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Location Allocation and Econometrics of a Solar Chimney with 50 KW Output Power in Terms of Climate Conditions of Southern Iranian Provinces

Abbas Sadri[a*], Roohallah Yazdanpanah[b], Abbas Korehbandi[c], Amin Roudhelehpour[d]

[a,b,d]*PhD student, Department of Mechanical Engineering, Dashtestan Islamic Azad University, Bushehr Province, Iran*
[c]*Bachelor of Mechanical Engineering, Dashtestan, Bushehr Province, Iran*
[a]*Email: Sadri.Abbas1359@gmail.com, Tell: +989365657025*
[b]*Email: Yazdanpanah.R1366@yahoo.com*
[c]*Email: Abbas.Korebandi@gmail.com*
[d]*Email: Aminroudhelehpour@yahoo.com*

Abstract

The aim of the current research is location allocation and econometrics of solar tower (chimney) for power generating in climate conditions of southern Iranian provinces. Location allocation means determining an appropriate location for constructing a solar chimney with appropriate size including receiving surface (absorber or collector), tower height and turbine diameter for 50 kW output power so that the location is compatible with climate conditions of the selected province. Firstly, the amount of solar energy received on the earth surface in one of the southern provinces of Iran is calculated and then, all available governing equations on tower elements (receiving surface, tower height and turbine diameter) are written and solved in MATLAB. The obtained results are validated by comparing the output of computer solution for 50 kW daily power with the model produced in Manzanares, Spain, where have a similar climate conditions with south of Iran. In addition to validation with experimental data, the computer solution is re-validated with the results obtained from finite element analysis performed by FLUENT software. The obtained results show that: in low power, solar tower is not cos effective without considering economic conditions.

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* Corresponding author.

Moreover, solar tower with small turbine diameter needs to large size receiver and high height that should be scientifically investigated. Further, after validation of results, the expected power is analyzed using the relationships between tower elements to achieve a comprehensive plan which has a complete analysis of relationships between the size and location of solar chimney and optimization process of final cost along with the plan econometrics in terms of the available facilities on the selected province.

Keywords: Southern Iranian provinces; Solar tower (chimney); Solar turbine; Solar Receiver (absorber or collector); Finite element numerical method; MATLAB language; Location allocation and econometrics; FLUENT software.

1. Introduction

Solar chimney consists of three main components including a long tower, which can be as high as 1000 m according new technologies, a land with large area (with diameter 1000-1500 m), which surrounded by plastic and connected to the tower, and finally, a turbine in the center of tower which generates power. The following figure schematically shows the plan. Solar radiation causes the trapped air beneath the collector to warm, usually up to 25 degrees higher than the outside air. This trapped air accelerates due to pressure difference produced as a result of height difference at the top and bottom of tower and then, hit the tower center with high velocity and generates power. Setting these dimensions including tower height, collector diameter and turbine diameter to generate the required power of the plan is the most important desire of the problem [2,3]. Regarding the high rate of population increase and improving the standards of life and increasing the demands and lack of appropriate management of available energy resources and unbalanced subsidies in Iran and using devices with high energy consumption, there is a high demand for alternative energy resources. Applying the technology of solar tower power plant in Iran is very important as the geographical position of the country is so relevant for this type of energy that its solar energy receive in many regions of Iran estimated as 1800 to 2000 kWh per square meter per year which is higher than global average. Hence, regarding the available potentials, solar chimney power plants are simple and effective solution and due to availability of raw materials and possibility of applying local workforce and resources, it can be an appropriate alternative for fossil power plants, although location allocation of such power plants should be highly considered to avoid construction of power plants in earthquake-prone regions and regions with long sand storms [1,4]. Economic assessments based on the collected information and previous experiments have been shown that large solar towers (higher than 100 MW) have power generation capacity with costs comparable to traditional power plants (Badenwerk and EVS, 1997). This fact can be a reasonable reason for developing this type of solar energy consumption in large scale and establishing applicable sections from economic point of view. In the future energy economy, solar towers can be safe (from environmental point of view) and economic electricity generation method for sunny regions. Three main components of initial plan of a solar tower – solar collector, chimney or tower and wind turbines – are constant for many years. Their combination for power generation was described in 1931. Haaf (1983, 1984) represented the results of experiments and the theory of first solar tower in Manzanares, Spain [11,12]. The obtained results in Manzanares discussed by Schlaich (1990). In 1995, he reviewed this process. In 1997, Kreeetz introduced the concept of updraft water tubes beneath the collector ceiling for heat storing [1,10,13,14]. Gannon and Backstrom represented the analysis of thermodynamic cycle of solar tower and an analysis of turbine characteristics in 2000 and 2003, respectively. In 2003, Ruprecht reported the results of fluid dynamic analysis and turbine plan for a 200 MW solar tower. Currently, a 200 MW solar tower project is under construction in Australia by a German company under supervision of Prof. Jorg Schlaich that will be completed in 2010. The appropriate weather conditions in Australia for such type of solar power plant, very high isolation planes, plenty of straight lands, high demands for electricity and the presence of Mandatory Renewable Energy Target (MRET) will lead to 9500 GWh power generation between 2010 to 2020 [1,14].

2. Costs and economic feasibility of the plan

Based on the costs of the plan such as the size and the generated electricity in Table (1), research costs are calculated. By annual output energy through similar performance, electricity costs are calculated using interest rate 6% during a 30 years period.

From Table (1), it is clear that levelized electricity cost (LEC) for a typical 5 MW solar tower is very higher than, for example, a typical photovoltaic system. By increasing the size, electricity generation costs are hugely reduced. It means that for a 200 MW solar tower, LEC is 0.07 $^{\varepsilon}/_{kWh}$ with interest rate of 6%.

Table 1: Investment costs and LEC [18]

Capacity	**MW**	**5**	**30**	**100**	**200**
tower cost	Mio. €	19	49	156	170
collector cost [A]	Mio. €	10	48	107	261
turbine cost	Mio. €	8	32	75	133
engineering, tests, misc.	Mio. €	5	16	40	42
total	**Mio. €**	**42**	**145**	**378**	**606**
annuity on investment	Mio. €/a	2.7	10.2	27.1	43.7
annual operation & maintenance cost	Mio. €/a	0.2	0.6	1.7	2.8
levelized electricity cost (LEC) [B]	**€/kWh**	**0.21**	**0.11**	**0.09**	**0.07**
[A] cost for unskilled labor assumed to be 5 €/h [B] at an interest rate of 6 % and a depreciation time of 30 years					

The variations of interest rate of financial parameters during a period of time is shown in Figure (1). The upper bound and lower bound are calculated for a 20 and 40 years period, respectively. As expected, the electricity generation cost in large solar towers is hugely reduced by reducing the interest rate. Further, the spent time is of great importance. Assuming interest rate of 12% and 20 years period, LEC for a 200 MW solar tower is 0.12 $^{\varepsilon}/_{kWh}$. When the interest rate 6% and 40 years period are available, LEC reduced down to 0.06 $^{\varepsilon}/_{kWh}$, i.e.

half of the previous case.

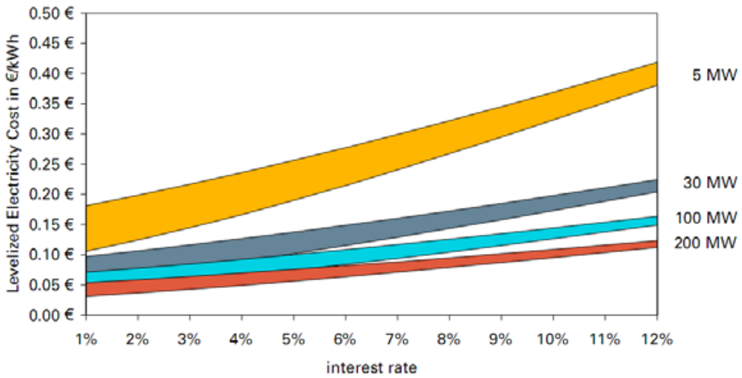

Figure 1: Variations of LEC against interest rate [6]

Figure (2) shows a schematic comparison between the electricity generated from coal burning and solar tower. In the selected example, the electricity costs for solar tower in initial years of operation is higher than the coal power plant. The gap between electricity costs becomes narrower by increasing the costs of fossil fuels. After 20 years, the electricity generation costs for both power plants are equal. From this time, solar tower generates electricity with lower costs. However, operation and maintenance costs should be paid. In contrast, the costs of electricity generation in coal power plant are still high because they are controlled with the cost of fuel. In our example, a new coal burning power plant should be constructed after 30 years, while solar tower still operates with its initial form. It shows the difference of two systems in modern life. So, the cost difference of coal power plant and solar tower will increase in the future. In the example of Figure 5-3, interest rate and coal price scale are intentionally selected to equalize the costs of electricity generation by both methods after a given time. In fact, depend on real costs and financial management data, it may need to more time for equal cost in both methods but this point may be achieved sooner. In the future, the number of countries with low investment costs and hence, high solar electricity generation costs will reduce. This issue will happen when the collector (which more than 1.2 investment costs of solar tower is for it) can be manufactured with low cost and easy testing, anywhere.

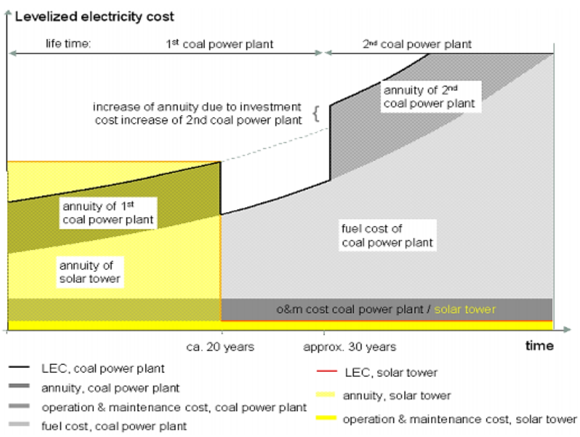

Figure 2: Comparing the electricity generation costs by solar tower and coal burning power plant [8]

Table (2) and Figure (3) show the comparison of the electricity generation costs by solar tower and combined cycle power plants which can be analyzed similar to the case of coal burning power plant.

Table 2: Various costs of electricity generation using solar energy, coal and combined cycles

Proportion of	Solar Chimney Pf/kWh	Coal Pf/kWh	2 x C.C. 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%

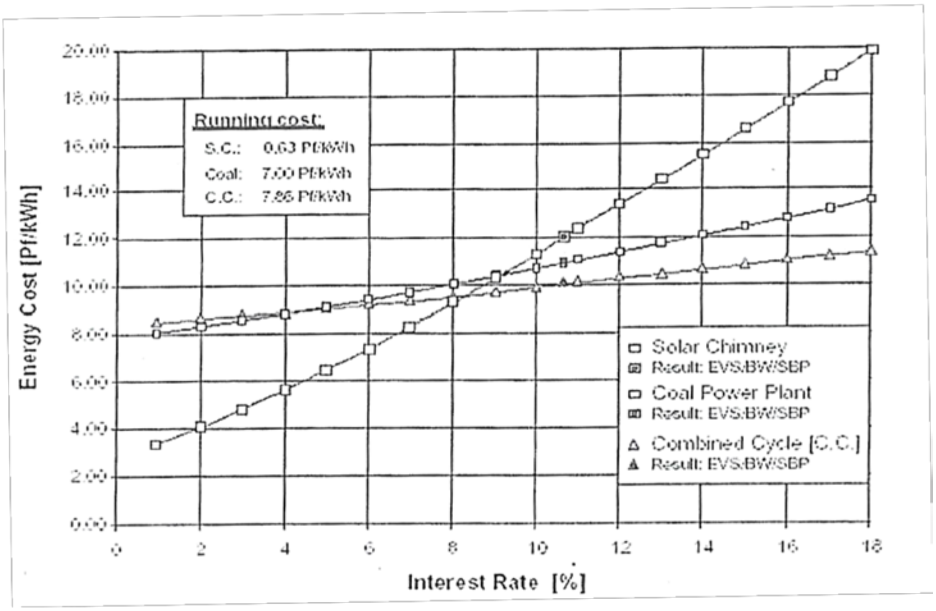

Figure 3: Comparing the electricity generation costs by coal, solar tower and combined cycles [8]

Comparison and physical validation of the problem

The size of typical model for the selected solar towers without additional storage of warm water is shown in Table (3).

These numbers are based on typical materials and constitutional costs.

The costs for simple test is assumed to be ε/h5.

Table 3: Typical sizes for the previously selected solar towers without additional storage of warm water [12]

Capacity	MW	5	30	100	200
Tower height	m	550	750	1000	1000
Tower diameter	m	15	70	110	120
Collector diameter	m	1250	2900	4300	7000
Electricity output	GWh/a	14	99	320	680
At a site with an annual global solar radiation of 2300 kWh/(m^2a)					

Considering the physical model in r-z coordination and regarding the symmetry of problem relative to z axis, the equations of continuity, momentum and energy are written in r-z coordination [10]. Figure (4) shows the schematic view of considered solar tower plan and its elements in R-Z coordination:

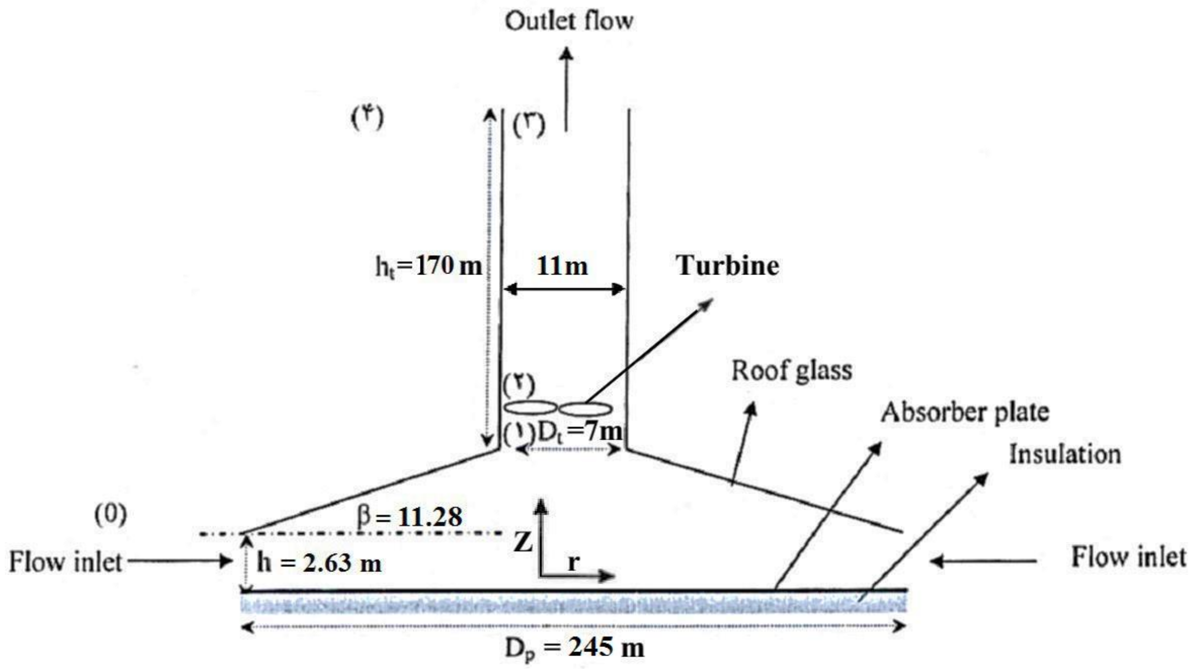

Figure 4: Schematic view of the considered solar tower plan and its elements in r-z coordination [5,10,19]

$$\frac{\partial v_z}{\partial_z} + \frac{v_r}{r} + \frac{\partial v_r}{\partial_r} = 0 \qquad (1)$$

$$p v_r \frac{\partial v_r}{\partial_r} + p v_z \frac{\partial v_z}{\partial_z} = -\frac{\partial p}{\partial r} + \mu \left(\frac{\partial^2 v_r}{\partial r^2} + \frac{\partial v_r}{r \partial r} - \frac{v_r}{r^2} + \frac{\partial^2 v_r}{\partial z^2} \right) \qquad (2)$$

$$p v_r \frac{\partial v_z}{\partial_z} + p v_z \frac{\partial v_z}{\partial_z} = -\frac{\partial p}{\partial z} + \mu \left(\frac{\partial^2 v_z}{\partial r^2} + \frac{\partial v_z}{r \partial r} + \frac{\partial^2 v_z}{\partial z^2} \right) - pg \qquad (3)$$

The Boussinesq approximations are used to relate density and temperature:

$$Pg - p_0 g - g\beta\ (T\text{-}To)\ ) \quad (4)$$

$$Pc_p\left(v_r \frac{\partial T}{\partial r} + v_z \frac{\partial T}{\partial z}\right) = k\left[\left(\frac{\partial\left(r\frac{\partial T}{\partial r}\right)}{r\partial r}\right) + \frac{\partial^2 T}{\partial z^2}\right] \quad (5)$$

The above equations are subsets of the general transformation equation.

$$Div\ (p\varphi\bar{U}) = div\ (\eta grad\varphi) + s_\varphi \quad (6)$$

$$\vec{u} = v_r\ \vec{e_r} + v_z\ \vec{e_z} \quad (7)$$

If φ substitutes with v_r, v_z and C_vT and s_φ substitutes with appropriate terms, r-momentum, z-momentum and energy equations can be obtained. Using Gauss divergence theory, we integrated Eq. (6) over small volumes:

$$\int_A n.(\rho\ \phi\ u\ )dA = \int_A n(\ \eta\ \text{grand}\ \phi\ )\ dA + \int_{c.v}\ s_\varphi\ dv$$

n is normal unit vector on the control volume surfaces and is positive towards outside.

η is diffraction coefficient which is kinematic viscosity (μ) for momentum equation and is conductive heat energy coefficient (K) for energy equation. Table (4) shows the amount of radiated solar energy in various wavelengths.

Table 4: Amount of radiated energy by sun in various wavelengths [5,19]

Wavelength	Percent of energy	Amount of energy (W/m^2)	
0 - 0.38	7	95	
0.38 - 0.78	42.29	640	
0.75 - ∞	45.71	618	
0 - ∞	100	1353	Sum

Radiation differs from one day to another. The following relationship is proposed for variation of radiation outside the atmosphere for various days of the year [5,6,19]. Figure (5) shows radiation angles on horizontal and inclined planes:

$$G_{on} = G_{sc}\left[1 + 0.033coss\left(\frac{360\ (n+81)}{365}\right)\right] \quad (9)$$

$$\delta = 23.4\sin\frac{360n}{365} \quad (10)$$

where, n is 1.0 for 1th Farvardin.

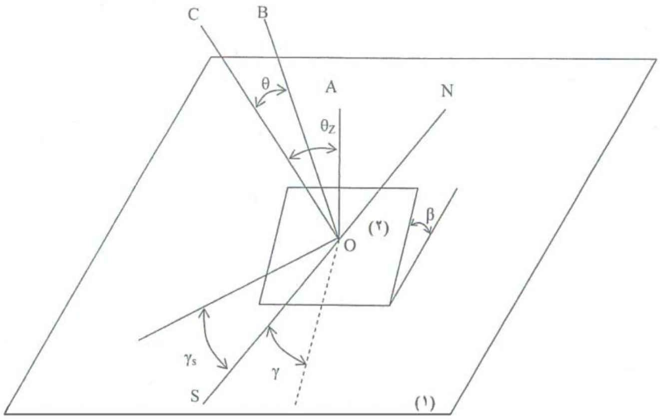

Figure 5: radiation angles on horizontal and inclined planes [8]

(1): horizontal plane.

(2): inclined plane with angle β from horizontal plane.

OA: perpendicular line to horizontal plane (1).

OB: perpendicular line to inclined plane (2).

OC: solar radiation line

β: slope of considered plane relative to horizon $180 \leq \beta \leq 0$.

γ: departure angle of plane which describes the deviation from south.

γs: departure angle of sun. It is positive afternoon and negative before noon. Figure shows afternoon.

θz: zenith angle or angle between the perpendicular line to horizontal plane and solar radiation.

θ: radiation angle.

For each hour in a day, the angle ω is defined and for each hour difference from solar PM, ω is 15 degrees. ω is positive before noon and it can be calculated as [17]:

$$\text{Cos}\,\theta = \text{Sin}\delta\,\text{Sin}\varphi\,\text{Cos}\beta - \text{Sin}\delta\,\text{Cos}\varphi\,\text{Sin}\beta\,\text{Cos}\gamma + \text{Cos}\,\gamma\text{Cos}\varphi\,\text{Cos}\beta\,\text{Cos}\,\omega \quad (11)$$

$$+ \text{Cos}\delta\text{Sin}\varphi\,\text{Sin}\beta\text{Cos}\gamma\text{Cos}\omega + \text{Cos}\delta\,\text{Sin}\varphi\text{Sin}\beta\text{Cos}\gamma\,\text{Cos}\omega + \text{Cos}\delta\,\text{Sin}\beta\,\text{Sin}\gamma\,\text{Sin}\omega$$

In a special case which plane is toward the south, γ = 0, and θ is:

$$. \operatorname{Sin}(\varphi - \beta) + \operatorname{Cos}\delta \,.\, \operatorname{Cos}\omega \,.\, \operatorname{Cos}(\varphi - \beta) \operatorname{Sin}\beta = \operatorname{Cos}\theta \quad (12)$$

For a horizontal plane, $\beta = 0$ and $\theta = \theta z$.

$$\operatorname{Cos}\theta_z = \operatorname{Sin}\delta \,.\, \operatorname{Sin}\varphi + \operatorname{Cos}\delta \,.\, \operatorname{Cos}\varphi \operatorname{Cos}\omega \quad (13)$$

If $\theta z = 90$ inserted into Eq. (5-2), sunrise and sunset can be identified.

$$\operatorname{Cos}\omega_s = -\tan\delta \tan\varphi \quad (14)$$

3-1- Solar irradiance intensity on a horizontal plane outside the atmosphere

For a horizontal plane outside the atmosphere, solar irradiance intensity can be calculated for various days of the year as:

$$G_{oh} = H_{sc}\left[1 + 0.033Cos\left(\left(\frac{360(n+81)}{365}\right)\right)\right] \times Cos\theta_z \quad (15)$$

By substituting θz into Eq. (5-2), we have:

$$G_{oh} = G_{sc}\left[1 + 0.033Cos\left(\left(\frac{360(n+81)}{365}\right)\right)\right] \times [Sin\delta \,.Sin\varphi + Cos\delta \,.Cos\varphi \; Cos\omega] \quad (16)$$

3-2- Ratio of direct irradiance on an inclined plane relative to horizontal plane

Solar radiation received on the earth is divided into direct and diffracted radiation (Figure 6). Solar radiation is usually measured by devices that horizontally installed and hence, it is necessary to determine direct radiation on an inclined plane from determined values.

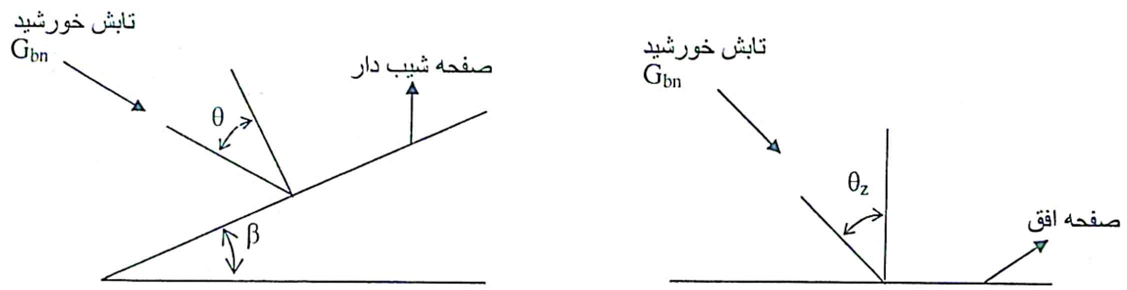

Figure 6: Solar radiation on horizontal and inclined planes [8]

$$R_b = \frac{G_{bt}}{G_{bh}} = \frac{G_{bn}Cos\theta}{G_{bn}Cos\theta_z} = \frac{Cos\theta}{Cos\theta_z} \quad (17)$$

Goh and Ghh are direct radiation on horizontal and inclined planes, respectively.

3-3- Determining solar time

For calculating irradiation intensity, we have to know solar time [17].

$$\text{Solar time} - \text{Local time} = 4(L_{st} - L_{loc}) + E \quad (18)$$

Lst is standard longitude and is determined for each country while Lloc is local longitude. Sign + is for western midday and sign – is for eastern midday relative to Greenwich.

$$E = 9.87 \text{ Sin } 2\beta - 7.23 \text{ Cos}\beta - 1.5 \text{ Sin}\beta \quad (19)$$

E is in terms of minute and is known as time equation.

$$\beta = \frac{360n}{364} \quad (20)$$

where, n=1 for 1th Farvardin.

4-3- Determining direct and diffracted radiation

For determining direct and diffracted radiation, a parameter called air non-cloudiness coefficient is defined [17]

$$K_T = \frac{I_h}{I_{oh}} \quad (21)$$

$$K_T = \left[a + b\, Cos\, \left(\frac{2\pi(t-12)}{24}\right)\right] \overline{K_T} \quad (22)$$

where, $\overline{K_T}$ is air non-cloudiness coefficient for the considered month and is defined as the ratio of received solar energy by a horizontal plane on the earth to the received energy by a horizontal plane outside the atmosphere.

$$a = 0.409 + 0.5016\sin(\omega_s - 60) \quad (23)$$

$$b = 0.6607 - 0.4767\sin(\omega_s - 60) \quad (24)$$

The coefficient differs for various months and locations [11].

Using Eq. (22) – (24), this parameter can be obtained and using Eq. (21), Ih can be obtained. The next problem is determining direct and diffracted radiations.

a- Diffracted radiation determination

$$\frac{I_d}{I_h} = 1 - 0.249\, K_T \qquad \text{for } K_T < 0.35 \quad (25)$$

$$\frac{I_d}{I_h} = 1.557 - 1.84\, K_T \qquad \text{for } 0.35 < K_T < 0.75 \quad (26)$$

$\frac{I_d}{I_h}$ = = 0.177 for $K_T > 0.75$ (27)

b- Direct radiation determination

$$I_b = I_h - I_d \quad (28)$$

5-3- Determining total solar radiation on an inclined plane

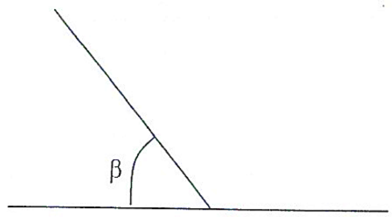

Figure 7: Inclined plane with angle β from the horizon [8]

Inclined plane see the sky with viewing angle $\frac{1+\text{Cos}\beta}{2}$ and see the earth with viewing angle $\frac{1+\text{Cos}\beta}{2}$. So, the amount of radiation on the inclined plane with angle β from horizon (Figure 7) is as following:

$$I_T = I_b R_b + I_d (I + \text{Cos}\beta) /2 + \rho_g(I_b + I_d) (1 - \text{Cos}\beta)/2 \quad (29)$$

where, ρg is diffraction coefficient of solar light by the earth. This depends on earth coverage and varied from 0.2 to 0.6. In normal condition, it equals to 0.2 and when earth covered with snow or when water is adjacent to the plane, it is equal to 0.5. Figure (8) shows colorful spectrum of solar radiation diffraction received by a collector from NREL research institute:

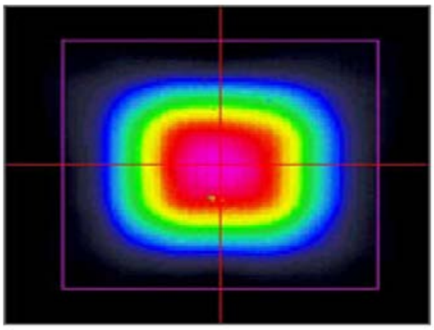

Figure 8: Colorful spectrum of solar radiation diffraction received by a collector from NREL research institute [1,9]

The point is that location allocation of the plan is calculated for Bushehr province with latitude of Φ = 28.5, in 15th day of the month, solar radiation on a horizontal plane considered by the plan. From previous relationships, it can be concluded that $\varphi \propto D^{\frac{3}{4}}$, it means that higher turbine diameter needs higher flow rate to generate a given power. At the other hand, A$\propto D^2$ means V= $\frac{Q}{A} \cong D^{\frac{2}{3}}$, i.e. higher turbine diameter needs lower velocity and vice versa. As we know, velocity is directly related with tower height, i.e. higher velocity demands higher tower height and vice versa. In this regard, there should be a balance between turbine diameter and tower height. By determining the diameter for output power 50 kW, flow rate can be determined from appropriate relationships. By a given flow rate and by assuming a volumetric mass in the entrance of turbine, velocity can be calculated and then, input temperature of turbine and corresponding volumetric mass are calculated and the calculated volumetric mass compares to assumed value. This iteration is continued until the difference between assumed and calculated volumetric mass becomes negligible. After calculation of volumetric mass, the pressure lose in tower $\Delta p_{\ Loss\ chimeny}$ and the pressure lose in turbine $\Delta p_{\ Loss\ turbine}$ are calculated and finally, the tower height is calculated. Table (5) shows the real size and technical properties of initial model compared to the model produced in Manzanares, Spain:

Table 5: The real size and technical properties of initial model compared to the model produced in Manzanares, Spain [1,14]

characteristics	Manzanares, Spain	Bushehr, Iran
tower height:	194.6 m	196 m
tower radius:	5.08 m	5.5 m
mean collector radius:	122.0 m	122.5 m
roof height:	1.85 m	2.63 m
number of turbine blades:	4	7
turbine blade profile:	FX W-151-A	FX W-151-A
blade tip speed to air transport velocity ratio:	1 : 10	1.57 : 11
operation modes:	stand-alone or grid connected mode	stand-alone or grid connected mode
typical collector air temp. increase:	ΔT = 15 C	ΔT = 15 C
nominal output:	50 kW	50 kW
coll. covered with plastic membrane:	40'000 m²	48'000 m²
coll. covered with glass:	6'000 m²	7200 m²

3. Conclusion

Firstly, the electricity generation costs are compared for coal burning power plant, solar tower and combined cycles through variations of LEC and Energy cost. Regarding the point that Iran is located between 25-45 north latitude and Bushehr province is located on Φ = 28.5, this region is one of the best regions in the world for receiving solar energy. In addition, huge investment is necessary for successful generation of power from solar energy. Therefore, the success of power generation from solar energy is related to easy and cheap manufacturing of collector, which is the most expensive parts of power generation process from solar energy. As a result, considering the order of equation solving which is on the basis of numerical study, it is possible to allocate the location of solar tower (chimney) regarding the climate condition of one of the southern Iranian provinces in terms of a given output power using the relationships between three main factors of solar tower including collector diameter (flatter), tower height (higher), and receiving diameter (larger). Using these relationships, the size of designed solar tower for diameter of turbine 7 m (seven turbines with 1 m diameter), tower height 196 m, and diameter and ceiling height of collector 245 m and 2.63 m, respectively, compared to the model produced in Manzanares, Spain, are predicted. Further, due to variation of solar irradiance intensity from 7 AM until 5 PM during a year, and hence, variation of irradiance on smooth plane, the values of output power, temperature and average wind velocity entered to the turbine are dependent on days of the year. However, regarding the fact that in low power, solar tower is not cos effective without considering economic conditions and considering the great importance of high previous reliability, only two dynamic – depreciatory elements of turbine and generator involved in a solar chimney power plant as well as no need to fossil fuels, experts, high costs of preparing and maintenance, by solving these problems using experimental data and the results of variations of LEC and Energy Cost, a basis can be achieved for optimizing the final cost and econometrics along with the preparation of required energy based on the facilities of one of the southern Iranian provinces, and to estimate the lifetime of solar chimney as high as 75 years.

4. Appendixes

Appendix 1: Amount of radiated energy by sun in various wavelengths in Bushehr province

Table 6

Wavelength	Percent of energy	Amount of energy (W/m^2)	
0 - 0.38	7	95	
0.38 - 0.78	42.29	640	
0.75 - ∞	45.71	618	
0 - ∞	100	1353	Sum

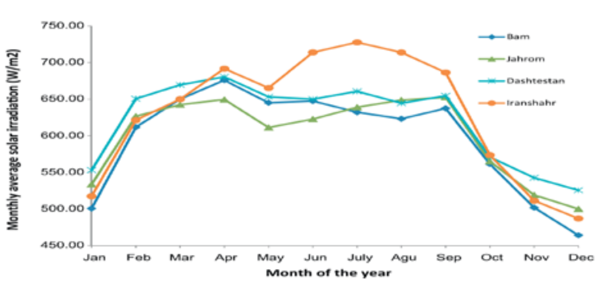

Figure 9

Appendix 2: Average monthly variations of global solar radiation in four places in Iran comparing to a month [5]

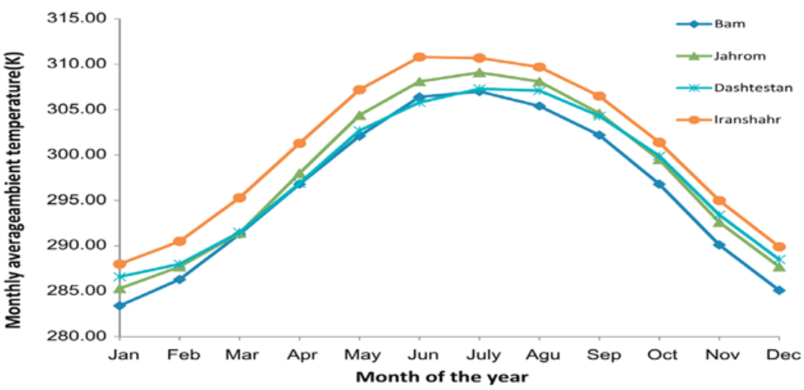

Figure 10

Appendix 3: Average monthly variations of air temperature in four places in Iran comparing to a month [5]

Appendix 4: Potential energy of towers in various countries [11,12]

Table 7

potential of energy Towers						
Region	200-600MW av. Net output		300-600MW av. Net output		6000 KWh/year per Capita	10,000 KWh/year per Capita
	Annual energy	No. of towers	Annual energy	No. of towers		
	10^9 KWh/year	-	10^9 KWh/year	-	10^6	10^6
North Africa	46 412	18 140	14251	4018	2375	-
South Africa	17 256	6 850	5932	1685	989	-
India	16 086	6 487	4407	1548	734	-
Saudi Arabia	8580	2 580	6072	1089	1,012	-
Persian Gulf	6 884	1 715	6440	1543	1,073	-
California $Mexico	27 182	10 956	4748	1442	-	474
Chile$ Peru	23 653	8 385	9542	2730	1590	-
Australia	111 783	5 004	907	289	151	-
Spain, Italy, Greece	3 320	1 666	-		-	-
The number of people that can be supplied by electricity from Energy Tower are shown in the last two columns (at 6,000 kWh/year/capita or at 10,000 kWh/year/capita).						

Appendix 5: Global annual solar radiation and climate conditions for 12 regions in Iran [2,3]

Table 8

Region	Province	Longitude	Latitude	Average annual temperature (K)	Average annual wind speed (m/s)	Annual sunshine duration (h)	Annual solar radiation (MJ/m²)
Bam	KERMAN	58°21′	29°6′	23.08	2.92	3381.6	7307.91
Tabas	YAZD	56°55′	33°35′	22.42	1.51	3322.3	6843.142
Jahrom	FARS	53°33′	28°30′	25.04	2.07	3398.4	7404.197
Zabol	SISTAN-VA BALUCHESTAN	61°29′	31°1′	22.73	5.23	3180.8	7218.597
Dashtestan	BUSHEHR	51°12′	29°16′	24.67	2.78	3172.3	7155.944
Ardabil	ARDABIL	48°18′	38°15′	9.87	3.22	2400.9	4650.103
Divandare	KORDESTAN	47°1′	35°54′	11.06	2.58	2940.7	6274.696
Iranshahr	SISTAN-VA BALUCHESTAN	60°41′	27°12′	27.52	2.05	3279.2	7481.012
KhorramAbad	LORESTAN	48°21′	33°29′	16.98	2.00	3044	6651.087
Sabzevar	KHORASAN-E-RAZAVI	57°40′	36°12′	17.18	2.86	3026.1	6295.426
Varamin	TEHRAN	51°39′	35°19′	16.76	1.57	3038.9	6431.607
Yazd	YAZD	54°22′	31°53′	19.58	2.68	3252.7	6890.823

Figure 11

Appendix 6: Location of 12 selected regions for evaluating the performance of SCPP in Iran [4]

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