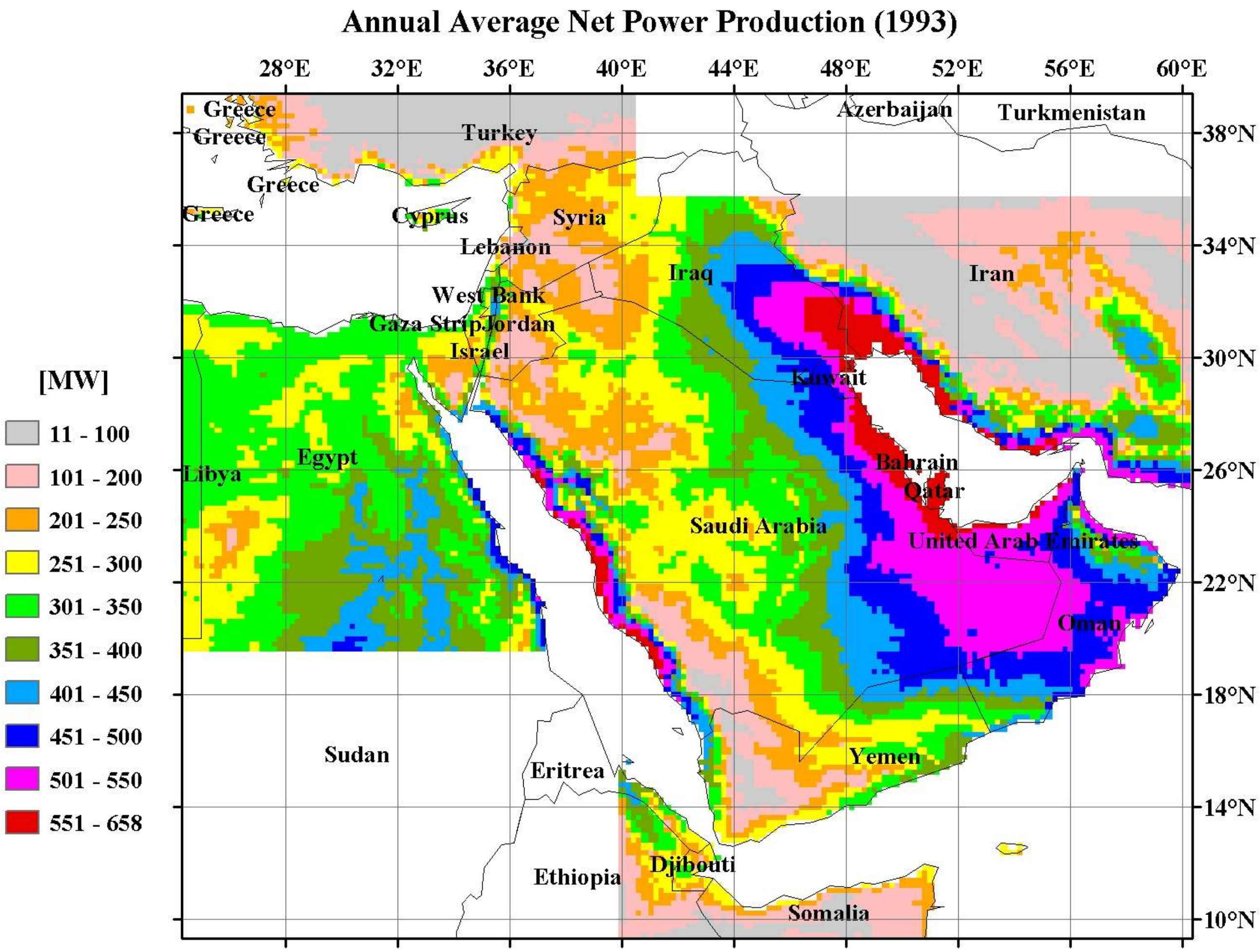

Figure 3.13- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for the ***Middle East***

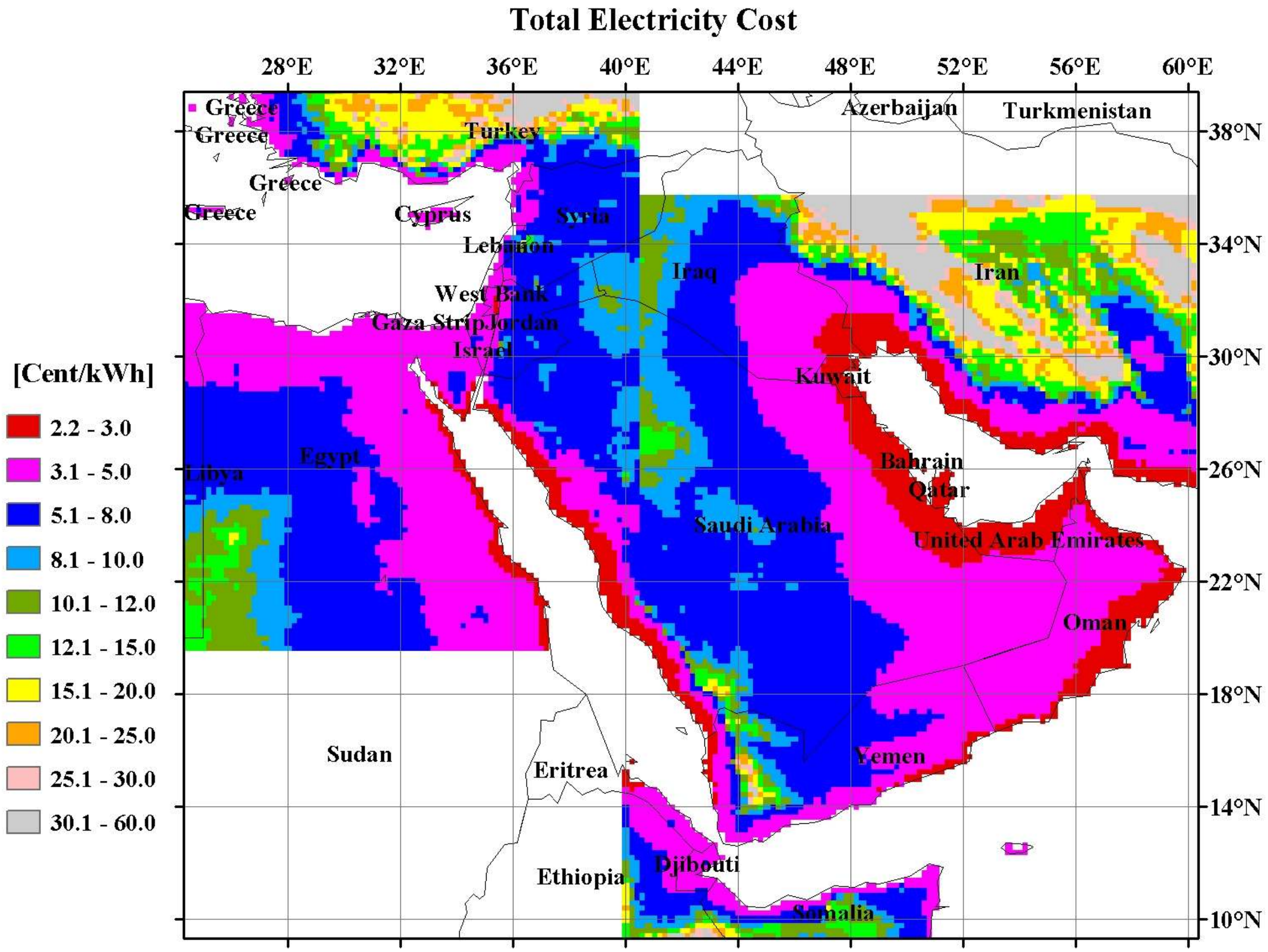

*Figure 3.14- Evaluation of the electricity production cost (year 1993) for the **Middle East***

Table 3.5 - Summary table for the evaluation of Energy Towers' potential in the ***Middle East***

Range net power	**Average net power**	**Area in this region**	**Annual energy for this area in this region**	**Number of required Energy Towers**	**Potential number of people at 6,000 kWh per year**
[MW]	**[MW]**	**[10^3 km^2]**	**[10^9kWh/year]**	**[-]**	**[millions]**
650-658	654	1.2	17	3	3
600-650	618	29.2	395	73	66
550-600	570	116.8	1459	292	243
500-550	519	412.4	4686	1031	781
450-500	475	413.2	4302	1033	717
400-450	423	460.8	4266	1152	711
350-400	375	615.6	5053	1539	842
300-350	323	1052.4	7440	2631	1240
250-300	277	942.8	5723	2357	954
200-250	226	631.2	3124	1578	521
TOTAL		**4676**	**36465**	**11689**	**6078**

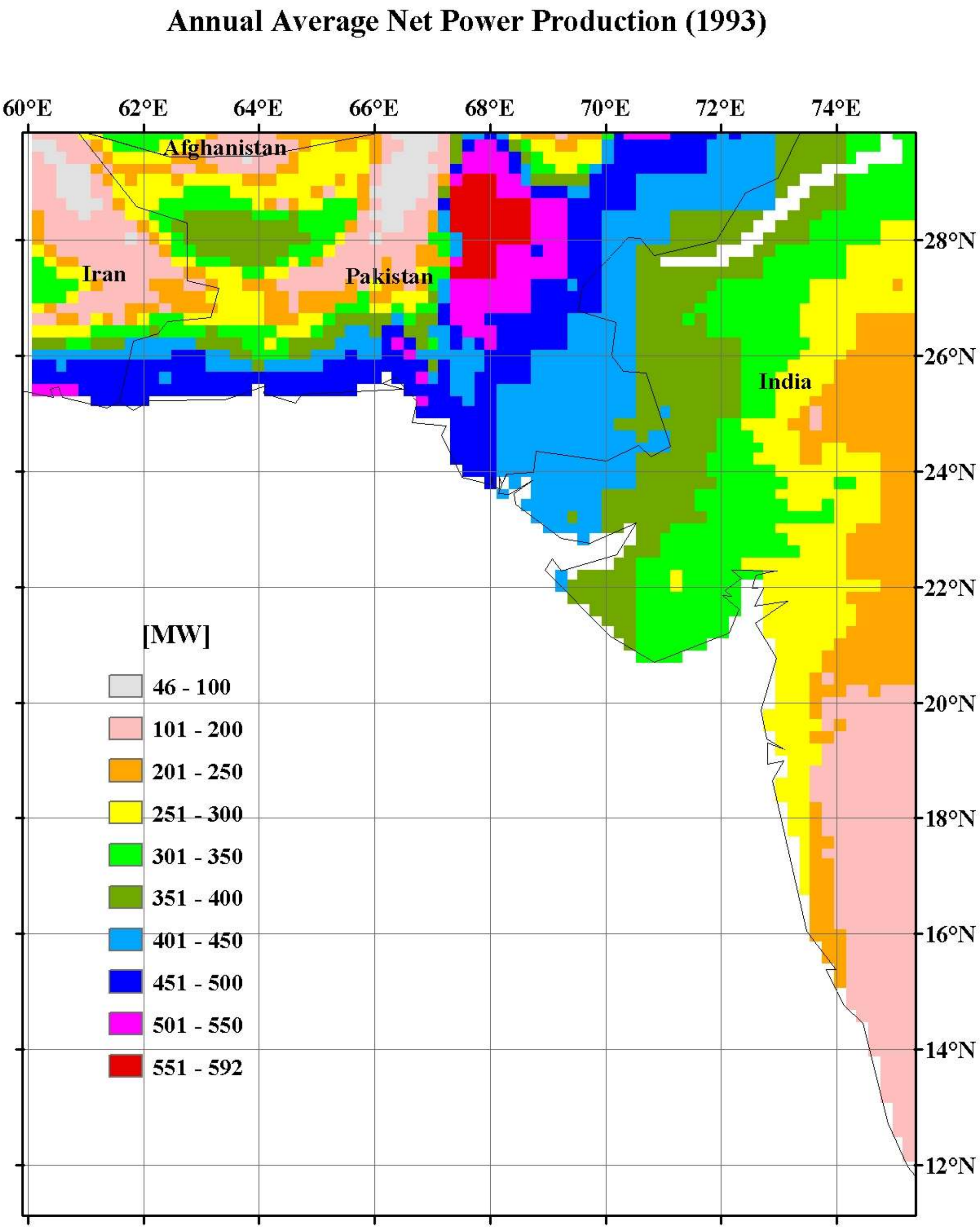

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Figure 3.15- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for ***India-Pakistan***

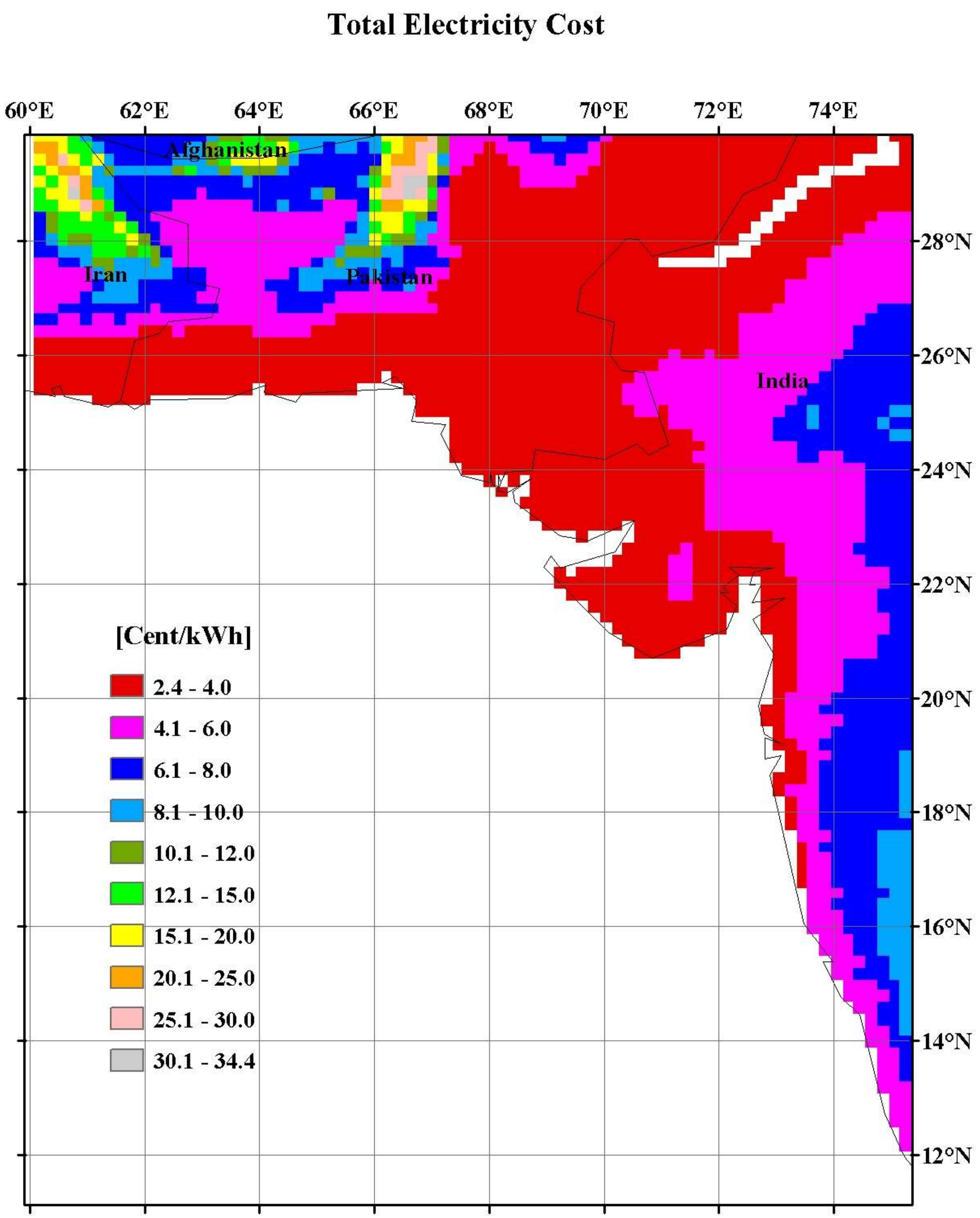


Figure 3.16- Evaluation of the electricity production cost (year 1993) for ***India-Pakistan***

Table 3.6 - Summary table for the evaluation of Energy Towers' potential in ***India-Pakistan***

Range net power [MW]	**Average net power** [MW]	**Area in this region** [10^3 km^2]	**Annual energy for this area in this region** [10^9kWh/year]	**Number of required Energy Towers** [-]	**Potential number of people at 6,000 kWh per year** [millions]
550-600	574	17.6	221	44	37
500-550	522	34.8	398	87	66
450-500	472	108.8	1124	272	187
450-400	425	147.6	1373	369	229
400-350	374	153.6	1258	384	210
350-300	324	173.6	1231	434	205
300-250	274	174.4	1048	436	175
250-200	228	154.8	772	387	129
TOTAL		**965**	**7425**	**2413**	**1238**

Table 3.7- Summary table for the evaluation of Energy Towers' potential in Australia

Range net power	Average net power	Area in this region	Annual energy for this area in this region	Number of required Energy Towers	Potential number of people at 6,000 kWh per year
[MW]	**[MW]**	**[10^3 km^2]**	**[10^9kWh/year]**	**[-]**	**[millions]**
450-400	406	5.6	50	14	8
400-350	368	80	645	200	107
350-300	315	441.2	3044	1103	507
300-250	273	1067.6	6383	2669	1064
250-200	223	2283.6	11152	5709	1859
TOTAL		**3878**	**21,274**	**9695**	**3,545**

From the global map one can realize that there are over 30 countries and probably close to 40 where the E.T can be utilized. These are concentrated in 7 centers: California and Mexico, Chile and Peru, in North Africa, the Middle East; India and Pakistan and finally Australia. The energy is not well distributed around the globe. It must be distributed by modern DC high voltage lines for distance of over 3000 kilometers in order to cover larger consumption zone.

Following one map of the individual 7 zones, a very important note has to do with the individual block sizes which are 20×20 km approximately and each block is allocated with one tower. The overall output assumes one standard tower in each square. This is in several ways a very conservation assumption.

A descending hot air over a square may exceed the flow downdraft needed air in one tower. To illustrate a 2 million cubic meters per second of air over 400 square kilometers mean a down flow of about 0.5 centimeter per second. More the one tower of the standard size could be build and have more than the outputs stated in the following.

Table 3.8 - Global summation

Country	**Annual Energy** [10^9kwh/year]	**Number of people served** [millions]
California + Mexico	4,435	739
Chile + Peru	1,753	292
North Africa	59,676	9, 946
South Africa	2,097	350
Middle East	36,465	6,078
India + Pakistan	7,425	1,238
Australia	21,274	3,545
Total	**133,125**	**22,188**

Straight summation of the annual power and the number of people served are very impressive.

In order to over wide areas long transmission lines are necessary. Another calculation of the potential was prepared by an independent effort prepared by German researcher, Gregory Chich, 2001. There are the climatic conditions were considered controversy. The results were given in table 3.9. With the present electricity consumption of about 14,000×10^9 kWh/year we see that the overall potential of electricity production is not less than 7 times the present consumption by the global calculation and 9.5 times the single 20×20 km square.

Table 3.9 - The average net power range [MW] from Energy Towers and the total area (thousand of square kilometers) in the world for each range

Average net power (1)	***Area (2)***	**Number of required Energy Towers (3)**	**Annual energy for this area (4)**	**Electricity cost (5% discount rate) (5)**	**Electricity cost (10% discount rate) (6)**
[MW]	*[10^3 km^2]*	*[-]*	*[10^9kWh/year]*	*[c/kWh]*	*[c/kWh]*
550-600	69	173	839	1.68-1.78	2.51-2.69
500-550	233	583	2,679	1.78-1.90	2.69-2.90
450-500	1,017	2,542	10,579	1.90-2.05	2.90- 3.16
400-450	2,248	5,620	20,923	2.05-2.24	3.16 - 3.49
350-400	4,167	10,418	34,221	2.24-2.48	3.49-3.91
300-350	5,989	14,973	42,627	2.48-2.80	3.91- 4.47
250-300	8,597	21,492	51,775	2.80-3.25	4.47- 5.25
200-250	13,137	32,843	64,733	3.25-3.93	5.25-6.42
Total	**35,457**	**88,644**	**228,376**		

4. Maps of the power production potential for selected countries

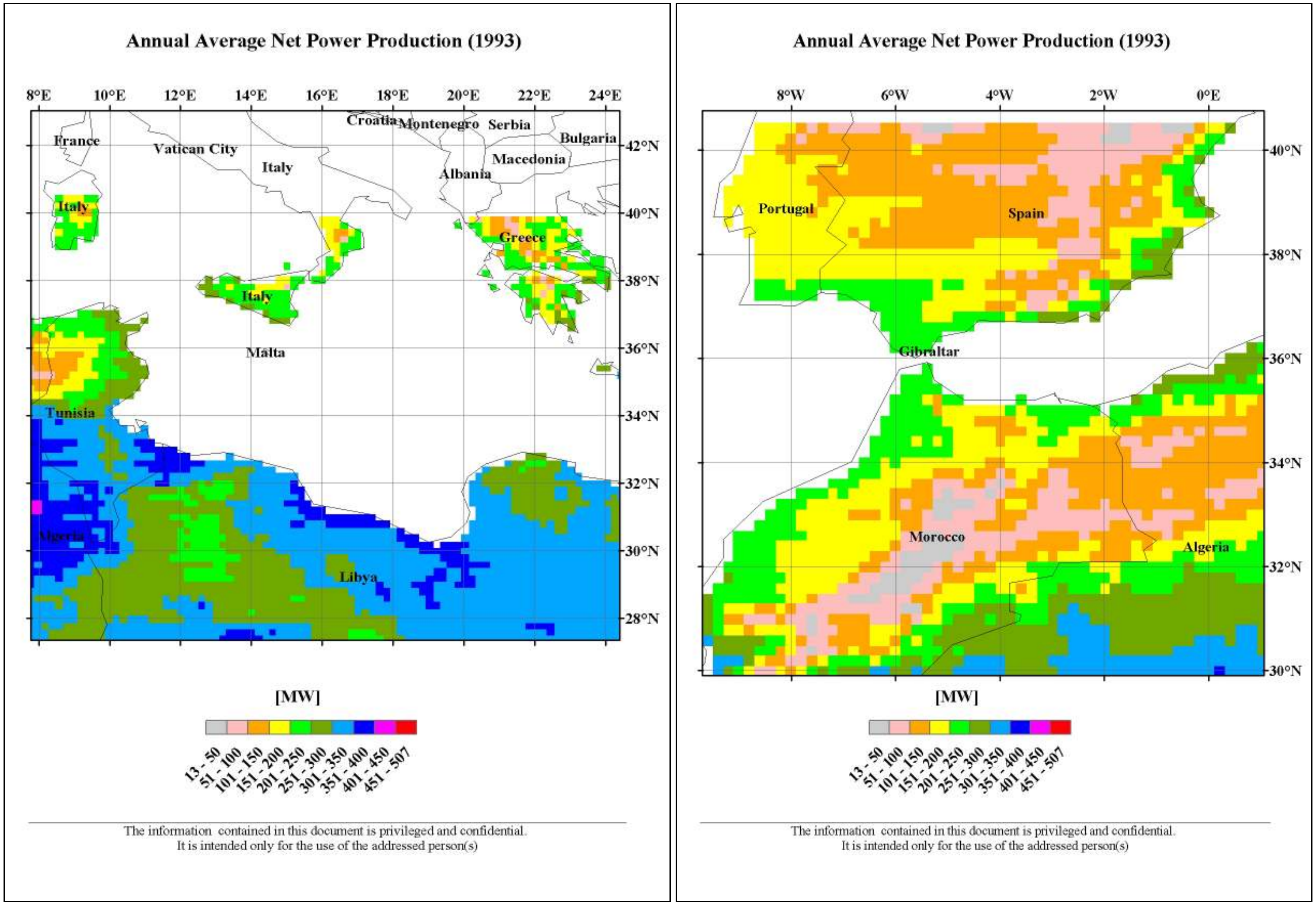


Figure 4.1- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for ***North Africa***

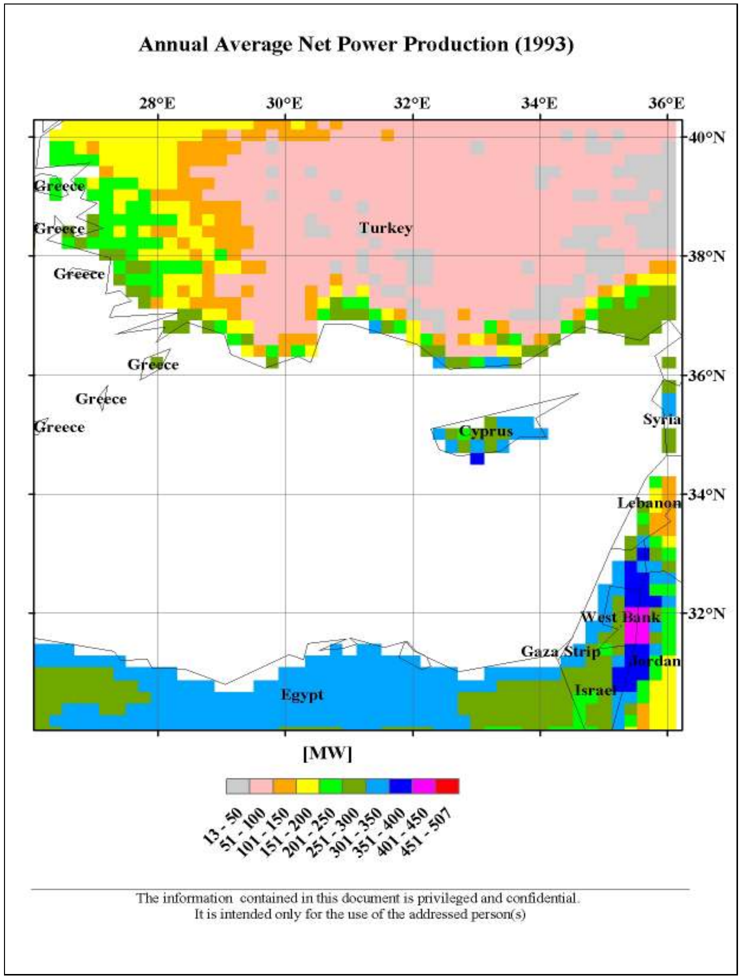


Figure 4.2- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for south Europe

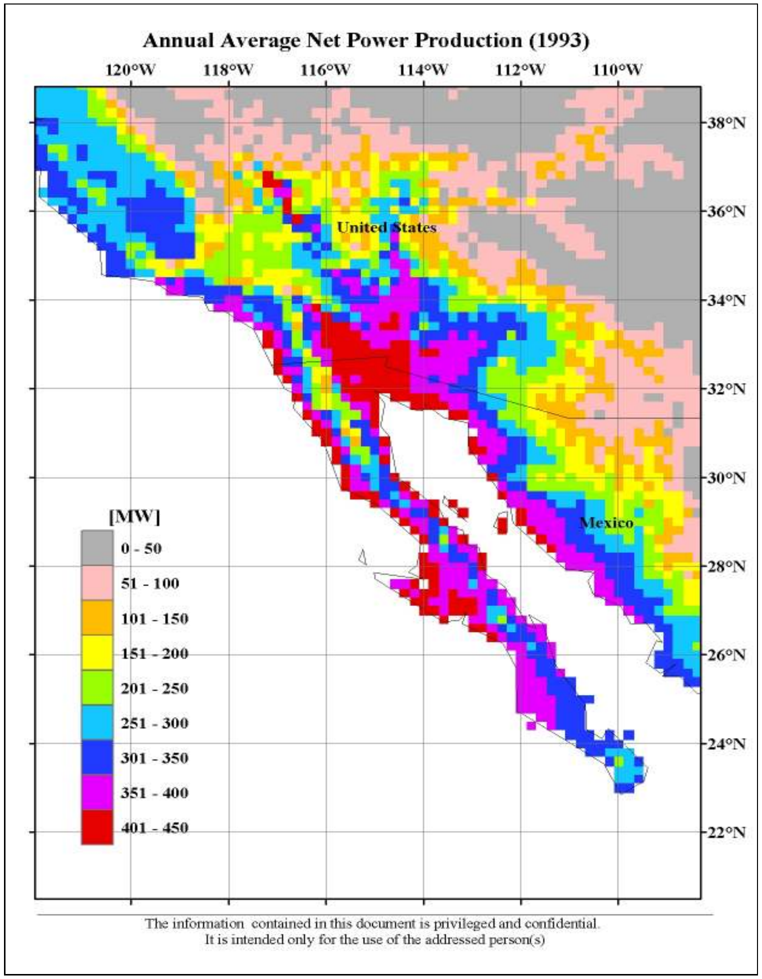


Figure 4.3- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for Mexico and California

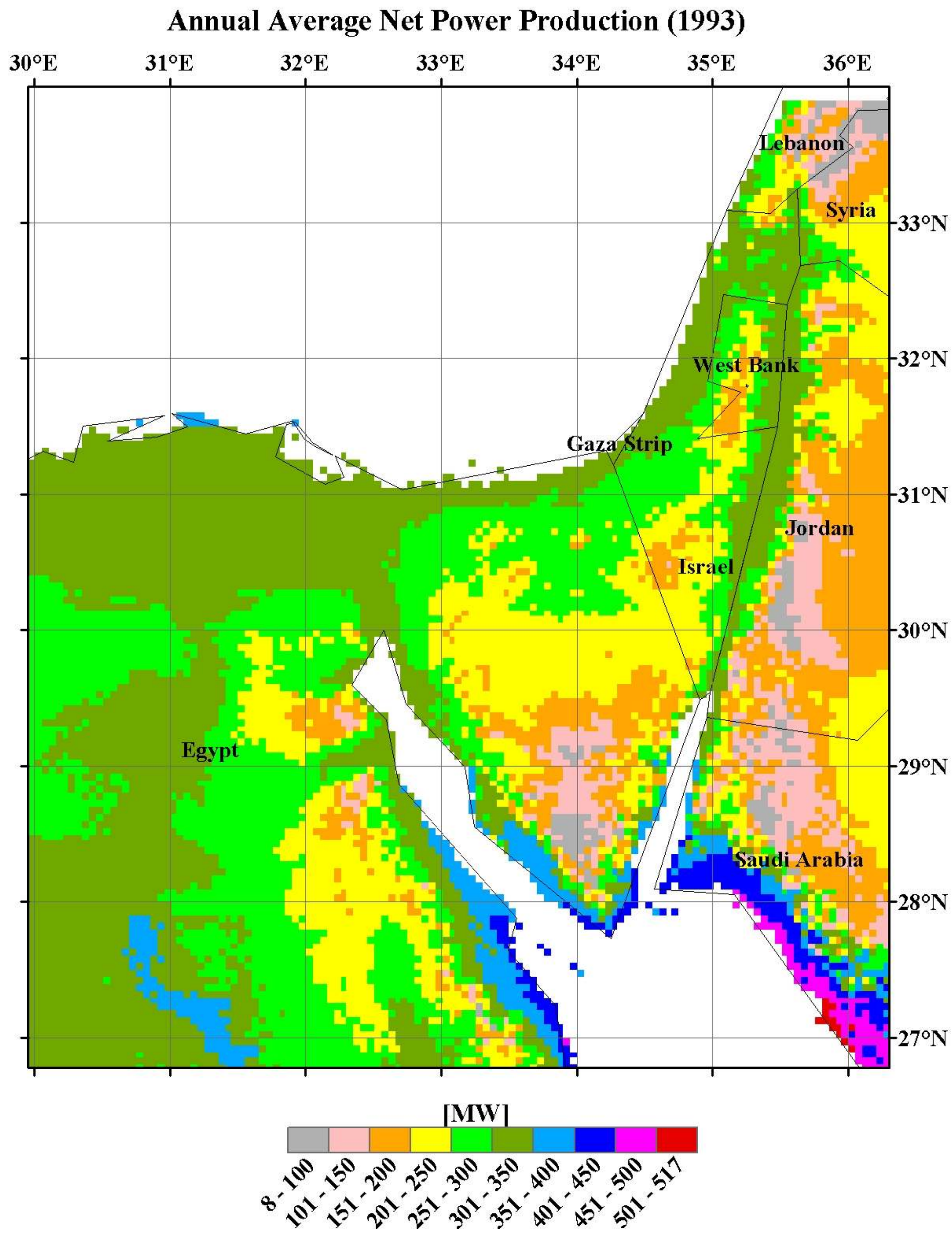


Figure 4.4- Evaluation of the annual average net power production of the "Energy Towers" (year 1993) for Israel (fine resolution)

5. Evaluation for the Desalinated Water Supply

The computation of sea desalinated water assumed that 20% of the power produced will be used for it and the power consumption will be 3 kWh per cubic meter desalinated, then the water quantity was divided by 1000 to find out how many people could be served, 1000 cubic meter per person per year is a very rich state as far as water is concerned. To find the overall potential one has to multiply by the number of small 20×20 km squares. First consider in the last way in the middle east over 200,000 people set in one square or over 200 million cubic meters per square spread over 400 square kilometer, it means more than half a meter water covering the whole land. Taking the total electricity in a year over north Africa 59676×10^9 kWh/year can easily provide nearly 10 billion people with electricity. This means that the whole of Europe and Africa can be provided by cheap and clean electricity. Moreover, let us say that only one billion people will be provided with 6000×10^9 kWh per year. Take 3 kWh per cubic meter and only 20% of this power for water desalination and we shall have 400×10^9 cubic meter per year, nearly 6 times the Nile for local water supply. Taking 1753×10^9 kWh/year in Chile and Peru to supply electricity fully for to 290 10^6 people. When with 20% of the electricity we can provide the same number of people with 403 m^3/ capita/year. (Israel has only about 350 m^3/capita before desalination.

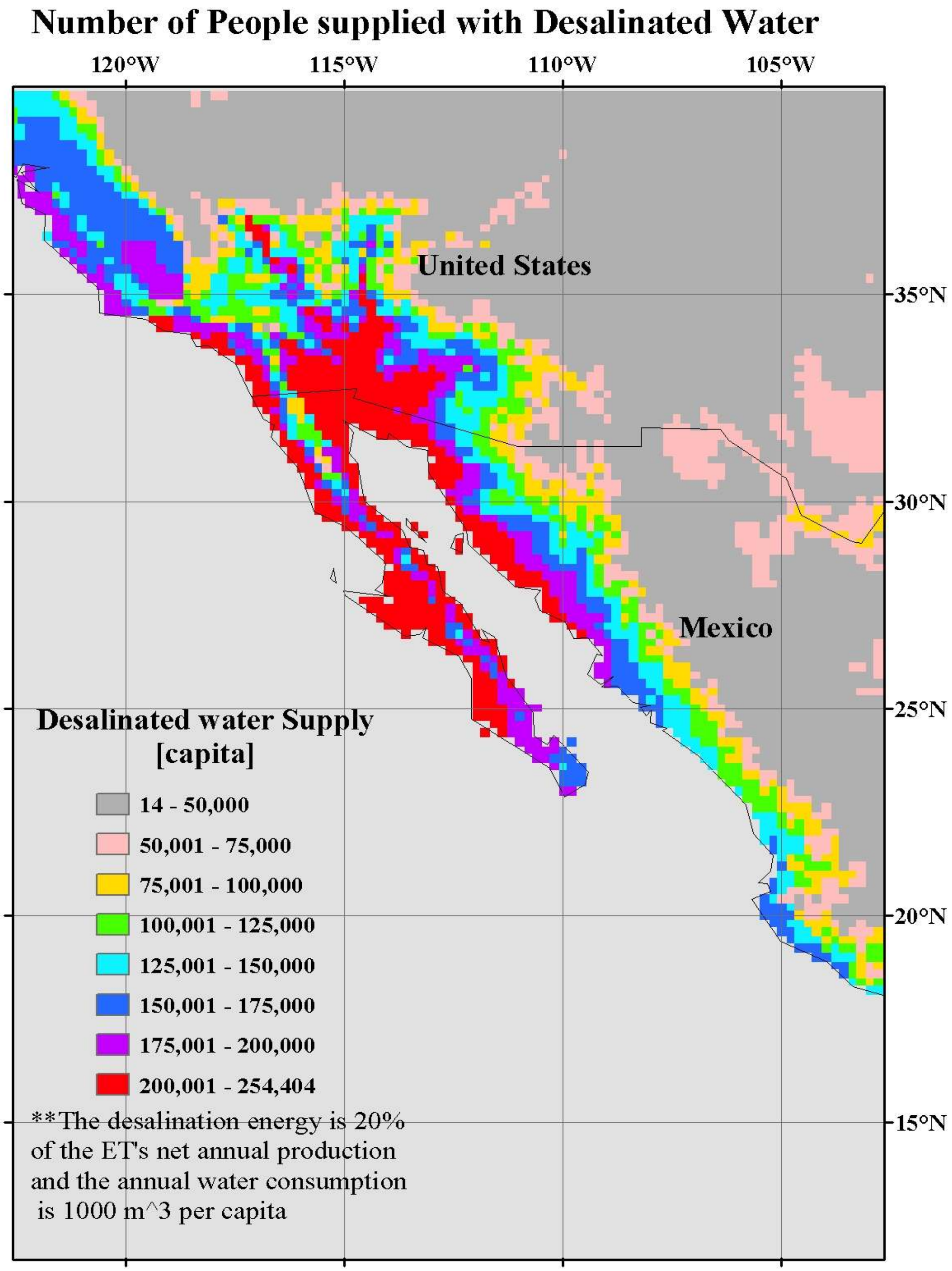


Figure 5.1- Evaluation of number of people supplied with desalinated water by the "Energy Towers" (year 1993) for California and Mexico

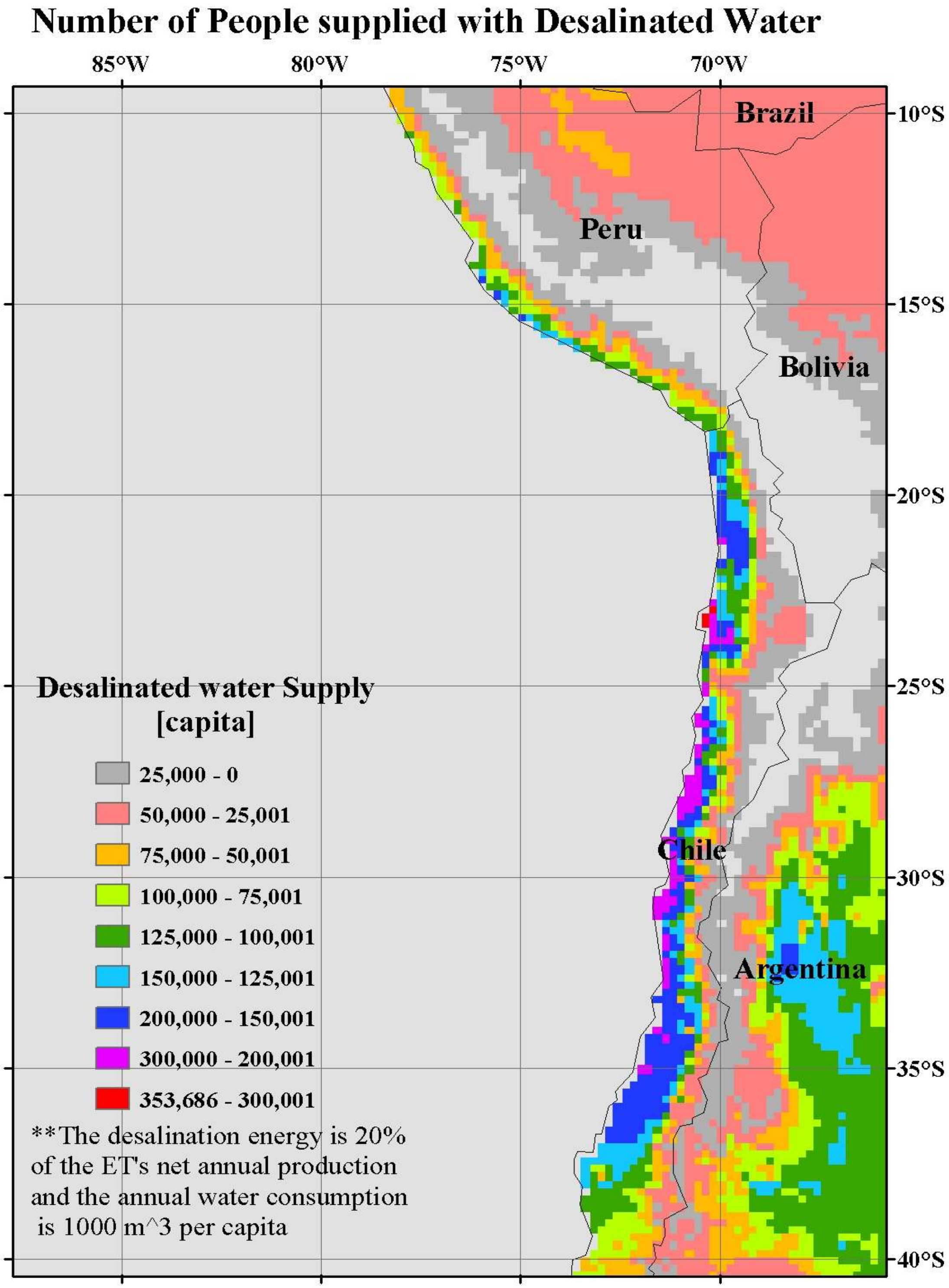
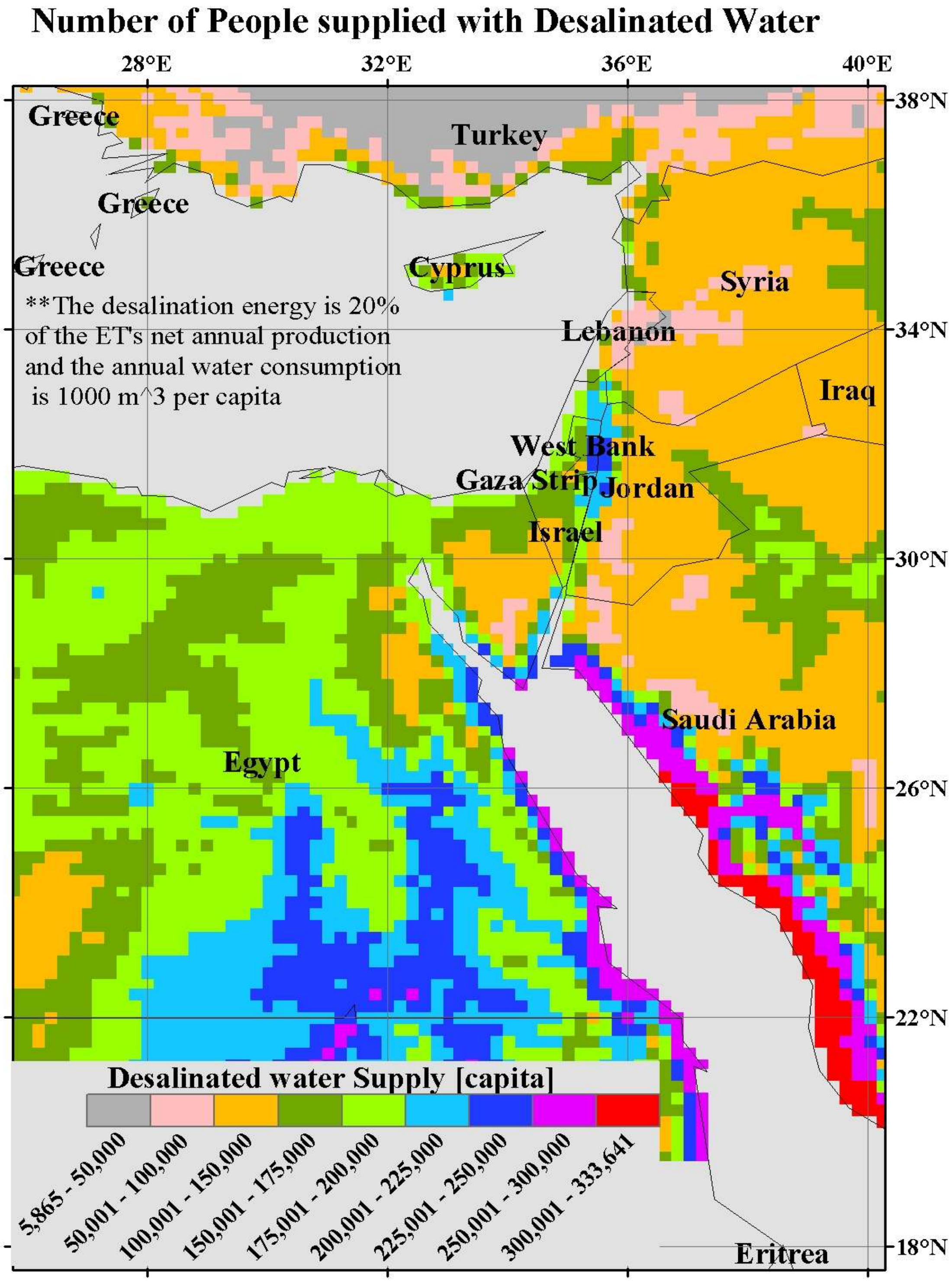


Figure 5.2- Evaluation of number of people supplied with desalinated water by the "Energy Towers" (year 1993) for ***Chile-Peru***



**The desalination energy is 20% of the ET's net annual production and the annual water consumption is 1000 m^3 per capita

Figure 5.3- Evaluation of number of people supplied with desalinated water by the "Energy Towers" (year 1993) for the Middle East

6. References

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List of publications/reports from the project with complete references

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Summary of plans for the continuation of the project

(10 lines max)

The program for the next years is to choose several sites in different regions and using detailed climate data for these sites. The predicted output: location of the tower, energy production along the year (gross power, pumping power, net power), optimized design and operation of the tower, electricity cost, economic analysis.