Concentrating Solar Thermal Power: A Viable Alternative in China's Energy Supply

By

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ABSTRACT

Study of low-carbon renewable alternatives for China revealed that concentrating solar thermal (CST) electric power was under-emphasized in China's renewable energy plan. The main motivation of this paper is to provide the analysis and strong arguments that CST power can be a viable renewable energy alternative for China to meet its challenges of: 1) continuing to fuel China's economic growth, 2) narrowing regional disparity, and 3) providing clean energy in China's path to a low-carbon economy.

There are many studies on the subject of China's economic growth and environmental impact, China's regional disparity, China's renewable energy plans, and concentrating solar thermal's potential and feasibility. However, not many have combined the above to examine comprehensively the role that CST may have in China's future. As such, this research integrates: 1) a review of China's past (post-reform), present, and future in terms of economic growth, energy consumption, consequent impact on the environment, and policy response; 2) a technical and economic analysis of CST technology; 3) a comparative economic impact assessment of CST adoption; and 4) a review of policy strategies that can lead to CST commercialization; to better assess the value of concentrating solar thermal power (both absolute and comparative) in China's geographical and social-economical environment.

The analysis shows the competitive viability of CST with major conclusions that include the following: 1) China has the key prerequisites to making CST power generation economical including high-quality solar resources (DNI level ranging from 5 to 9 kWh/m^2 per day in the Western region of China), appropriate land requirements, and power grid availability; 2) CST's proven history, 100s of MWe scale capacity, and

dispatchability makes CST a good utility-scale clean energy power plant option for China especially in the economically under-developed Western regions; 3) CST power is currently not cost competitive to coal-fired electricity on a nominal basis (10 cents per kWh for CST parabolic trough compared to 4.6 cents per kWh for coal-fired electricity in Xinjiang), but can be a very competitive electricity generation alternative when costs of externalities (depending on the assumptions used as externalities estimates vary greatly) are accounted for; 4) with externalities, CST, at 11.4 cents per kWh, can become 57% cheaper than scrubbed coal and 29% cheaper then nuclear power according to estimates; 5) CST power has great potential for continued cost savings from both economies of scale and technological improvements in efficiency and can potentially realize a levelized electricity cost of around 4 cents per kWh within ten years; 6) CST has the potential to positively impact Xinjiang and Tibet's economy ($5M to $30M of additional GDP per MWe of CST capacity installed), but proper policy and deal structure must be in place to ensure that the local community receives the benefit.

In sum, this comprehensive study present a document that is intended to decisively convince the Chinese government and related industries in China that CST is a viable technology to pursue (and invest in). If currently not the main focus in China's energy plans, CST, at least, should be one of the most promising ones.

ACKNOWLEDGEMENT

Grateful acknowledgment is made to my thesis advisor Professor Noam Lior for his immense knowledge, broad understanding of the inter-connecting issues, and endless patience in guiding, critiquing, and enriching my understanding of different forms of energy and their impact on the environment.

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1. Introduction

In less than 30 years, China has gone through a spectacular transformation. From a closed economy, that sometimes failed to produce enough to feed its own people, to a market-based economy, that is a major contributor to world trade, China's economic development has not only benefited the world, but also its 1.3 billion people. With this sustained growth, at a speed and magnitude that have no comparable parallel in history, China's greatest achievement is also its greatest challenge. On the one hand, China's appetite for dirty electricity, to fuel the expansion of heavy industry and urbanization, is causing severe environmental degradation with alarming global consequences. On the other hand, China's uneven growth is creating regional disparity that if left unchecked will yield severe social and political repercussion. China's goal of quadrupling its GDP by 2020 will only intensify the severity of these problems. In this regard, China must make immediate and effective use of renewable energy sources to help transform itself into a low-carbon economy. While renewable energy plans are in place, the lack of focus on concentrating solar thermal is a mistake as it can play an important role in China's energy supply that will be needed to solve China's 3-headed problem: (1) fuel China's growing need, (2) drastically reduce carbon emissions, and (3) bridge regional income disparity.

While there are many studies on the subject of China's economic growth and environmental impact, China's regional disparity, China's renewable energy plans, and solar power and concentrating solar thermal's potential and feasibility, not many studies have put all of the above together to examine comprehensively the role that concentrating solar thermal may have in China's future. Thus, the main contribution of the paper is to integrate all the information above, assess the value of concentrating solar thermal power (both absolute and comparative) in China's geographical and social-economical environment, and present a document that is intended to decisively convince the Chinese government and related industries that CST is a viable technology to pursue (and invest in), if not the main goal in their energy plan but as one of the most promising.

This paper is divided into two parts. Part one of the paper reviews China's past (post-reform), present, and future in terms of economic growth, energy consumption trends, and the consequent impact on the environment. Part two of the paper analyzes the potential, feasibility, regional socio-economic impact, and the path to commercializing concentrating solar thermal electric power technology (CST) for China quest to a low-carbon economy.

2. Part I: China's Economic Growth, Energy Consumption, and Impact

2.1. Benefits of Economic Growth

From 1978, the time China reopened its doors to the world, to 2007, China's GDP grew at an average of 9.88% per year – a rate equivalent to doubling China's GDP every 7.27 years. Over the same period, per capita GDP grew from $154 USD in 1978 to $2,485 USD in 2007. The effect of this explosive and sustained high growth propelled China from 11th place in 1980, to 6th place in 2000, and to 4th place in 2007 (just behind Germany by half a percent) [1] – transforming China from a centrally planned, agricultural-based economy to a market-oriented, manufactured-based economy.

China's economic growth has made significant contribution to the world trade. In 1983, China represented only 1.2% of the world's trade. In 2007, however, China represented 8.9% of the world's trade and contributed to 10.15% of overall world trade growth over the same period.[2] During this time, China has established itself as the world's factory and some China watchers have even credited the "china price" to holding down inflation over the last decade.

While China's economic success contributed greatly to global commerce, it also significantly improved China's standard of living. After examining poverty data from the United Nations database, China's National Bureau of Statistics, World Bank's WDI, and World Bank's PovcalNet database, this paper finds that PovcalNet database offers the most-up-to-date poverty with 2005 data as the latest. From 1981 to 2005, the percentage of households living in poverty decreased drastically from 84% to 15.9% - effectively lifting 600 million people out of extreme poverty.[3] Table 1. Remarkably, China started 1981 with a higher poverty rate than South Asia, Sub-Saharan Africa, and India, but achieved a lower poverty rate than all three comparisons in 2005.[4]

Table 1 - China's poverty reduction vs. select regions and countries

% of People living on less than $1.25 per day (2005 PPP)									
Selected Regions	**1981**	**1984**	**1987**	**1990**	**1993**	**1996**	**1999**	**2002**	**2005**
East Asia & Pacific	77.7	65.5	54.2	54.7	50.8	36.0	35.5	27.6	16.8
Europe & Central Asia	1.7	1.3	1.1	2.0	4.3	4.6	5.1	4.6	3.7
Latin America & Caribbean	12.9	15.3	13.7	11.3	10.1	10.9	10.9	10.7	8.2
Middel East & North Africa	7.9	6.1	5.7	4.3	4.1	4.1	4.2	3.6	3.6
South Asia	59.4	55.6	54.2	51.7	46.9	47.1	44.1	43.8	40.3
Sub-Saharan Africa	53.4	55.8	54.5	57.6	56.9	58.8	58.4	55.0	50.9
Selected Countries	**1981**	**1984**	**1987**	**1990**	**1993**	**1996**	**1999**	**2002**	**2005**
India	59.8	55.5	53.6	51.3	49.4	46.6	44.8	43.9	41.6
China	84.0	69.4	54.0	60.2	53.7	36.4	35.6	28.4	15.9

Source: Compiled by author from The World Bank PovcalNet Database (2009)

However, despite the benefit to its 1.3 billion people and the world, China's transformation has created two major adverse results: (1) negative environmental impact resulting from increased energy consumption; (2) regional income disparity. Before diving deeper into the adverse effects of economic growth, it is important to first establish the relationship between growth and energy consumption.

2.2. A Brief Note on the Relationship between Growth and Energy

Most reports on the topic of growth and environmental degradation take for granted that the key link between economic growth and environmental pollution is energy consumption. But does a relationship exist between economic growth and energy consumption?

Many studies have examined the relationship between economic growth and energy consumption and a comprehensive review of published research shows that this topic has been the focus of academic researchers in the past two decades. Specifically, while some concluded that no statistically significant relationship exists between the two variables, the majority (in the magnitude of 5-to-1) of the researchers found a relationship between economic growth and energy consumption.[5]

The key contention, however, is in the direction of the causation of these relationships. In other words, is the increase in energy consumption driving GDP growth or the other way around or both? The answer to this question has tremendous policy implications. If the common claim that increased energy consumption leads to a corresponding increase in GDP is genuine, then we might have to rethink our strategies in response to climate change. This is because a reduction in carbon dioxide emissions brought through a reduction in energy consumption will have a negative impact on the income in developed countries. Moreover, the statement can, and possibly will, be used by developing countries like China to justify their increased energy usage on the ground that it will result in an increase in their GDP.

Based on a survey of leading papers,[6] it appears that the more recent papers tend to conclude that a bi-directional causality exists, while the earlier papers are split on the direction of the uni-directional causality. Also, while the earlier papers tend to focus more on individual countries, the more recent papers uses data from dozens of countries. For instance, Huang et al. 2008[7] used 82 countries and reached multiple conclusions depending on the countries examined. The result from Chien and Li's 2008[8] investigation, with data retrieved from the World Bank and using exploratory data analysis and regression analysis, is consistent with Huang's findings. In summary, it shows: 1) the results are statistically significant in nine out of the ten countries examined; 2) the direction of causality depends on the type of economy. Specifically, GDP drives energy consumption in developed countries like the United States, but increased energy consumption drives economic growth in developing countries like China. Of course, even with all the studies in this field, it is still hard to tell definitively. The consequence of this is also problematic, because it then encourages energy consumption and the question is whether economic growth (or rather, improvement in standard of living of individuals, in fact national economic growth may do little for individuals when there is a large income disparity) can be obtained with small energy consumption growth. But for the purpose of discussion, going forward, this paper is of the position that 1) there is a relationship between economic growth and energy consumption; and 2) for a developing country like China, energy consumption drives economic growth.

2.3. Negative Environmental Impact

With the link between China's economic growth and energy consumption established, it becomes evident that energy is one of the important foundations for China's economic growth. At 1,717 MTOE of energy consumption in 2005, China is the second largest consumer of energy in the world (behind the United States). China's energy consumption grew at about 4.5% compounded annual growth rate (CAGR) from 1980 to 2005 with a sharp increase in trajectory after 2000 (CAGR 2000 to 2005 at 9.2%) - narrowing the gap between China and the United States from 1,213 MTOE to 623 MTOE. Figure 2. Interestingly, while both the United States and China show increasing consumption in energy, in terms of percentage of world energy consumption, the United States shows a decreasing trend - from around 25% in 1980 to just above 20% in 2005. In contrast, China's share of world energy consumption increased from around 8% to around 15% over the same period. Figure 3. China's appetite for energy is expected to continue, reaching 2,906 MTOE by 2015 and 3,885 MTOE by 2030 - surpassing that of the United States.[9]

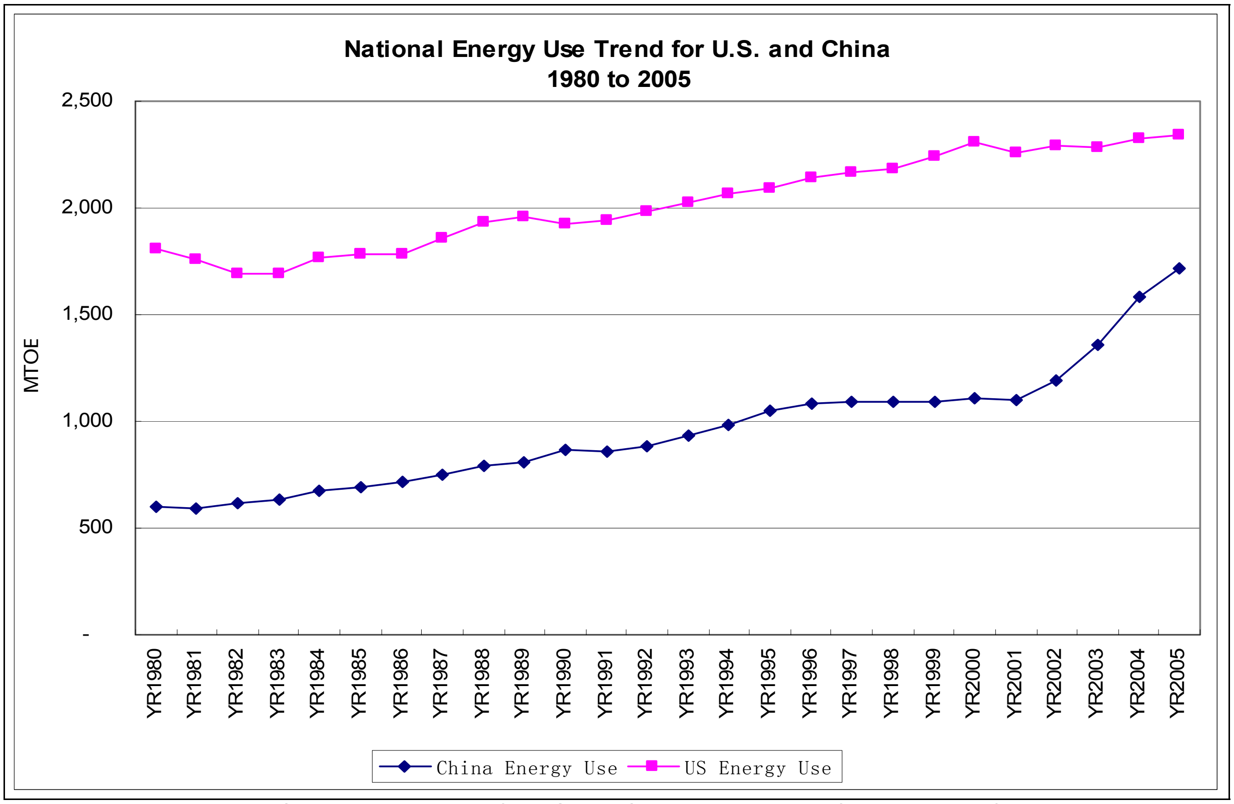


Figure 2 – National Energy Consumption Trends for U.S. and China in metric ton of oil equivalent from 1980 to 2005
Source: Compiled by author with data from The World Bank WDI Database (2009)

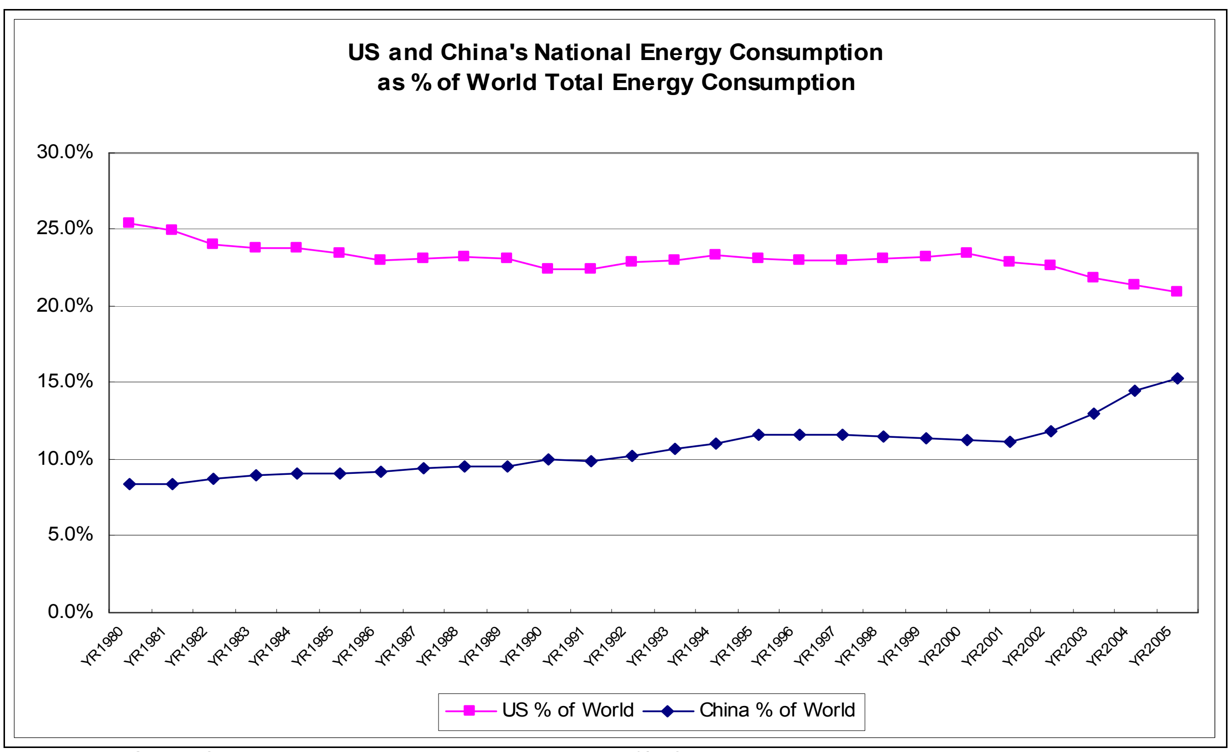


Figure 3 – U.S. and China's national energy consumption as a % of total world energy consumption.
Source: Compiled by author with data from The World Bank WDI Database (2009)

The world's two largest consumers of energy are also the world's two largest polluters of CO_2 emissions. China, while a distant second in energy consumption, is a close second to the United States in terms of CO_2 emissions. Table 4. China's CO_2 emission, representing 20% of the world's total emissions in 2006, has grown almost four times from 1980 to 2006 with a CAGR of 5.7%. Consistent with China's energy consumption trend, there was a sharp increase in the rate of CO_2 emission from year 2000 with a CAGR of 10.75% from 2000 to 2006. Figures 5 and 6. According to the latest report from the International Energy Agency (IEA), China has already surpassed the United States in 2007 as the number one CO_2 emitter in the world[10] and by 2030 China is expected to emit 11,710 MT of CO_2 - doubling its current emission volume.[11]

Table 4 – Top Energy Consumer and CO_2 Polluters for 2005

Energy Consumption (2005)			CO2 Emissions (2005)		
Rank	Country	MTOE	Rank	Country	MT CO2
1	United States	2,340	1	United States	5,785
2	China	1,717	2	China	5,060
3	Russian Federation	647	3	Russian Federation	1,531
4	India	537	4	Japan	1,228
5	Japan	530	5	India	1,161

Source: Compiled by author with data from World Bank WDI Database (2009) and OECD IEA Statistics Database (2009)

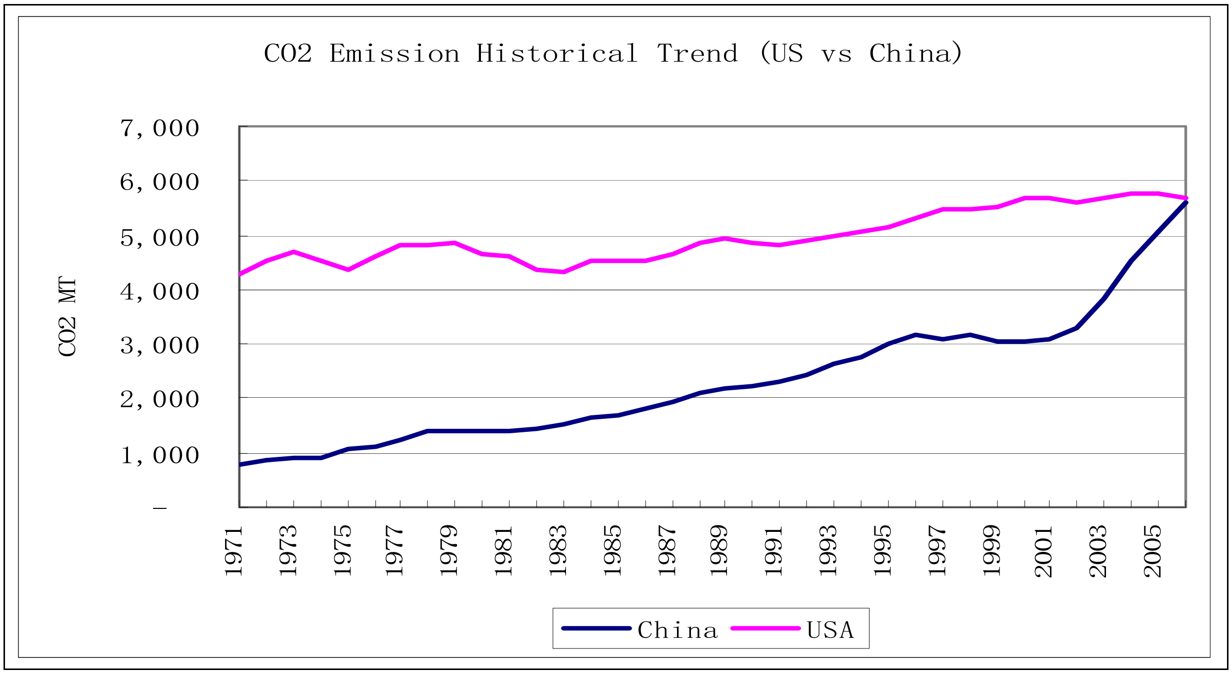


Figure 5 – CO_2 Emissions 1971 to 2006 (US vs. China)
Source: Compiled by author with data from OECD-IEA Statistical database (2009).

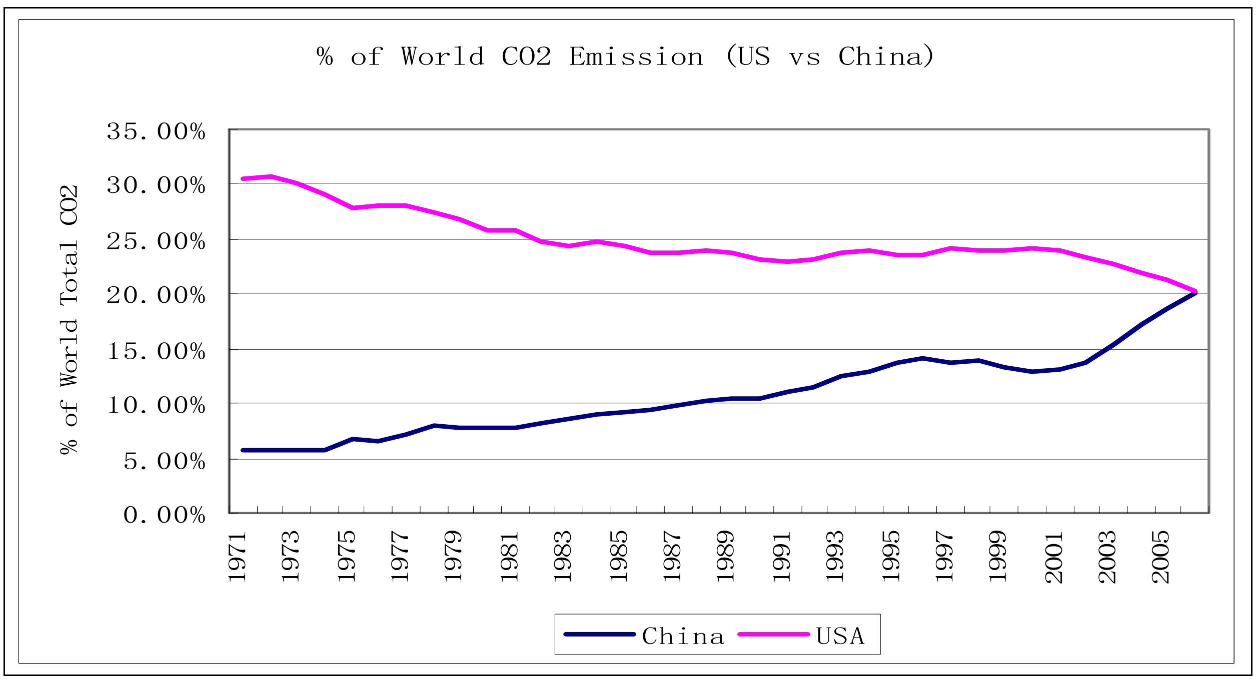


Figure 6 – Share of World CO_2 emissions 1971 – 2006 (US vs. China)
Source: Compiled by author with data from OECD IEA Statistical database (2009).

The increased emission of CO_2 is a direct result of human activities with the largest contributing share from the use of energy. Data from UNFCCC[12] shows that energy activity emissions represent 82.3% of all human activity related GHG emissions. Of the energy related GHG emissions, 93.7% are CO_2 emission. Figure 7. While not represented in the UNFCCC data, China's situation presents a similar story. Figures 8a and 8b shows that electricity production, heating production, and other energy industries in China produced 53% of China's total CO_2 emissions in 2006. China's extraordinary economic growth and rapid industrialization led to an enormous demand for electricity. Between 2000 and 2006, China added 303 GW of capacity – approximately equal to the total net installed capacity of Australia, Brazil, and India by the end of 2006.[13] And with coal as the dominant (79%) fuel for electricity generation, China's appetite for electricity is the largest driver in the rise of CO_2 emissions.[14] Figure 9.

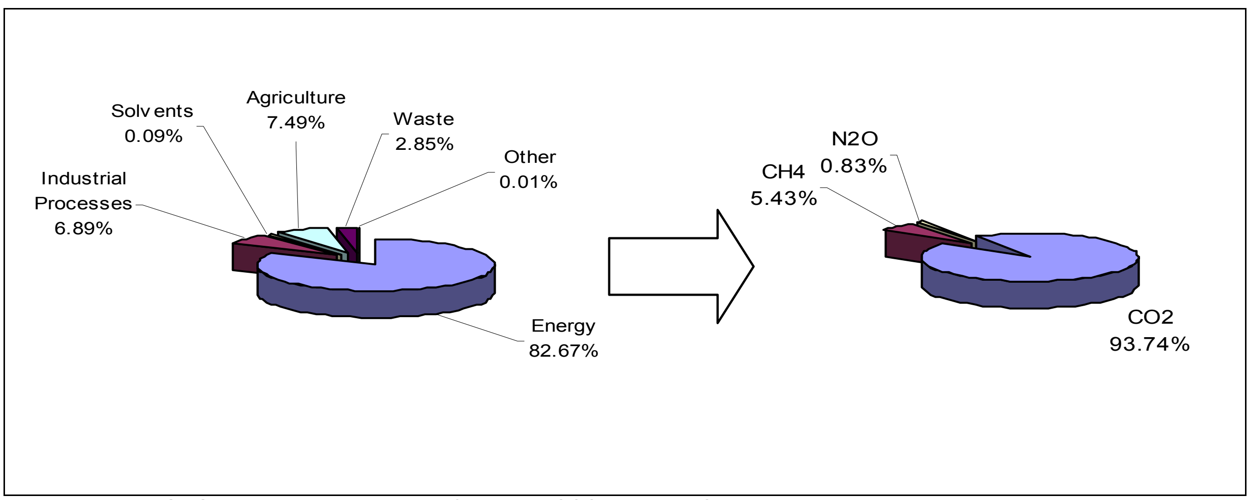


Figure 7. 2006 GHG emissions by activity from UNFCCC Annex I Countries excluding land use, land use change, and forestry (Left). Breakdown of energy-based GHG by gas type (Right).
Source: Compiled by author with data from UNFCCC Data Interface (2009)

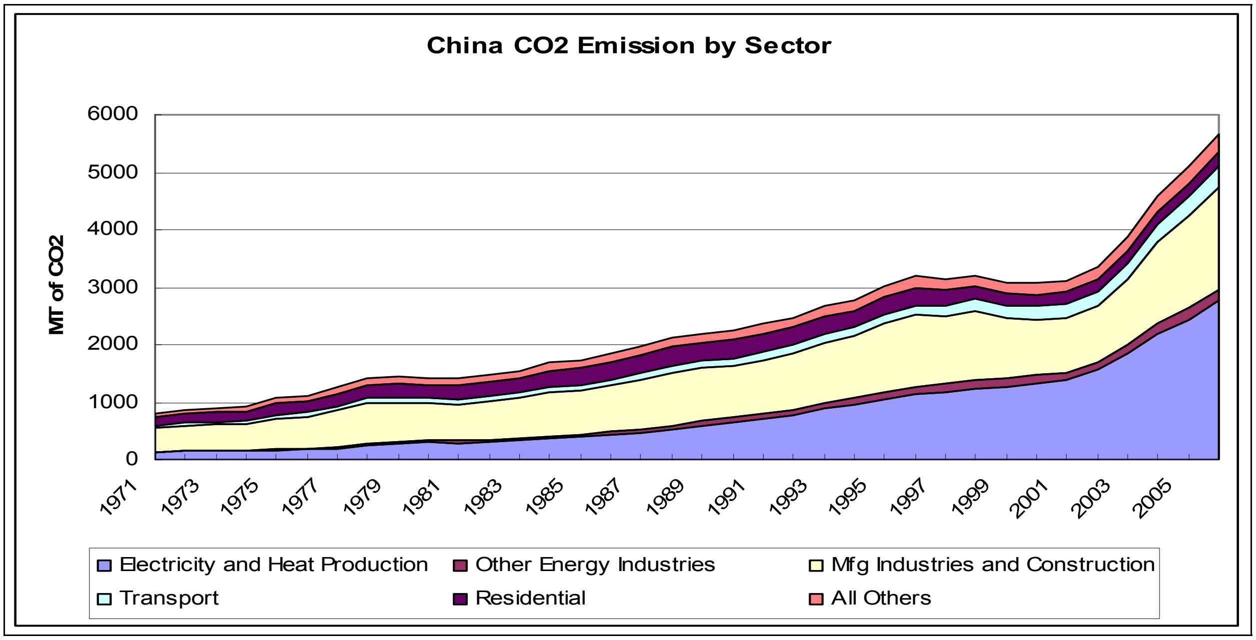


Figure 8a. – China CO_2 Emissions by Sector (1971 – 2006)
Source: Compiled by author with data from OECD IEA database. 2009.

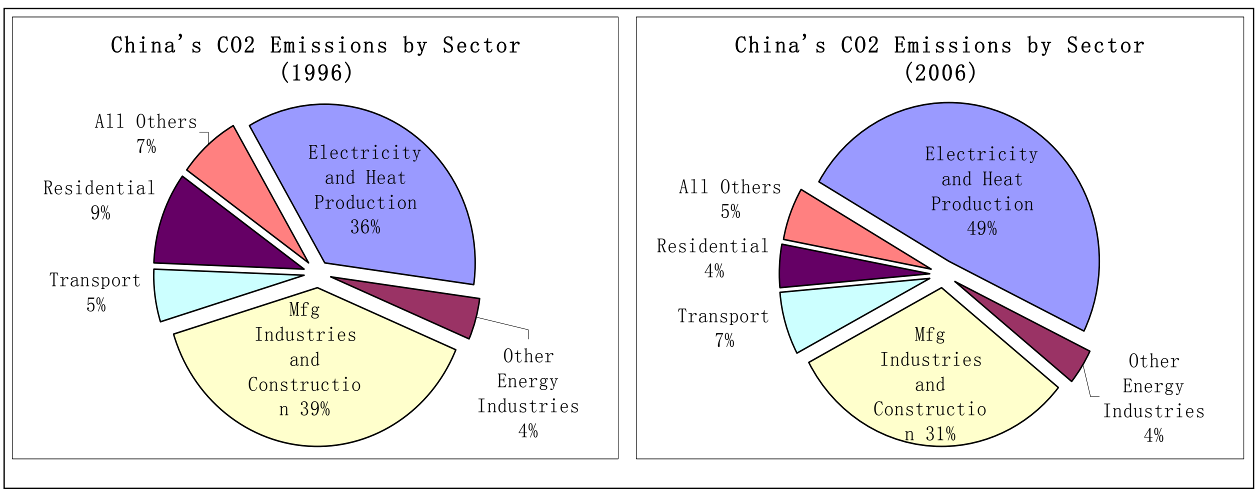


Figure 8b. – China CO_2 Emissions by Sector for 1996 and 2006. Electricity, heating, and other energy industries represented 40% and 53% of China's total CO_2 emission in 1996 and 2006 respectively.
Source: Compiled by author with data from OECD IEA database. 2009.

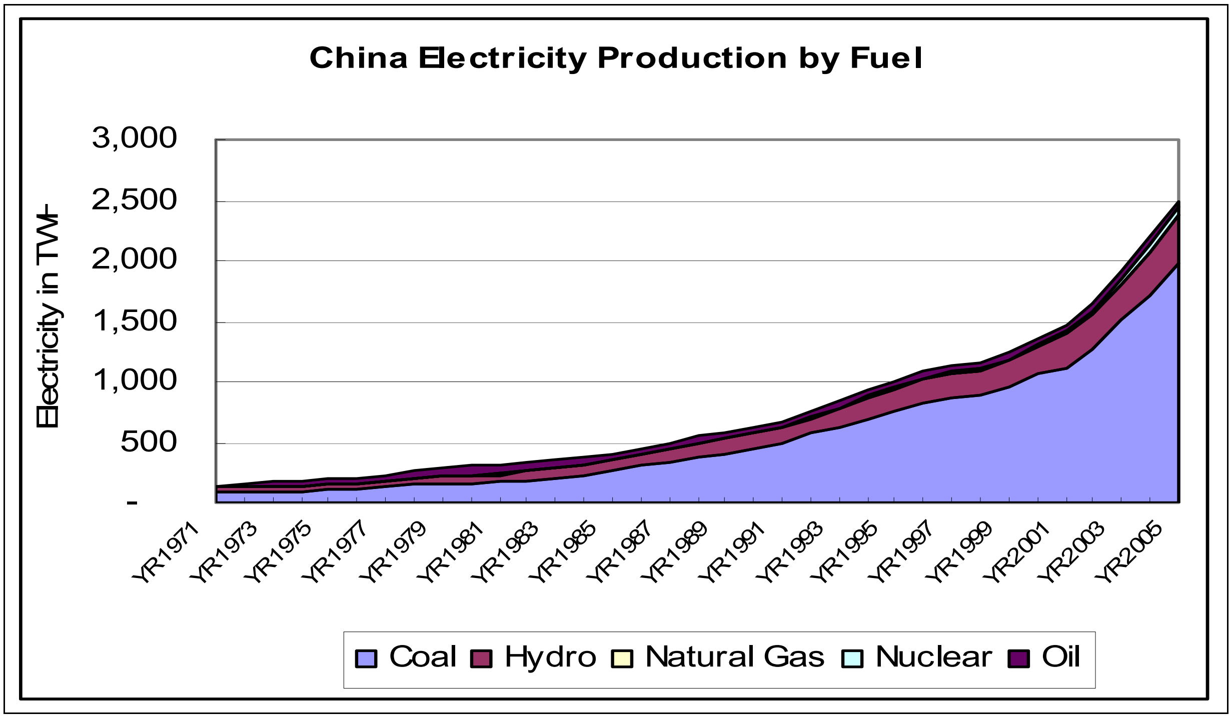


Figure 9 – China Electricity Production by Fuel type
Source: Compiled by author with data from World Bank WDI database. 2009

Unfortunately for China and the rest of the world, CO_2 is the major cause of greenhouse gases (GHG) that contribute to global warming. GHG accumulation in the atmosphere is long lived and traps radiated heat from the sun that leads to a higher global temperature. The Fourth Assessment by the Intergovernmental Panel on Climate Change (IPCC) report that global warming is "unequivocal" and is driven by significant atmospheric concentration of GHG (mainly CO_2) due primarily to fossil fuel use.[15] In describing the link between GHG emissions and global warming, the report upgraded the language from "likely" (as stated in the Third Assessment Report) to "very likely".[16] This reflects the scientific community's increasing acceptance of the belief that the accumulation of GHG will result in long-term, detrimental consequences of global climate change.[17]

2.4. Regional Income Disparity

Another adverse effect from China's economic success is the growing regional income disparity. While economic growth has lifted hundreds of millions out of extreme poverty, the rising economic tide did not raise all boats equally. From 1980 to 1990, the gap between urban and rural average income as well as regional share of GDP and population remained fairly constant. Figure 10 and Table 11. Though, in terms of per capita GDP, many studies found that regional disparity actually declined significantly due to a heavy focus on agricultural production in the rural regions.[18]

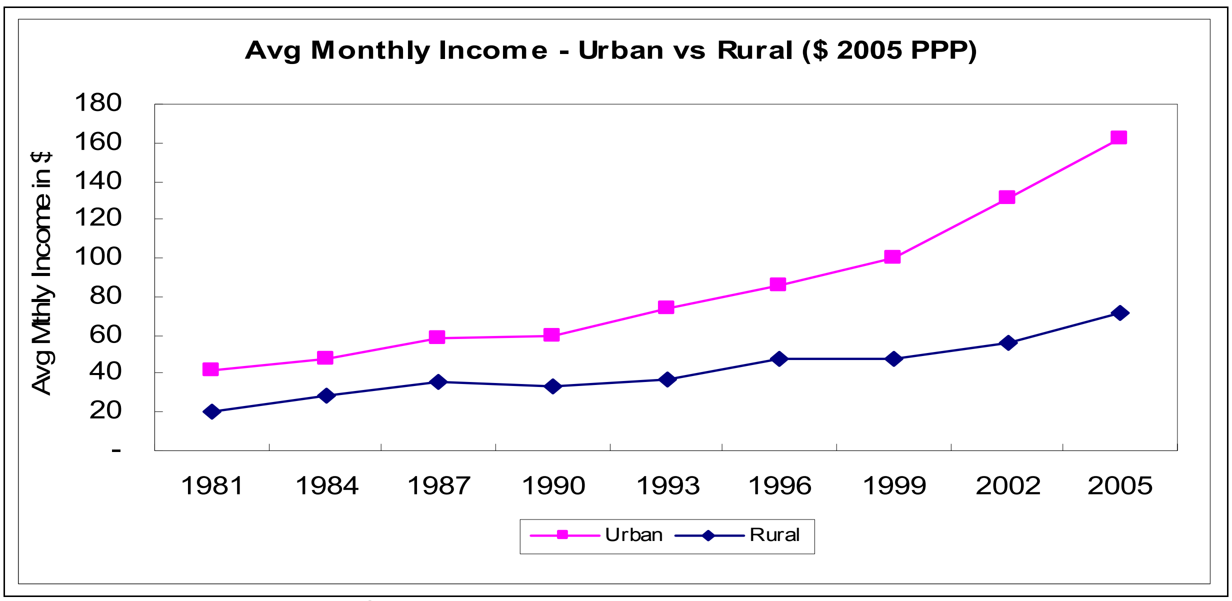


Figure 10 - Urban vs. Rural Income Gap
Source: Compiled by author with data from The World Bank PovcalNet Database (2009)

Table 11
Regional Share of GDP and Population (%)

	1980		1990		2000		2005	
	GDP	Population	GDP	Population	GDP	Population	GDP	Population
Eastern	43.8	33.9	45.9	34.1	53.5	35.1	55.6	35.8
Central	22.3	28.3	21.8	28.5	19.2	28.1	18.8	27.5
Western	20.2	28.7	20.3	28.5	17.3	28.3	16.9	28.2
Northeastern	13.7	9.1	11.9	8.8	9.9	8.6	8.7	8.4
Total	100	100	100	100	100	100	100	100

Source: Li, Shantong and Zhaoyuan Xu. "The Trend of Regional Income Disparity in the People's Republic of China. ADBI Discussion Paper #85." (2008).

From 1990 to 2005, however, a trend of growing regional disparity can be observed. The gap between the average urban income and the average rural income widened greatly. The difference between urban and rural average income was $25.15 in 1990 which widened more than 3 times to $90.49 in 2005. Figure 10. In terms of regional[19] differences, the Eastern regions' share of GDP increased from 43.8% in 1980 to 55.6% in 2005. This came at the expense of the Central, Western, and Northeastern regions' economic contribution with the Northeastern region experiencing the largest percentage drop of 5% over 25 years. Table 11. China's vast territory with its varying geographies, natural endowments, and socio-economic conditions predispose China to regional disparity. But studies have found that factors including China's regional development strategies, regional protectionism, lack of uniform market, labor migration, and preferential policies for coastal cities all contribute to the expansion of regional disparities.[20] In fact, some studies suggest that the main driver of regional disparity is the faster economic growth experienced by China's coastal regions (i.e. the interior regions are not getting poorer, just that coastal regions are getting wealthier). Consequently, the faster economic growth of the coastal regions is driven by rapid increase in foreign investments and foreign trades in these regions which is helped by preferential governmental policies, better established infrastructure, and geographical proximity to international markets, and development of non-state-owned enterprise.[21]

Regional disparity is a tough, yet crucial issue faced by the Chinese government in their search for the magic formula that balances high-growth and the development of a harmonious society. Past experience shows that with the proper government policy, infrastructure build-up, and investments, urban-rural disparities can be narrowed by strengthening the rural economic system and connecting it to the mainstream economy. The expansion of the national highway and railway system (e.g. Tibet-Qinghai Railway connection) are good example of this strategy. However, China must also take into account the challenging geographical attributes of some of these rural regions. For example, 27.3% of China is categorized as desert[22] with low precipitation and high levels of solar radiation – attributes that are difficult to translate into useful economic use under conventional means. Thus, to achieve a coordinated regional development, China must also devise innovative solutions that can turn deserts into competitive advantages.

2.5. China in 2020 – "Quadrupling GDP while only doubling energy consumption"

China's plan for the next 11 years is to continue its economic growth with the stated goal of quadrupling its GDP by 2020 versus the year 2000 while only doubling energy consumption by 2020.[23] Though this GDP target may be reduced in view of the current financial crisis, this economic policy target signifies the importance of economic growth in China's vision of realizing the building of a "well-off society in an all-round way" as set forth in the 17th CCP National Congress.[24] Having experienced traditional development issues and faced with increasing international pressure on environmental pollution, Chinese leaders now recognize the need for sustainable development – balancing economic, social, and environmental factors – in reaching the country's objective.

The seriousness of the global environmental consequence from China's continued pursuit of economic growth has not been lost on the global stage. At the World Economic Forum of 2007 at Davos, climate change and China's CO_2 emission trends was a key issue at the meeting of international leaders. President Obama and Secretary Clinton have made climate change a key item on the foreign policy agenda for China. On

Clinton's inaugural visit to China as Secretary of State in 2009, Clinton remarked that a key area of collaboration with China is "clean energy and climate change" to "speed transformation to low-carbon economies."[25] Reassuring China's right to continued economic growth, Clinton said that the US wants "China to grow" and wants "the Chinese people to have a good standard of living". But, Secretary Clinton preempted the oft used argument that developed countries polluted their way to affluence by saying "when we [US] were industrializing and growing, we didn't know any better; neither did Europe. Now we are smart enough to figure out how to have the right kind of growth...we hope you won't make the same mistake we made."[26]

China's initiatives and actions thus far suggest that it is trying hard not to make those same mistakes as US and Europe. China started promoting the development of renewable energy with their 8th Five Year Plan. Other notable legislations and regulations include: Energy Conservation Law of PRC (1997), Air Pollution Prevention Law of PRC (2000), 1996–2010 New Energy and Renewable Energy Development Principles, 2000–2015 New Energy and Renewable Energy Development Principles, Comprehensive Working Programs on Energy Saving and Emission Reduction, and many others.[27] All of these policy actions are aimed at encouraging the use and development of energy conservation and efficiency, renewable energy power, the build up of a renewable energy industry, and promoting greater renewable energy applications in emission reduction. China also passed the PRC Law of Renewable Energy in 2005 which raised the focus of renewable energy to "strategic heights", representing the Chinese government's priority on the issue of sustainable development, and setting the framework to enact supporting laws and policies to further renewable energy development.[28]

Against this backdrop, Hu Jintao, President of China and Chairman of the CCP, stressed the need for “energy resource conservation and environmental protection” and called for the implementation of a “system for the work of conserving energy and reducing emissions, develop and promote advanced practical technology that can save, replace, and recycle energy resources, and develop clean energy and renewable energy.”[29] In short, China plans to achieve a sustainable policy in the energy sector by saving energy resources, increasing energy efficiency, and adding an increase of renewable energy resources into China’s energy mix.

However, China’s goal of quadrupling GDP while only doubling energy consumption by 2020 may be too optimistic. The recent study by Li and Oberheitmann shows that to achieve China’s stated goal above, the energy intensity[30] has to “decrease by 53% by 2020” which is “a level of 30% below the year-2000 level of industrialized countries” and represents an improvement “2-5 times than what has been achieved during the past 20 years.”[31] Moreover, while China has made great progress in reducing energy intensity since the 1980s, as observed from the energy intensity reduction trend of developed countries such as US, Japan, and Germany, energy intensity reduction will become more difficult as China’s economic development advances. Table 12. Note that manufacturing nations typically have higher energy intensities than those focusing on trade, business, banking, software development, so as the world’s factory China would have a higher intensity if they wish to stay in that category.

Table 12 – Energy Intensity Reduction Trends

Selected Developed Countries vs China	Energy Intensity (KG OE / 2005 PPP $) 1995	2005	Total Reduction % 1995 - 2005	Avg Reduction / Yr (%) 1995 - 2005
Japan	0.144	0.137	4.9%	0.55%
United States	0.232	0.188	19.0%	2.31%
Germany	0.155	0.137	11.6%	1.36%
China	0.469	0.321	31.6%	4.13%

Source: Compiled by author with data from WDI database 2009.

Against the same back drop of building a "well-off society in all-round way", Hu Jintao also reiterated the goal of "building a new socialist countryside" by promoting "coordinated urban and rural development", by "guiding reasonable cross-regional movements of production factors", by "breaking through administrative regional boundaries, form a few economic spheres and economic belts that are strong in leading and close in links", and by "grooming a new type of peasants who are educated, understand technology, and know management".[32] In short, Chinese leaders plan to pull out all stops to improve the problem of regional income disparity.

A key ingredient in bridging regional disparity is economic and infrastructure integration. This integration involves not just roads and railways, but also the electrification of rural regions[33] (Western and Central) which translates to an increase in electricity demands. Additionally, the realization of a new socialist countryside with educated and technologically savvy peasants will almost certainly mean a drastic rise in China's growing middle class. As the standard of living in the underdeveloped regions improves, the "new peasants" may increase the demand for modern appliances leading to greater electric power consumption. Thus, while a necessary goal for China's social and political stability, the success in "building a new socialist countryside" will further frustrate China's energy consumption diet plans as well as reduction objectives for CO_2

emission.

Some studies suggest that China may already be off target in meeting the stated 2020 energy consumptions goals. According to a 2007 Center for Strategic International Studies[34] (CSIS) report, China is not only off track, but is at a point where it will be "nearly impossible to reach its stated energy consumptions goals".[35] The report also urge the Chinese government and major energy statistics agencies (IEA and DOE) to wake up from their optimistic fantasy forecasts as they no longer have a realistic basis with the observed current trend.[36] The current trend shows a bleak future where the pursuit of quadrupling GDP will lead to quadrupling the use of coal and thereby lead to the quadrupling of CO_2 emissions.

To address this concern, one area China should focus on is the supply side of the energy equation by aggressively incorporate large-scale renewable energy supplies into China's energy mix. According to Chien and Hu 2007 study,[37] increasing the share of renewable energy into a nation's energy mix has significant positive effects on the macroeconomic technical efficiency (TE) index (which incorporates energy along with traditional key inputs such as labor, and capital stock to produce GDP) and thereby the economic efficiency of producing GDP. Conversely, increasing the input of traditional energy sources decreases technical efficiency. This is a powerful result in that it suggests the use of renewables fundamentally changes the relationship between GDP and energy consumption, allowing a country to produce more output for a given amount of energy consumed.

Using OECD and non-OECD economies as a proxy for developed and non-developed economies respectively, Chien and Hu's research also showed that

OECD economies have higher TE and a greater share of geothermal, solar, tide, and wind fuel in renewable energy than in non-OECD countries. This implies that while all renewable energy sources have positive impact on TE, geothermal, solar, tide, and wind renewables may produce higher TE then biomass.

Thus, by adding renewable energy alternatives into its current energy portfolio, China not only expands its energy supply, but may also be able to increase economic efficiency in producing GDP.

2.6. China's Renewable Energy Focus

While China's renewable energy production currently represents only 2.8% of total energy consumed in 2005,[38] it is setting aggressive targets with priority focus on hydro, wind, and biomass. Table 13 shows that hydro power, currently the largest contributor to China's renewable energy supply, will continue to play the biggest role in 2020 in terms of total installed capacity. China is also planning a significant push on wind power and biomass with an expected 600% increase of total capacity from 2010 to 2020. Conspicuously, in China's plan for the future, solar will play a relatively minor role - contributing less than 1% of China's total renewable energy capacity by 2020. Table 13.

Table 13 – Current and Planned Targets for Renewable and Nuclear Energy

Installed Capacity	**2010**	**2020**	**2010 - 2020**
% of total energy structure	10%	16%	% Increase
Hydro	180GW	300GW	167%
Nuclear*	NA	40GW	NA
Biomass	5.5GW	30GW	545%
Wind	5GW	30GW	600%
Solar	500MW	1.8GW	360%

* Nuclear power is not categorized as renewable energy, but it is included here by the author for comparison purpose.
Source: NDRC - medium and long term plan for renewable development; medium and long term plan for nuclear development.
http://www.sdpc.gov.cn/zcfb/zcfbtz/2007tongzhi/t20070904_157352.htm

China's decision to marginalize solar energy in its renewable energy plan is a mistake and should be reconsidered. First, from a resource perspective, solar energy is the most abundant, most widely distributed free energy resource on the planet. In general, the earth's atmosphere receives about 1,354 W/m^2 of solar radiation (also called the solar constant) of which 50% makes it down to the surface of the earth.[39] By some estimates, this is equivalent to 173,000 TW of energy[40] received on the earth's atmosphere per year or 86,500 TW of energy received on the earth's surface per year. Putting the above data in perspective, the amount of solar energy received on the earth's surface is about 5,550 times the world's total primary energy supply (TPES) in 2006 and 3,829 times the world's total primary energy supply predicted for 2030.[41] In other words, the amount of energy received on the earth's surface from the sun can potentially fulfill our world's annual supply of primary energy in less than two hours.

Of course, the key assumption to the above potential is the ability to effectively convert and distribute the sun's energy. As such, a correct assessment of solar energy resource must also consider transmission and storage availability and efficiency, intermittency of solar energy supply due to climate and seasonality, and collector incidence angle effects. With these considerations, the available energy from the sun would be much smaller given current technology.

Some propose that tapping into the deserts alone may be enough to produce more energy than the world needs. DESERTEC, a concept created by Trans-Mediterranean Renewable Energy Cooperation (TREC) to leverage North African deserts' solar energy potential to provide electricity to Europe, proposes that solar radiation from deserts are the most accessible, but least tapped form of energy source.[42] With the potential to receive 2.2 TWh per year per km of desert, the sun can provide an amount of energy equivalent to that of all fossil fuel consumption in less than six hours and an amount of energy equivalent to that of all fossil fuel proven and expected reserves in 274 days. Table 14. Based on current solar technology with a 15% solar to electricity efficiency, DESERTEC estimates that using just 1% of the area of the world's deserts can provide enough energy to satisfy the world's primary energy consumption.[43] Figure 15. But, it is important to note that the solar potential in the African deserts may not be exactly the same as the deserts in China. There are differences in strength of solar radiation, cloud cover, and ambient temperature.

Still, with more than two-third of China receiving radiation of more than $5.02\text{x}10^6$ kJ/m^2 per year[44] and direct normal insolation values between 5 and 9 kWh/m^2 per day in China's Western regions (as presented in 3.4.1 on Solar Resource Assessment), the key message is that China is well-endowed with solar energy resources and should attempt to exploit it fully.

Table 14 – Solar Energy Potential in Global Deserts

Fossil Energy Source	Annual Production / Consumption (1000 TWh)	Equivalent Solar delivery time in deserts (hours)	[A] Proven Reserves (1000 TWh)	[B] Exp Add'l Resources (1000 TWh)	Equiv Solar Delivery Time for [A] (days)	Equiv Solar Delivery Time for [B] (days)
All fossil fuels	107	5.7	10,400	50,700	47.0	227.0
Oil (conventional)	45	2.4	1,900	960	8.5	4.3
Oil (non-conv.)	-		780	2,900	3.5	13.2
Natural gas (conv.)	24	1.3	1,600	1,900	7.2	8.4
Natural gas (non-conv.)	-		2	1,687	0.1	6.2
Coal (hard and lignite)	33	1.8	5,700	29,000	25.0	129.0
Uranium, Thorium	4	0.2	460	1,740	2.0	7.8

Source: Knies, Gerhard. Clean Power from Deserts: The DESERTEC Concept for Energy, Water and Climate Security; 4. Ed. Hamburg: 2008.

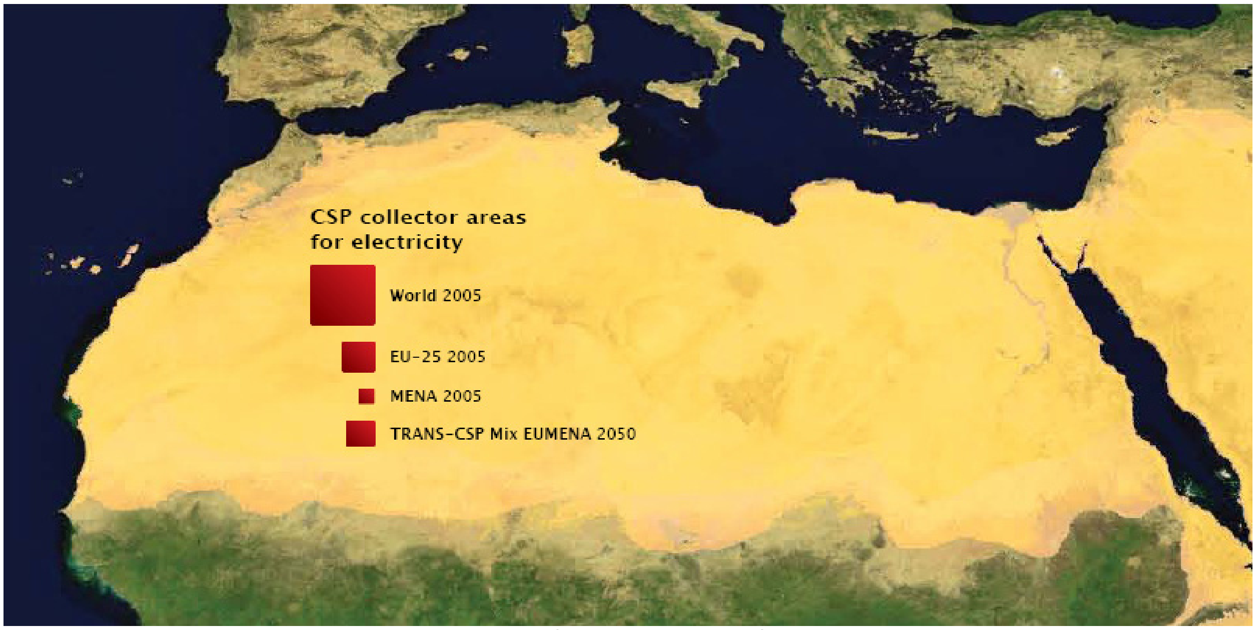


Figure 15. The red squares represents the amount of land area needed for concentrating solar thermal power plants to satisfy the annual electricity demands of the labeled categories.
Source: Knies, Gerhard. Clean Power from Deserts: The DESERTEC Concept for Energy, Water and Climate Security; 4. Ed. Hamburg: 2008.

Second, in contrast to nuclear power development, solar energy as an alternative has the potential to provide China more than just the benefit of electricity. For example, China's nuclear power development plans call for new nuclear power facilities to be located in the relatively prosperous coastal areas.[45] The solar energy option, however, must be located in sun-filled regions of China's deserts like Xinjiang and Tibet to access the abundant supply of solar radiation for electricity generation. This, in turn, will transform the desert lands into competitive advantages and boost the economic development of the under-developed Western regions. However, investments in these regions will only help bridge regional disparity if the economic benefits associated with those investments can directly affect the local community. Thus, with CST and the right policy, the Chinese government has the opportunity to help bridge China's regional disparity..

Third, in contrast to hydroelectric power, solar power poses fewer objections on the grounds of environmental and social intrusion. The prerequisite for hydroelectric power is the need to dam rivers; the larger the river flow, the larger the hydroelectric potential, the larger the dam. Unfortunately, large dams, which are often ill-planned, carry an enormous social and environmental price tag. The social impact includes large scale resettlement of surrounding communities that are usually poor and need to subsist on the fertile lands near the river. The environmental impact includes reduced biodiversity, degradation of water quality, arguably, the releases GHG emissions (methane), a fragmented ecosystem, land erosion, and may even cause earthquakes.

With more than 25,800 large dams[46] and the Three Gorges Dam (the world's largest) partially operational, China is now feeling the social and environmental pains from hydroelectric projects. So far, the construction of the Three Gorges project has necessitated the inundation of 2 cities, 11 counties, 140 towns, 326 townships, and 1351 villages covering 23,800 hectares and involved resettling over 1.2 million people.[47] Chinese government officials who have long dismissed warnings of environmental damage have now admitted that the Three Gorges Dam has caused an ecological catastrophe including frequent landslides and pollution.[48] Worst still, there are new reports produced by both Chinese and US scientists examining the possibility that the world's largest dam may have helped trigger the 7.9 Sichuan earthquakes that killed 80,000 people.[49] While no one is claiming direct proof that the Three Gorges dam caused the Sichuan earthquake, the U.S. experience with the Hoover dam shows that dam reservoir does increase seismic activity.[50]

To be sure, hydroelectric power is currently cheaper than solar and has a higher availability factor. But, in light of the huge environmental and social costs (as illustrated by the Three Gorges project), the infrastructure required for solar electricity generation, with a simple and proven design, a proven record of reducing GHG emissions without environmental risk, [51] and an optimal location at desert areas, creates less environmental and social intrusion compared to hydroelectric power.

Solar energy, of course, is not without its drawbacks. The dependence on the sun for fuel means that solar energy solutions are captives to the low density solar energy at earth's surface and the intermittent nature of solar rays. So, like wind power, the intermittent nature of the renewable fuel means that electricity conversion will not be continuous. However, there is a solar energy technology called concentrating solar thermal (CST) electric power that can overcomes these barriers. CST with a thermal storage system and/or through hybridization can be used effectively as a source of dispatchable power. In fact, CST has 20 years of operating experience in providing dispatchable electric power on a commercial scale.[52] The proven success of CST may be one of the reasons why some of the largest wind power companies are adding CST technology into their wind power portfolio to prepare for their next stage of growth.[53]

CST's relatively low cost, ability to dispatch power, and proven history is helping to grow public awareness of the benefits and feasibility of CST, encouraging research in continuous improvements in efficiency and costs, and consequently motivating many utilities to include CST into their electric power generation portfolio.[54]

2.7. Proposal of Concentrating Solar Thermal for China's Challenges

Given solar energy's many benefits to China in terms of clean power generation, bridging economic disparity, and virtually zero environmental hazards, China should take a serious look at solar energy – especially concentrating solar thermal (CST) electric technology as a solution for China's renewable energy drive.

China should build CST power stations in the Western regions where direct normal insolation (DNI) levels range, on average, between 5 kWh/m^2 per day to 9 kWh/m^2 per day, and sell the generated electricity to the more industrialized Eastern region (where the bulk of the demand occurs). By doing so, China can turn less productive lands of the Western regions into competitive advantages and at the same time provide the much needed electricity to the Eastern regions driving economic growth. This will also bring economic benefits to the underdeveloped Western region via construction, infrastructure build-up, maintenance, and other beneficial trickle-down effects. Ultimately, solar thermal electricity generation will continue to fuel China's growth cleanly while reducing regional disparity.

This paper proposes that CST power generation is a viable solution for China and that it should be scaled up to bridge China's three challenges: 1) continuing to fuel China's economic growth; 2) narrowing regional disparity; and 3) providing clean energy in China's path to a low-carbon economy.

3. Part II – Potential, Feasibility, and Path to CST Reality in China

3.1. Solar Thermal Electric Systems – Concentrating Solar Thermal

CST is a solar thermal concentrating technology that converts solar energy to electricity. Though at origin, solar radiation is a source of high density thermal energy with radiosity of 63 MW/m^2, the geometrical limitation of the sun and the earth drastically dilute the solar energy to less than 1 kW/m^2 on the earth's surface on average.[55] Thus, concentrating sunlight to produce power effectively reverses the dilution effect and produces “higher flux density at the focal point” which “overcomes the effect of thermal loss due to conduction, convection, or radiation.”[56] Combined with an ideal engine, Table 15 shows the relationship between solar concentration, temperature, and system efficiency when converting solar energy to electricity. A low concentration yields low temperatures that result in low efficiency and thus require larger collector areas and vice versa with high concentration. This implies that a minimum level of solar concentration is needed for CST systems to be cost effective.

Table 15 – Theoretical Analysis of Effective Concentration and System Efficiency with Carnot Engine

Effective Concentration	**1**	**3**	**10**	**100**	**1,000**	**10,000**
Optimum Temp in K	325	355	415	590	1,000	1,600
Optimum Temp in C	52	82	142	317	727	1,327
% Efficiency @ Temp	4.2	9.4	19.0	42.6	63.2	76.4
% Efficiency with Practical Engine	3.1	6.0	14.2	32.9	47.4	57.3
Relative Collector Area	20.4	6.7	3.3	1.5	1.0	0.8

Source: Vant-Hull, L. "Concentrating Solar Thermal Power (CSP)." ISES Solar World Congress 2007. Solar Energy and Human Settlement, 18-21 Sept. 2007.

While CST is dependent on an intermittent source for fuel, the CST system can provide non-intermittent electricity generation (firm capacity) or to satisfy peaking or intermediate load capacity demands (dispatchability) making CST standout from other renewables options such as wind energy. This is because the CST system is designed with heat storage systems and fossil fuel backups making CST highly flexible yet dependable. With the use of heat storage systems, CST can store excess thermal heat collected during periods of high solar radiation and shift the energy output to periods where little and no solar radiation is available (i.e. evenings). Since the heat storage systems are designed to shift energy output for only short durations (i.e. hours), the use of fossil fuel backups come into play during seasonal changes (summer to winter) where the availability of the sun may be drastically reduced. Thus, hybridization, or the combination of CST and a traditional fossil fuel electricity generation technology, can ensure that the appropriate amount of electricity is supplied regardless of the sun's availability. Figure 16.

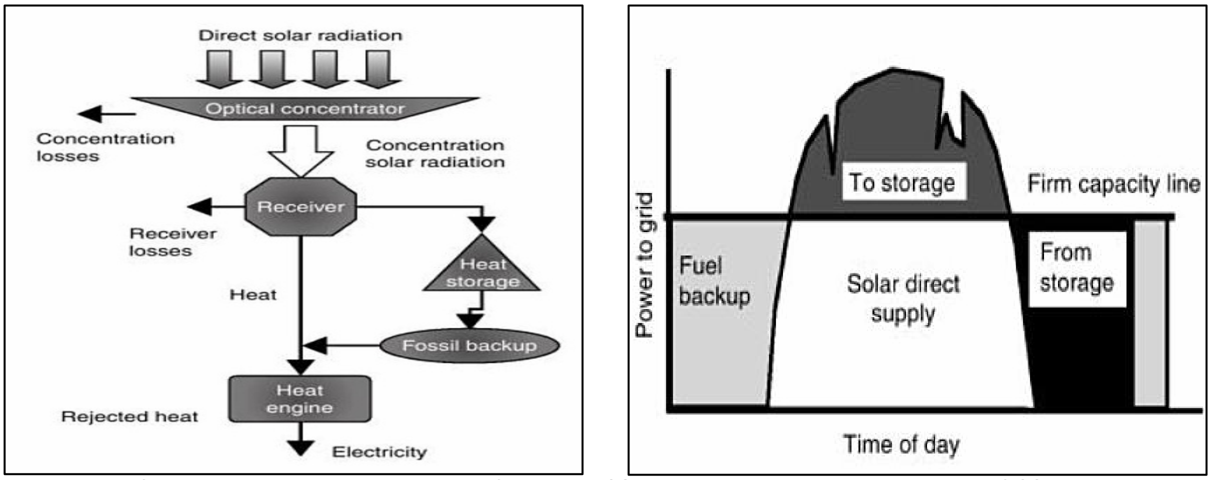


Figure 16. Left is a conceptual representation of a typical CST power plant. Right is a diagram of CST power plant using hybridization and heat storage to maintain power at a firm capacity.

Source: Kreith, Frank and D. Yogi Goswami. *Handbook of Energy Efficiency and Renewable Energy*. Mechanical Engineering Series; Variation: Mechanical Engineering Series (Boca Raton, Fla.). Boca Raton: CRC Press, 2007.

Other benefits of the CST system include[57]: 1) proven technology and capability with over 20 years of operational experience in California which reduces overall project risk; 2) use of conventional technologies and materials allowing for CST systems to scale with existing infrastructure; 3) flexible and modular to suit the needs of large utility-scale central power facilities in the 100s of MW scale (e.g. SEGS in California) or to smaller, distributed power generation system in 10s of kW scale (e.g. solar-fuel hybrid system such as NREL's Solar Thermal Organic Rankine Electricity System or STORES[58] with some of the earliest work on the solar-fuel concept done by researchers at University of Pennsylvania[59] under Department of Energy support); 4) real and significant impacts on reaching climate change targets when employing large scale CST; 5) significant potential for continued cost savings from both economies of scale and technological improvements in efficiency.

With the ability to provide dispatchable power, integration with traditional power plant technology, and other benefits listed above, CST is a good utility-scale clean energy power plant option for China.

3.2. Types of CST Systems

CST uses sun tracking mirrors to reflect and concentrate the sun's energy 50 to 3,000 times onto a thermal receiver where the heat transfer fluid in the receiver can reach a temperature of 400^{C} to 800^{C}.[60] This high-temperature thermal energy is then used to drive turbines or Stirling engines to produce electricity at a solar to electric efficiency ranging from 8% to 30%[61] depending on the type of CST technology used.

The CST systems are categorized by the method in which the system collects solar energy and the three main types are: (1) dish/engine; (2) power tower; and (3) parabolic trough. All three systems are described briefly below.

Dish/engine (DE) systems consist of a parabolic dish point-focus concentrator similar to that of a satellite dish, a thermal receiver, and heat engine/generator situated at the focal point of the concentrator. They need biaxial (3-d) sun tracking. The engine/generator is usually a Stirling (dish/Stirling system) or Brayton or concentrating PV (CPV) module. In a dish/Stirling, the heated fluid from the thermal receiver moves pistons in the Stirling engine to create mechanical power which then drives the generator to produce electricity. In the CPV version, the heat engine/generator is replaced by a cluster of high-efficiency photovoltaic modules that convert solar energy directly to electricity. Compared to the other two CST technologies, the currently used dish/engine system have the smaller per unit capacity of electricity in the range of 3 to 25 kWe per dish,[62] but can be clustered to produce 1 to 10 MWe[63] for larger scale applications. Figure 17.

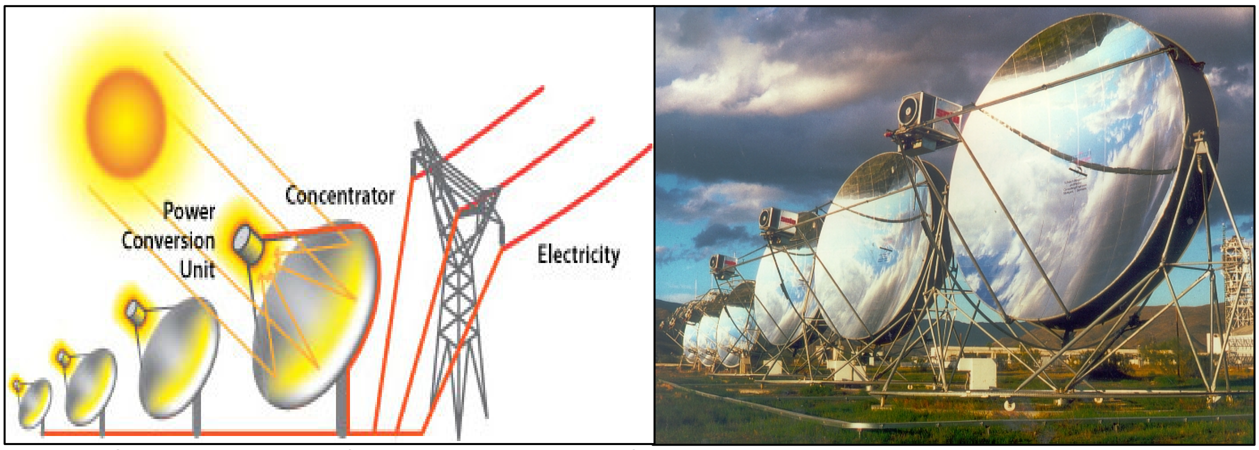


Figure 17. Conceptual drawing (left) and actual photo (right) of dish engine system
Source: U.S. DOE-Solar Energy Technologies Program; Sandia National Laboratories SunLab.

In a power tower (PT) system, a field of two-axis sun tracking mirrors, called heliostats, focus and concentrate sunlight onto a receiver that is mounted on top of a centrally-located tower. The thermal receiver uses either a heat-transfer fluid to generate steam to power a steam turbine generator or a molten-salt working fluid that provides superior heat transfer and energy storage capabilities. Power tower plants can be sized from 30 to 200 MWe.[64] Figure 18.

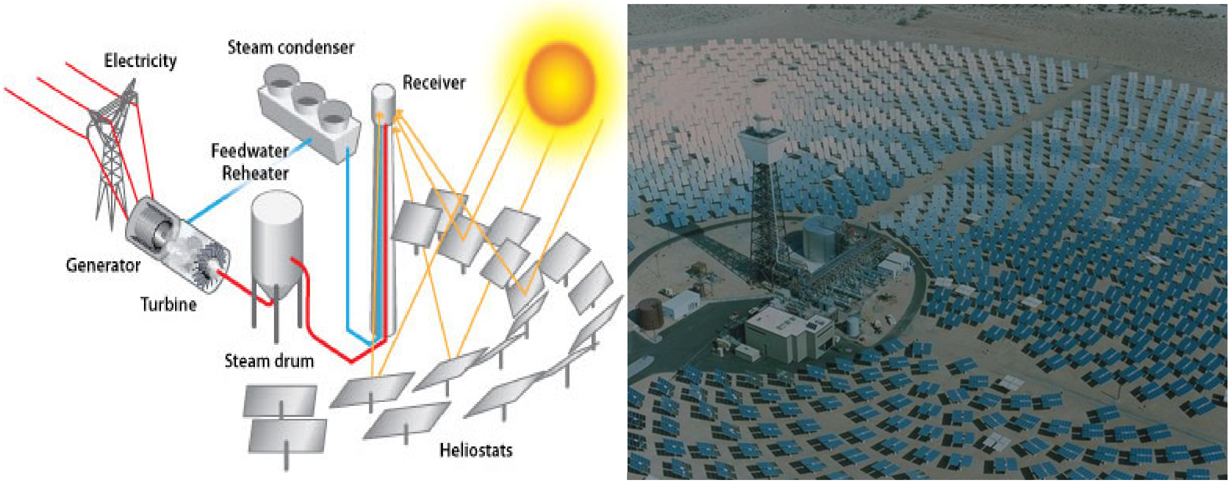


Figure 18. Conceptual drawing (left) and actual photograph of power tower system (right).
Source: U.S. DOE-Solar Energy Technologies Program; Sandia National Laboratories SunLab.

Out of the three CST technologies, the parabolic trough system (PTC) is the most predominant and the most commercially mature CST system. The parabolic trough uses parabolic or U-shaped concentrators to focus sunlight along the focal lines of the collectors where the receiver tube is positioned, and only uni-axial sun tracking. A heated fluid (heat-transfer fluid or water/steam) flows through the receiver tube carrying the collected thermal energy and is typically used to generate steam for powering a traditional steam turbine to generate electric power. Figure 19.

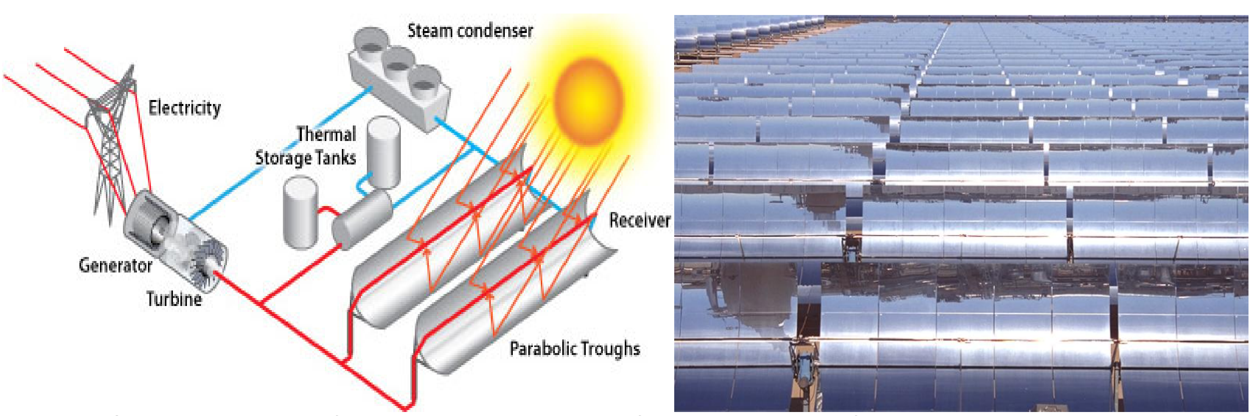


Figure 19. Conceptual drawing of parabolic troughs system (left) and actual photo of parabolic trough collectors (right).
Source: U.S. DOE-Solar Energy Technologies Program; Sandia National Laboratories SunLab.

3.3. Comparison of CST Systems

With three different technologies, CST systems cover a diverse range of scale, capacity, applications, and costs with each combination having its own advantages and disadvantages. Table 20 shows the qualitative differences between the three main CST technologies. Table 21 provides a summary of operating characteristics. Table 22 provides a summary of estimated costs for the three CST technologies.

Table 20. Summary comparison of three different CST technologies

	Dish Engine	**Power Tower**	**Parabolic Trough**
Applications	• Stand-alone, small off-grid power systems • Can be clustered to form larger grid-connected dish parks. • Highest per unit solar capacity in 2005 is 25 kWe	• Grid-connected plants, high temperature process heat • Highest per unit solar capacity in 2005 is 10 MWe with another 10 MWe under construction	• Grid-connected plants, mid to high process heat • Highest per unit solar capacity in 2005 is 80 MWe • Total capacity as of 2005: 354 MW.
Advantages	• Very high conversion efficiency • Peak solar to electrical efficiency can achieve 30% • Modularity • Hybrid operation possible, but not proven • Operational experience on demonstration projects	• Good prospects for high conversion efficiencies with operating potential beyond 1,000C (565C proven at 10MW scale) • Storage at high temperatures • Hybrid operation possible, but not proven	• Commercially available – over 12 billion kWh of operational experience • Operating temperature potential up to 500C (400C proven) • Commercially proven annual net plant solar to net electric efficiency of 14% • Commercially proven investment and operating costs • Modularity • Best land-use factor of all solar technologies • Lowest material demand • Hybrid concept proven • Storage capability
Disadvantages	• Needs improvement in reliability • Projected cost goals of mass production still need to be achieved	• Projected annual performance values, investment and operating costs still needs to be proven commercially	• Use of oil-based heat transfer limits temperature to 400C yielding only moderate steam quality • Long (70km) continuous tubing through the parabolic trough collectors make it susceptible to breakdown interruptions

Source: Aringhoff, Rainer, European Solar Thermal Power Industry Association, IEA SolarPACES Implementing Agreement, and Greenpeace International. *Concentrated Solar Thermal Power - Now!*. Amsterdam: Greenpeace; Brussels; Aguadulce: ESTIA; IEA SolarPACES Implementing Agreement, 2005.

Table 21. Summary of current CST operating characteristics

Operating Characteristics of CST Technologies							
CST technology	**Concentration ratio (times)**	**Operating temperature**	**Unit capacity range**	**Peak efficiency**	**Average solar to electric efficiency**	**Annual Capacity Factor**	**Status**
Dish - Engine	500 - 1000	600 - 1500C	5 - 50 kWe	29%	15 - 30%	25% (p)	Demonstration and testing at 10MWe scale
Power Tower	10 - 100	400 - 600C	30 - 200 MWe	23%	12 - 18%	25 - 70% (p)	Prototypes tested at 25kWe
Parabolic Trough	600 - 3000	100 - 400+C	30 - 100 Mwe	21%	8 - 12%	24% (d)	20 years of opearing experience in Calif

(d) = demonstrated, (p) = projected based on demonstration testing
Source: Kreith, Frank and D. Yogi Goswami. *Handbook of Energy Efficiency and Renewable Energy*. Mechanical Engineering Series; Variation: Mechanical Engineering Series (Boca Raton, Fla.). Boca Raton: CRC Press, 2007.

Table 22. Summary of current cost estimates for different CST technologies

CST technology	Dish - Engine			Power Tower			Parabolic Trough		
	2005	**2010**	**2020**	**2005**	**2010**	**2020**	**2005**	**2010**	**2020**
Levelized Electrictiy Costs USD/kWh	0.15	0.10	0.06	0.06-0.11	0.06-0.07	0.40	0.10	0.05-0.08	0.07
Capital Cost USD/W	5.0	3.2	1.2	2.8-4.1	2.1-3.5	1.1-2.5	2.6-3.6	2.2-2.9	1.4
O&M Costs USD cents / kWh	4.0	1.5	0.9	1.0-1.2	0.4-1.0	0.30	1.0	0.5-.7	0.4
Surface Costs USD/m^2	3000	1500	320	475	265	200	630	315	275
Uncertainty	Moderate			Moderate			Low		

Source: (1) Aabakken, J. and National Renewable Energy Laboratory (U.S.). "Power Technologies Energy Data Book." National Renewable Energy Laboratory. http://purl.access.gpo.gov/GPO/LPS90138; http://purl.access.gpo.gov/GPO/LPS90138;
(2) International Energy Agency. "Renewables for Power Generation: Status & Prospects." OECD/IEA. http://proxy.library.upenn.edu:2635/9264019189; http://proxy.library.upenn.edu:2635/9264019189 (accessed 02/20, 2009).

Though the dish engine may still have much to prove, its small capacity, modular design and significant potential for decrease in capital costs (estimated at 57%) make the dish engine a potential future solution in building a decentralized power infrastructure in China. But in terms of utility-scale electricity generation, the two centralized systems, parabolic trough and power tower, with high power output potential (100s of MWe) and thermal storage and hybridization capabilities (provide power around-the-clock), are best suited for China's large-scale power generation needs.

For China, the choice between power tower and parabolic trough may not be an easy one. While the parabolic trough offers commercially proven experience (operation, efficiency, investments, and returns), lowest material demand, and highest land-use, the 400^{C}+ operating temperature limitation and susceptibility to significant interruption from a single point of breakdown (over 70 km in continuous tubing through the U-shaped collectors) may be the Achilles' heel of the parabolic trough technology. Unless technology innovation overcomes these limitations, some experts argue that the power tower will be the future of CST as it will offer higher solar to electric efficiency at a lower levelized cost of electricity compared to the parabolic troughs.[65]

From a holistic perspective, however, there are good reasons for China to start with parabolic troughs. The trough is at an advanced development stage as witnessed by the U.S. National Renewable Energy Laboratories' focus on parabolic trough technology in the field of CST research and development.[66] The R&D efforts are expected to result in the following:[67] 1) higher efficiency mirrors and improved tracking of the sun to improve solar field conversion efficiency; 2) improvements in heat transfer techniques to overcome the current temperature limitations and improve overall solar to electric conversion efficiency; 3) improvements in mirror cleaning techniques to lower O&M costs; 4) improvements in manufacturing efficiencies and economies of scale for ramp up production to lower overall capital costs; all of which help make parabolic troughs even more economically feasible than they are today. Further, the parabolic trough has become the preferred technology for developers and investors in large-scale CST projects in Europe, United States and Combined Cycle CST projects in Algeria, Egypt, India, Iran, Mexico and Morocco.[68]

Thus, in line with President Hu Jintao's scientific concept of development, China may wish to start the CST development with the commercially mature parabolic trough technology to leverage the knowledge and experience of previous parabolic trough learning while keeping a close eye on power tower advances and developments for future CST expansion.

3.4. Potential of CST in China

The potential for CST implementation in China depends on identifying and analyzing the fit between parameters required of CST systems and China's respective characteristics. While these parameters cover many technological, economic, and environmental variables, the 20 years of commercial operating experience at SEGS power plants in California pinpoints the key CST parameters with the most significant impacts on cost. Specifically, the key parameters identified are: 1) solar resource; 2) land topography; 3) land space; 4) land use, 5) power grid availability and capacity; 7) water availability; and 8) fossil fuel availability (in the case of hybridization). Table 23. These factors are discussed below.

Table 23. Summary of key siting factors

Siting factors	Requirements
Solar Resource	> 1800 kWh/m^2 per yr or 5 kWh/m^2 per day for economical operation
Land Topography	0% to 3% grade as potential. Less than 1% grade most economical
Land Space	5 acres or 20 km^2 per MWe
Land Use	Low biodiversity. Limited productive use.
Grid Availability & Capacity	Close by. Transmission lines costs $50K to $180K per mile for 100 MW capacity
Water Availability	Water required for steam turbine. Dry cooling is an option with 10% increase in cost
Fossil Fuel Availability	Needed for hybridization, but not considered critical
Transportation Infrastructure	Proximity to roads and railways necessary for access and construction

Source: Adapted by author from Cohen, Gilbert, Solargenix Energy, California Energy Commission, and Public Interest Energy Research. Solar Thermal Parabolic Trough Electric Power Plants for Electric Utilities in California PIER Final Project Report. Sacramento, Calif.: California Energy Commission, 2005.

3.4.1. Solar Resource Assessment

Due to the nature of CST technology, only direct un-scattered solar beams or direct normal insolation (DNI) can be used which limits high-quality CST sites to areas characterized as deserts with low levels of atmospheric moisture and other particles, little or no cloud cover, and high levels of year around DNI. Further, the required solar field size for CST is directly proportional to the level of DNI and with the solar field representing about 50% of total project cost, the DNI level will have the greatest impact on overall CST system cost.[69] Given the need for accurate DNI data, this paper references the satellite data from U.S. National Renewable Energy Laboratories (NREL) that provides 40 km resolution direct normal (DNI) GIS dataset with monthly and annual average over a period of seven year (from 1985 to 1992) for China. This dataset uses NREL's Climatological Solar Radiation (CSR) Model which accounts for cloud cover, atmospheric water vapor, trace gases, and aerosol in calculating the insolation with measurements checked against ground stations where available.[70] At the time of this writing, the author is not aware of any solar energy mapping activity by Chinese institutions. As solar resource mapping is an important first step in assessing China's solar potential, developing this capability should be a priority for China.

Note that in an actual solar assessment exercise, the dataset should be of a higher resolution both in the size of grid and time. In addition, a correction factor should be computed across the satellite DNI data based on discrepancies between the satellite and ground measurements. For example, the California SEGS project used a 10 km grid and hourly averages over a five year period and reduced that value by 7% based on two ground measurement cross-checks.[71] But, for the purposes of this paper, the DNI values from NREL will be used as is.

In general, over two-thirds of China's land surface areas receives more than 5.02 x 10^6 kJ/m^2 per year of solar radiation of.[72] In terms of DNI resources, the values range from less than 2 kWh/m^2 per day at the Eastern and Central regions to more than 9 kWh/m^2 per day in the high altitude, arid areas of the Qinghai-Tibetan Plateau. With the assumption that the DNI value needs to be greater than 5 kWh/m^2 per day to make CST economical,[73] the Tibet Autonomous Region, Xinjiang Autonomous Region, central areas of Inner Mongolia Autonomous Region, parts of Qinghai, the western tip of Gansu, and the northwestern border of Sichuan are all potential candidates for CST. Figure 24. However, if the minimal DNI criterion is raised to 6 kWh/m^2 per day[74] (level used by the SEGS CST plants in California), only Tibet, Xinjiang, Inner Mongolia, Qinghai, and some parts of Northeast China would remain as potential areas for CST.

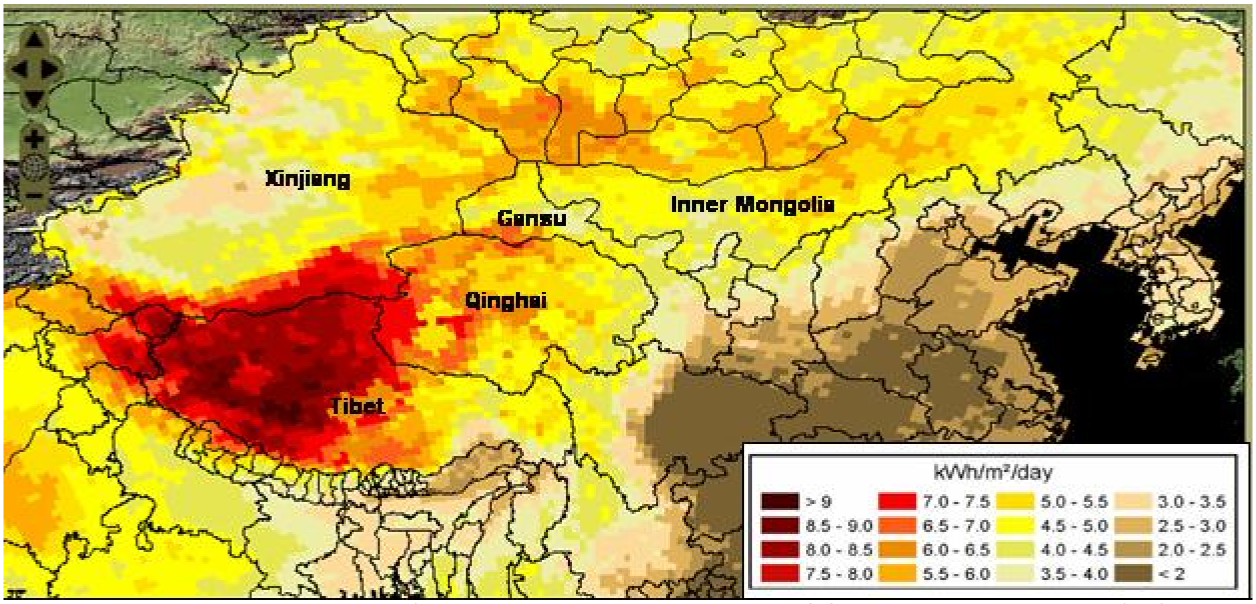


Figure 24. Monthly and annual average (from 1985 to 1992) direct normal (DNI) GIS dataset at 40km resolution for China
SWERA now also has an interactive map tool called RREX that turns this map into an interactive and dynamic solar resource tool. Source: NREL / SWERA. Link: http://na.unep.net/swera_ims/map2/#

3.4.2. Land Assessment

As described above, the need for direct normal insolation, high quality CST sites are limited to desert with low levels of atmospheric moisture and cloud cover, and high levels of direct sun beam year-round. In addition, the land should have minimal value for agricultural or residential use and have minimal biological habitat. In other words, potential sites for CST deployment are in desert regions.

China has about 2.63 million km^2 (27.3% of China's territory) of desert with most of the areas covering northern parts of central China, parts of Northeast China, and most of the Northwest region of China.[75] Tibet, Inner Mongolia and Qinghai alone have about 987,900 km^2 of desert.[76] Coincidentally, these are all areas identified above in the solar assessment as area with high-quality direct solar insolation.

In terms of land space requirement, experts with experience on California's SEGS plants estimate the land space requirement for parabolic trough plants at 20,000 m^2 per 1 MWe or about 1 km^2 per 50 MWe of capacity not including thermal storage and hybridization. Using the DESERTEC perspective of leveraging deserts to fulfill civilization's electricity needs, this means China can match its 2006 total net installed electricity generation capacity of 602,570 GW[77] by utilizing only 12,031 km^2 of its desert area (only 1.2% of the combined desert area of Tibet, Inner Mongolia and Qinghai) with parabolic trough technology.

Of course, not all desert lands are suitable as land topography, geology, and soil quality also need to be considered. In general, lands with less than 3% slope are considered to have potential (3% slope may increase costs of up to 10%) with lands less than 1% slope considered to be the most economical.[78] Other factors that require consideration include flood potential, seismic history, stability of soil, potential obstructions of the sun, and existence of dust or other debris that may degrade the effectiveness of mirror reflectors.[79]

Wind conditions at the site should also be considered in the siting assessments. Since the amount of wind determines the structural design of the collectors and the collector structures represent 40% of the solar field costs, the consideration of wind force is necessary to optimize this decision.[80] As reference, the SEGS plants are designed to operate at less than 35 mph winds and can operate in protected-mode (face down position) in 80 mph winds. But, in all practicality, wind turbines, rather than CST systems should be considered in high wind areas.

Ideally, a rigorous assessment similar to that of the solar assessment should be performed using GIS software to highlight areas that match all the land assessment criteria parameters listed above.

3.4.3. Power Grid Assessment

Access to an electric power transmission line is another crucial factor for site selection. As transmission line costs to connect into the grid are high, the proximity of CST systems to a transmission power grid is an important factor in the overall calculation. Experts estimate that transmission line costs in the United States can range from $50,000 to $180,000 per mile for a 100 MW capacity line depending on voltage level and length of required transmission line.[81] In China, a survey of recently approved grid construction projects suggests a 500kV, 250,000 kVA transmission line costs about $350,000 per mile and a similar line with 750,000 kVA costs around $800,000 per mile.[82] Of course, in addition to line voltage, capacity, and length, line costs will vary depending on the need for substations, transformers, and the difficulty of the terrain. Thus, close proximity to a power grid is critically important to the viability of the CST system.

China's interconnected power grid network consists of different types of power generation stations (hydro, nuclear, thermal), power substations, and transmission lines mainly of the 330kV and 500kV variety. Currently, there are seven inter-provincial power grids (East China, Northeast, Central China, North China, Northwest, Sichuan–Chongqing and South China) and four independent provincial power networks (Shandong, Fujian, Xinjiang and Tibet) operating in mainland China. As of 2003, the Shandong power grid has joined the North China power grid, but has not yet interconnected; the Xinjiang power grid has joined the Northwest power grid, but has not yet interconnected; Tibet remains unconnected to the rest of China's power grid.[83]

Overall, China’s power grid now extends to all cities and most villages throughout China but interconnection between grids are not complete, especially in the Western regions. Figure 25.

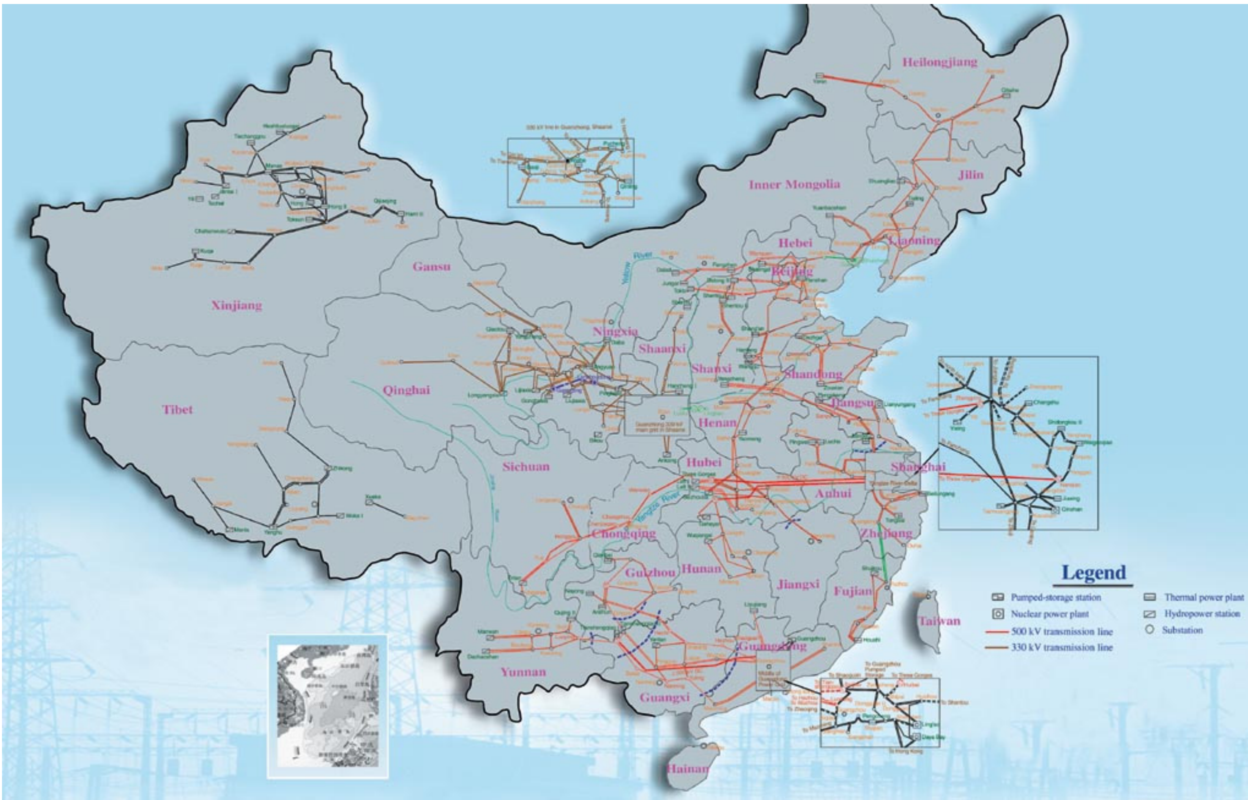


Figure 25. Map of China’s Power Grid (circa 2003)
Source: China State Power. http://www.sp-china.com/powerNetwork/gridmap.htm

Without interconnection to the rest of China, Xinjiang and Tibet are their own isolated “islands”. Unfortunately, these two “island” regions are also the regions with the most potential (in terms of DNI and land slope and use) for CST system implementation. But, if the vision for CST systems to generate electricity in the West and export excess electricity to the East is to be realized, the interconnection between Xinjiang, Tibet and the rest of the country is a mandatory prerequisite.

Driven by China’s current five year plan, China’s grid is constantly updating with newer technology, higher capacity, and increase in new interconnections. As an example of new technology and higher capacity, China, in 2007, awarded Siemens a 300 million euro contract to construct the world's first high-voltage DC transmission (HVDC) system of an 800kV and 5000 MW capacity between Yunnan and Guangdong – a distance that traverse 1400 km (870 miles) of challenging terrain – to be operational by mid-2010.[84] The purpose of this high voltage, high capacity line is to bring the abundant hydroelectric power from Yunnan to power hungry mega cities in Guangzhou and Shenzhen. Proving that seaway barriers can also be conquered, China connected its Hainan Island to the national power grid in March this year (2009) with a 32 km long seabed power transmission cables (500 kV, 600 MW of initial capacity to be doubled when the project is complete) at a cost of 2.5 billion RMB (368 million USD).

Most importantly, from the CST system implementation perspective, China's drive to modernize its power grid will work in CST's favor. Based on the current five year plan, Xinjiang, one of the regions identified with rich DNI solar resources, is expected to complete its 500kV interconnection into the Northwest power grid by 2011 effectively connecting Xinjiang to the rest of China.[85] Tibet, another top ranked region in terms of DNI resources, is expected to be connected to the national grid by 2011. The Qinghai-Tibet power line will traverse 1,100 km of diverse terrain from Goldmud, Qinghai heading westward to Lhasa, Tibet mostly following the route already established by the Qinghai-Tibet railway line and will be the world's first transmission line at plateau altitude of 5,000 meters above sea level.[86] This project, which started in 2009 and is expected to be complete in 2011, will consist of 500 kV of direct current transmission lines with an initial capacity of 750 MW (1500 MW when fully complete) at a cost of over 6 billion RMB

($857M USD).[87] Notably, the purpose of this interconnection is to allow the Northwestern provinces to provide electricity to Tibet during winter and spring season shortages, to meet the demand for the development of local economy, and to allow for surplus electricity to be sold back into the national grid.

In sum, while the most optimal regions for CST may not currently be connected to the national grid, the drive to modernize China's electricity grid through their five year plan (which includes opening up the power transmission sector to foreign investments[88]) will result in a modern, high capacity, nationally integrated power grid network connecting the power hungry mega cities in the East to renewable energy rich regions of the West by 2011. As seen from China's many transmission line projects, the main reason for the interconnections is to optimize electricity allocation – selling surplus electricity from one region to other regions of high power demand. This trend is in line with the vision of this paper and gives added evidence that the time for CST in China is now.

3.4.4. Fossil Fuel and Water Assessment

The primary requirement for fossil fuel is to support hybridized CST plants. As described earlier, CST technology stands out for its ability to provide firm or dispatchable power made possible by the integration of a pure CST plant with a conventional fossil fuel powered generator. While natural gas is the preferred, coal also works with hybridized plants. Hybridized CST plants are valuable in supporting peak demands as well as providing steady power during seasonal changes where the sun may not be as available.

The primary requirement for water in a CST power plant is for cooling, steam cycle (generating electricity), and solar field maintenance (washing the mirrors). The water requirement for solar thermal system ranges between 3 to 3.5 m^3 per kWh[89] with 95% of the water usage in cooling tower and the remaining 5% the water consumption committed to the steam cycle and mirror maintenance.[90] Unfortunately, as described previously, high quality CST sites with high levels of DNI are usually limited to arid and semi-arid deserts where water does not come easily or cheaply. As water-based cooling (cooling via evaporation) is technically considered the most efficient cooling technology available,[91] the cost effectiveness of a CST system with water cooling becomes dependent on the cost of bringing water to the site and more importantly the cost of wasting a precious resource.

The best scenario, then, is for the CST site to be located close to a water source – be it a rivers, lakes, or aqueducts. If those sources prove to be unavailable, the next best locale is a desert with underground water that can be tapped to provide the water needed. For example, two of the SEGS Mojave Desert parabolic trough sites use underground water, and one uses aqueduct water.[92] If no water resources are available or economically feasible, dry cooling can also be considered with a cost and efficiency penalty. Table 25. The dry cooling technology component currently costs about 3.3 times more than water cooling technology and results in an increase in plant electricity cost by 10% or more.[93] Of course, as technology improves, these costs will change. In addition, dry cooling increases parasitic power consumption (from fans) and lowers the overall efficiency of the steam cycle (due to less efficient cooling by dry cooling).[94]

Interestingly, if the desert region considered has saline underground water that needs to be desalinated, building a hybrid dual-purpose plant that uses solar energy as fuel to produce electric power in conjunction with powering water desalination would increase the attractiveness of a CST system. Here, the desalting portion of the plant can use the low temperature reject heat of the electric power plant and thus increase the economic viability significantly and also reduce to some extent the need for cooling the plant.

Table 25. Comparison of dry and wet cooling in terms of costs and efficiency

Cooling	Wet	Dry
Steam Cycle efficiency	37%	35%
Parasitic electricity consumption	5 MW	7 MW
Energy yield	117 GWh	109 GWh
Evaporated water	180 M3 / MW	-
Investment (cooling component only)	4.09M USD	13.54M USD

Source: Al-Soud, Mohammed S. and Eyad S. Hrayshat. "A 50 MW Concentrating Solar Power Plant for Jordan." *Journal of Cleaner Production* 17, no. 6 (4, 2009): 625-635.

The importance of fossil fuel and water assessments, including water costs and cooling options, cannot be overemphasized. These assessments must be considered and optimized with other criteria in order to find the most economically feasible site for CST in China.

3.4.5. Previous Assessments of CST in China

Previous assessments for CST potential in China have identified Inner Mongolia, Xinjiang, and Tibet as potential regions – consistent with this paper's initial analysis based on DNI levels and a large amount of flat, unproductive space. In one early (1997) study by China's Center for Renewable Energy Development, Lhasa was found to be the most suitable site after ruling out most of Tibet due to its harsh, mountainous terrains and glancing over Xinjiang due to its abundant supply of cheap fossil fuel resources and lack of other detailed assessment.[95]

A more recent (2008) study, by Qu Hang et al, [96] identified Lhasa, Xigaze, Qamdo (cities in Tibet), Hohhot, Linhe, Naiman (cities in Inner Mongolia), and Urumqi, Hami, and Kashi (cities in Xinjiang) as potential sites for CST implementation based mainly on DNI resources and diversity in weather conditions. The main purpose of the study was to simulate the efficiency and potential of 35 MW CST parabolic trough plants (modeled after SEGS LS2) under diverse meteorological conditions as represented by these nine sites. The simulation was conducted in the TRNSYS (version 16) environment, STEC model library, and a process flow identical to that of a traditional power plant with the exception of the solar field. Based on the cross-reference of absorptivity assumptions in Qu Hang et al's study and LS-2 specification in Dudley et al's test report[97], the LS-2 collector used in the simulation is identified as the Cermet selective surface type. Description and specification of the solar field collectors LS-2 with Cermet selective surface and overall model flow is presented below. Figure 26a, 26b, and 26c.

Collector type	Collector length/m	Aperture width of SCA/m	Aperture area of single solar collector /m^2
LS-2	47.1	5.0	235

Focal length of SCA/m	Inner diameter of the absorber/m	Outer diameter of the absorber/m
1.49	0.065 5	0.070

Figure 26a. Characteristics of the LS-2 solar collector.
Source: Hang, Qu, Zhao Jun, Yu Xiao, and Cui Junkui. "Prospect of Concentrating Solar Power in China-the Sustainable Future." *Renewable and Sustainable Energy Reviews* 12, no. 9 (12, 2008): 2498-507.

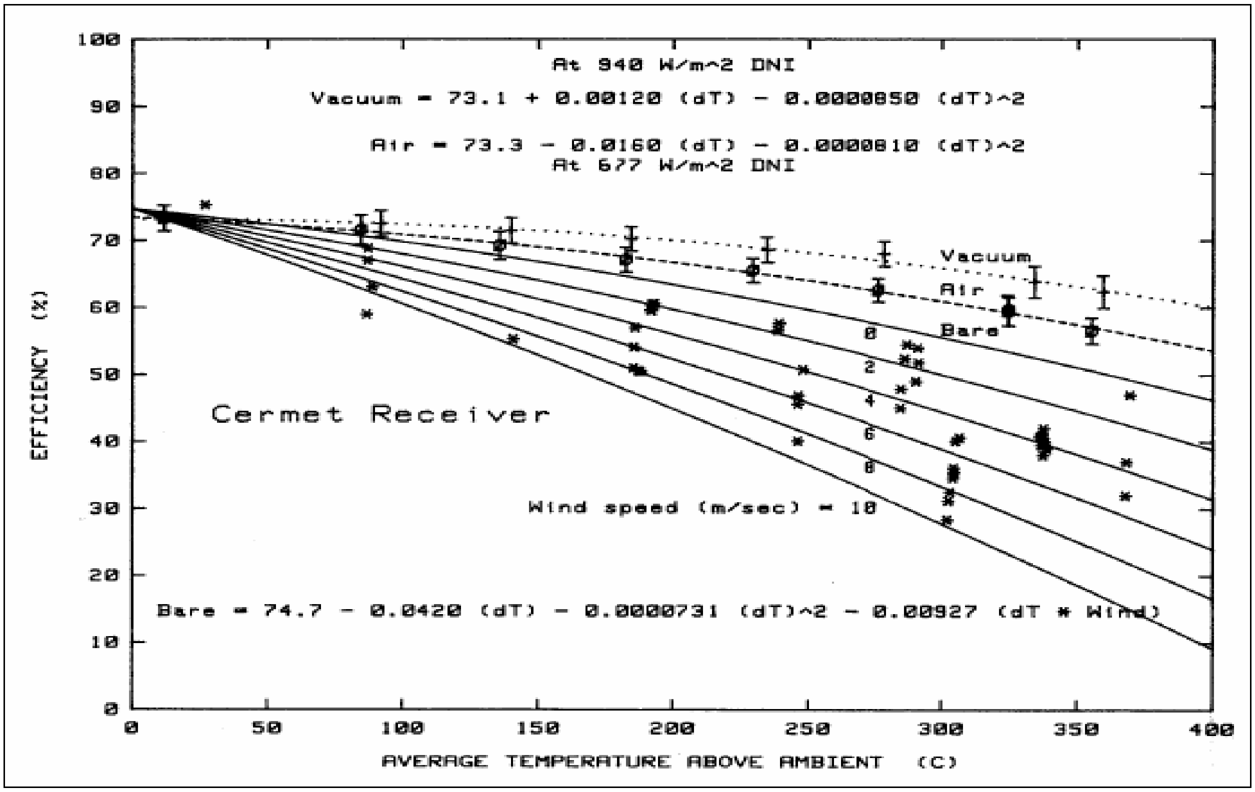


Figure 26b. SEGS LS-2 Efficiency vs. Temperature Above Ambient (dT) and Wind – Cermet Receiver.
Source: Dudley, V., G. Kolb, R. Mahoney, T. Mancini, C. Matthews, M. Sloan, and D. Kearney. *SEGS LS-2 Solar Collector: Test Results*. United States: Sandia National Laboratories, 1994, http://www.nrel.gov/csp/troughnet/pdfs/segs_ls2_solar_collector.pdf (accessed April 2009).

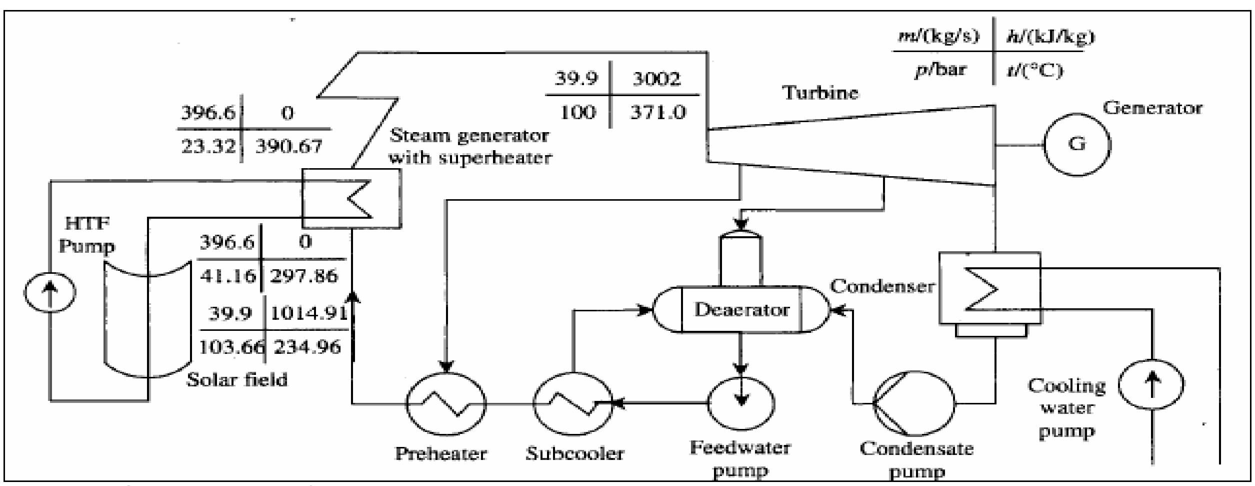


Figure 26c. Simulation model flow.
Source: Hang, Qu, Zhao Jun, Yu Xiao, and Cui Junkui. "Prospect of Concentrating Solar Power in China-the Sustainable Future." *Renewable and Sustainable Energy Reviews* 12, no. 9 (12, 2008): 2498-507.

This study concluded that: 1) based on simulated annual electricity output, the top 3 cities are located in Tibet and Xinjiang region – confirming once again that these regions are high CST potential regions. Figure 26d (left). 2) Low ambient temperatures can negatively affect electricity production even with high solar radiation. Taking Lhasa for example, Figure 26d (right) shows that while solar radiation is high in the month of Nov and Dec, electricity output actually decreased drastically. The study proposes that this is due to the colder temperature during the winter season as shown in Figure 27. The bubble chart demonstrates that high DNI at a low temperature (bubble A) produces significantly less electricity than low DNI at a high temperature (bubble B). On the other hand, with colder temperature, the condenser will operate at a lower temperature, which will raise the overall power generation efficiency and reduces water consumption. Importantly, these contrasting effects should be examined closely when siting CST system in China as the regions with the best solar resources also suffer from the severest temperature. Also, choice of collector tubes that have low heat losses can improve the situation.

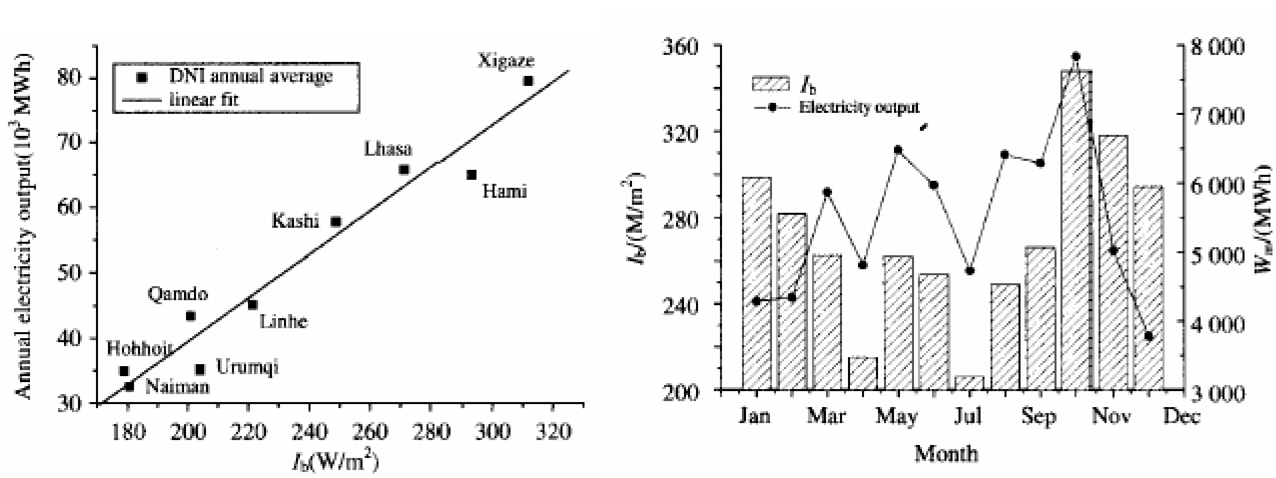
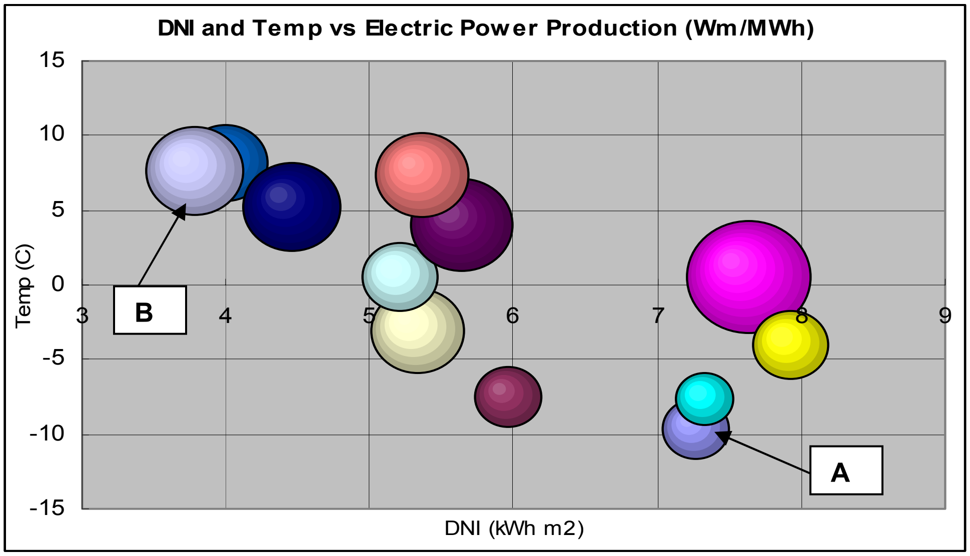


Figure 26d. Relationship between electricity generation and DNI (I) by site (left). Relationship between DNI (I) and electricity output for Lhasa by month (right).
Source: Hang, Qu, Zhao Jun, Yu Xiao, and Cui Junkui. "Prospect of Concentrating Solar Power in China-the Sustainable Future." *Renewable and Sustainable Energy Reviews* 12, no. 9 (12, 2008): 2498-507.



Lhasa	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DNI (kWh m2)	7.26	5.96	5.33	5.21	5.64	5.36	4.00	3.79	4.46	7.63	7.92	7.33
Temp (degree C)	(9.60)	(7.48)	(3.07)	0.53	4.08	7.38	8.20	7.64	5.23	0.59	(3.96)	(7.64)
Elec Output (Wm/MWh)	4,300	4,400	5,900	4,800	6,500	6,000	5,600	6,400	6,300	7,900	5,000	3,800

Figure 27. Graphical representation of the affect of DNI and temperature on electricity output. X-axis is DNI value, Y-axis is temperature value, center of bubble is where x and y crosses, and diameter of bubble represents relative electricity output. Source: Created by author with data from NREL SWERA and Hang, Qu, Zhao Jun, Yu Xiao, and Cui Junkui. "Prospect of Concentrating Solar Power in China-the Sustainable Future." *Renewable and Sustainable Energy Reviews* 12, no. 9 (12, 2008): 2498-507

3.4.6. Improvements to Previous Assessments of CST in China

While the previous assessments selected potential sites for CST and performed simulations that demonstrated the relationships between a site's solar radiation level, temperature, wind, and its electricity production potential, and system efficiency, the report did not explain how these sites were selected. Interestingly, Qu Hang et al's assessment mentioned the importance of considering land slope and land use, but did not incorporate these criteria in selecting the nine sites for simulation. As a result, the lack of site selection explanation leaves many questions unanswered and provides only a partial picture and understanding of the potentialities of these sites.

In order to gain a more holistic understanding of the site selected, this paper builds on the previously selected nine sites and performs additional assessment using the siting criteria described in section 3.4 of this paper. The meteorological data (DNI, temperature, wind speed) were obtained from Solar Wind Energy Resource Assessment (SWERA)[98] using the exact coordinates provided by Qu Hang et al for the nine sites. The electricity output potential data were referenced from Qu Hang et al's report. In addition, the nine sets of coordinates were plotted on a simple, online GIS tool (Google Map) to assess the quality of land space, land slope, water access, transportation infrastructure access, natural gas and water access, and potential proximity to a power grid. Due to the simplicity of the GIS tool, only a qualitative assessment was made for the respective criteria. For example, land slope and land space were estimated using a simple topographic view of Google Maps. Access to water, roadway, and railways were qualitatively assessed based on their distance to the site observed using a satellite view of the map. Natural gas and power grid access information were not available on the GIS tool. As such, access to natural gas and a power grid was assumed available if the site was in or near a big city (e.g. Urumqi). Result of the assessment is presented in Table 28.

Table 28. Comparison of selected sites in China for CST potential

Province	Tibet			Inner Mongolia			Xinjiang		
City	Lhasa	Xigaze	Qamdo	Hohhot	Linhe	Naiman	Urumqi	Hami	Kashi
LAT LONG	29.43N 91.02E	29.15N 88.53E	31.09N 97.10E	40.78N 111.62E	40.83N 107.50E	43.82N 121.30E	43.80N 87.58E	42.80N 93.45E	39.48N 75.97E
DNI Wind Temp Elec output	5.82 6.53 0.16 66	6.31 6.39 -1.41 79	4.95 7.28 -0.33 44	4.97 4.38 3.95 35	4.32 5.7 5.92 45	4.85 4.76 6.62 27	4.87 4.57 4.47 35	4.81 5.28 6.69 65	3 7.41 3.01 58
Slope Water Road/Rail Natural Gas Power Grid	Poor Poor Poor NA NA	Good Poor Good NA NA	Poor Poor Good NA NA	Good Good Good Good Good	Good Good Good NA NA	Good Good Poor NA NA	Good Good Good Good Good	Good Poor Good NA NA	Good Poor Good Good Good
Comments	Spacious, flat land, potential access to water via small river, but far from road or railway. These are not the best coordinates within Lhasa.	Spacious, flat land, over 10 miles from nearest river, close to major road way G318.	Mountainous region, 12 miles away from nearest river and roadway. May be better if located closer to Qamdo city.	Spacious, flat land, near city, river, and major road and railway with high probability to good access to transmission and natural gas grid.	Somewhat spacious, flat, with good access to river and road ways.	Somewhat spacious, flat land, 2 miles from lake and 3 miles from small river, over 20km to major road and railway.	Spacious, flat land, near big city with access to power grid, gas, water, and transporation infrastructure.	Spacious, flat, no water access observed, 10KM away from major road and railways	Spacious, flat, near city with probable access to power grid and natural gas, no observable water access, 2 miles from major road, 4 from major railway.

Note: DNI is kWh/m^2, average wind speed in m/s, average temperature in degree C, electric output in Wm/MWh. Qualitative assessments are categorized into Good, Potential, and Poor. For slope, Good represents less than 100m of altitude change over 2000m of distance otherwise poor. For water and road/rail, good represents less than 5 km from source otherwise poor. Natural gas and power grid information is not available for any of the sites. However, for sites near sizeable cities, access to natural gas and power grid is assumed. Sites tagged on Google Map available at: http://maps.google.com/maps/ms?ie=UTF&msa=0&msid=100156243307106856588.000466fe0a7475f445f7c

Source: (1) Hang, Qu, Zhao Jun, Yu Xiao, and Cui Junkui. "Prospect of Concentrating Solar Power in China-the Sustainable Future." *Renewable and Sustainable Energy Reviews* 12, no. 9 (12, 2008): 2498-507.
(2) Solar and Wind Energy Resource Assessment (SWERA). "SWERA - Renewable Energy Resource EXplorer (RREX)." Solar and Wind Energy Resource Assessment (SWERA). http://na.unep.net/swera_ims/map2/# (accessed 04/06, 2009).;
(3) Google Map satellite and terrain information;
(4) Analysis by author
Google Map satellite and terrain information; Analysis by author.

The result of this analysis suggests the following: 1) the nine sites selected had no discernable pattern in terms of DNI, temperature, wind, land, water, and transportation infrastructure. In other words, it may have been selected solely on the basis of diversity and suggests that there was no systematic approach in selecting these sites; 2) no one perfect site stood out in the list of nine sites. Sites with favorable DNI tended to have poor access to infrastructure. Sites with favorable land, water, and infrastructure access tended to have lower DNI values (< 5 kWh/m2) and low electricity outputs - for example, Hohhot and Urumqi; 3) Tibet and Xinjiang should be highlighted for the amount of electricity generation potential, but note that compared to Xinjiang, Tibet has higher DNI values and lower temperature values.

The limitation of this assessment is that it is anchored to the nine sets of coordinates. For example, the assessment shows that the coordinates for the Lhasa site is not ideal for a CST systems. However, from a high-level satellite view, there are plenty of other coordinates within Lhasa that may be more suitable (higher DNI, closer to water, closer to infrastructures) for a CST system. Thus, while assessments of these nine sites shed valuable insights and support the conclusion that Tibet and Xinjiang have high CST siting potential, assessments should not be limited to these sites. This paper recommends further studies using a more systematic and comprehensive framework and integrated system (see next section) to assess the Tibet and Xinjiang region for CST potentiality.

3.4.7. Framework for Comprehensive Assessment

In general, a comprehensive framework includes all of the above described siting requirements (plus many more) and organizes them in a unified system or model that systematically assesses CST potential and can also act as a decision support system. Two often cited systems are the 1) DLR (German Aerospace Center) developed STEPS system and 2) NREL developed Concentrating Solar Deployment System Model (CSDS). Both systems are similar in their approach to assessment which involves: 1) determining the solar resources available, 2) determining potential sites that are technically suitable, 3) allowing for CST system configurations and simulations (does output meet demand patterns), 4) allowing for financial constraints, and 5) providing economic assessment of

CST systems.

The STEPS system is a good example of the type of comprehensive framework needed for CST assessment which includes meteorological data, geographical data, country specific data (in relation to the economics of the electric power industry), financial and business model data, a simulator for CST plant output and efficiency, and a main module that compiles all the different data together and outputs results that include the determination of all sites principally suitable and classifies these sites by criteria of optimality (site ranking). Figure 29. STEPS utilizes a series of satellites to obtain high resolution (1km x 1km) and high temporal (hourly) irradiance, meteorological, and geographical data which yields a high accuracy reading. In addition, the combination of a high resolution dataset as a base layer and the overlay of industry and economic data will result in a more accurate economic assessment of the project.

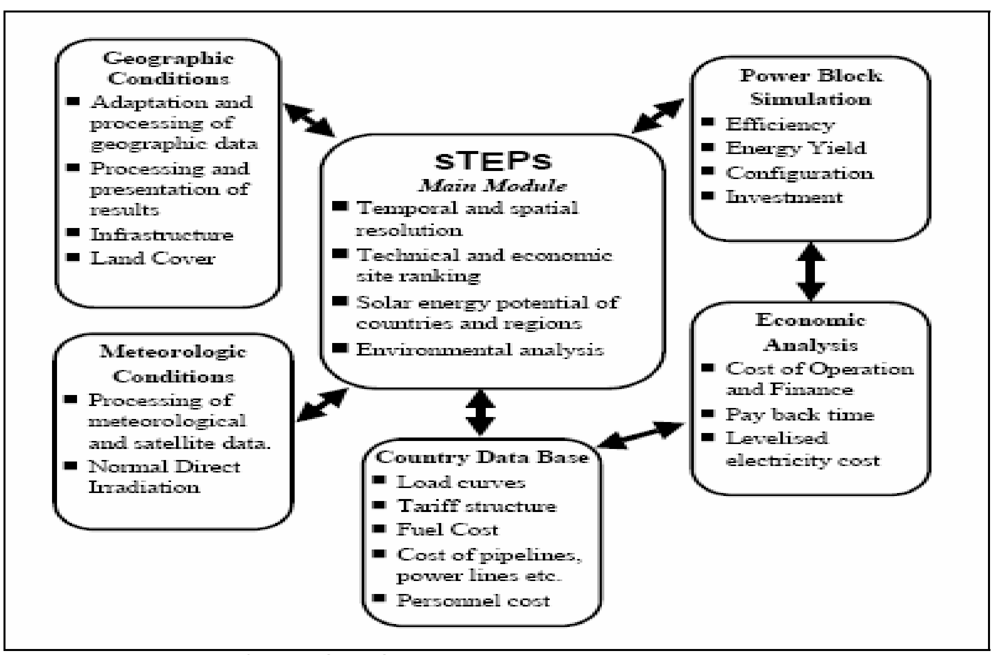


Figure 29. Framework of DRL's STEPS model.
Source: German Aerospace Center (DLR) and Institute of Technical Thermodynamics, Stuttgart (DLR-TT). *Energy-Specific Solar Radiation Data from Meteosat Second Generation (MSG): The Heliosat-3 Project Example Application no.2: Solar Thermal Power Plants*. Europe: European Commission Community Research - Energy, Environment, and Sustainable Development, 2005, http://www.heliosat3.de/documents/Heliosat3_WP_6020_D15.2_Solar_thermal.pdf (accessed April 2009).

For processing and output, Figure 30 presents a sample set of outputs in GIS format with each screen representing a different step of processing. The solar energy resource assessment identifies areas of high DNI. Land resource assessment uses an exclusion template to identify technically feasible areas. Combining the performance results of the simulation, along with other constraints in the system, STEPS can provide site ranking in a GIS map format based on the chosen criteria. In this example, the site ranking is based on levelized electricity cost (LEC).

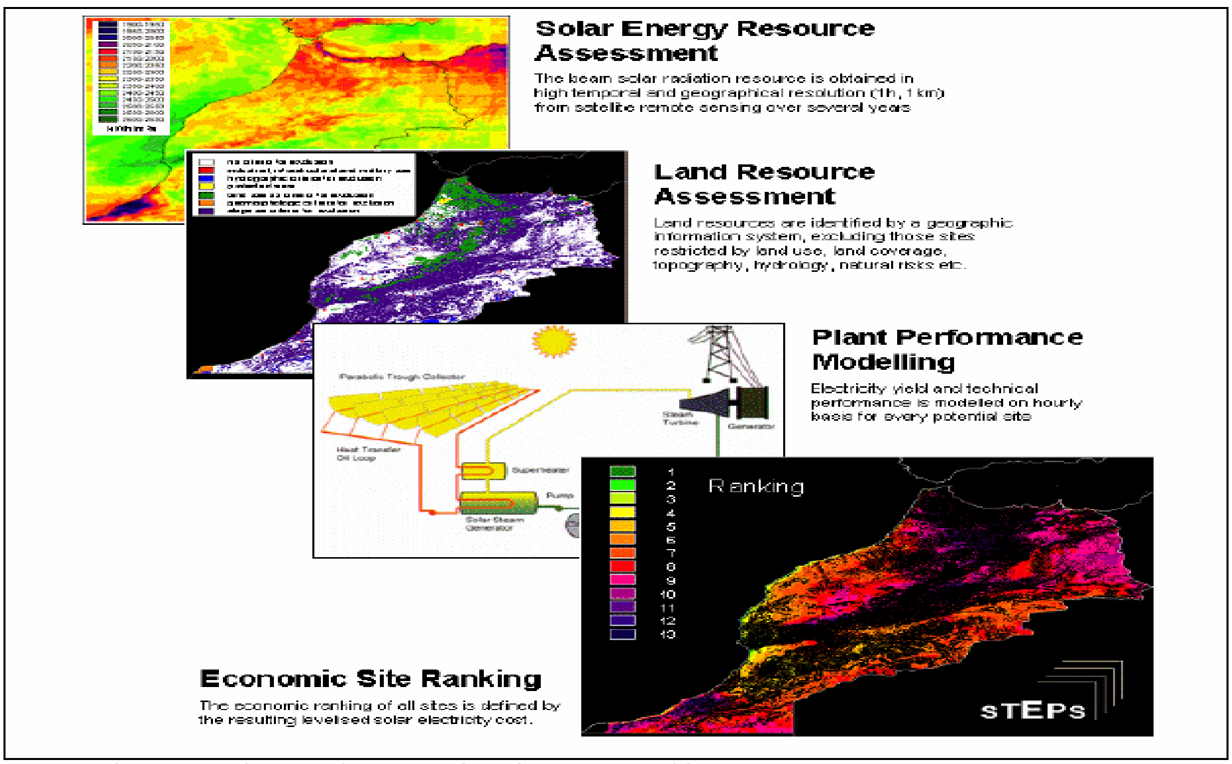


Figure 30. Sample set of outputs from DRL's STEPS in assessing CST potential.
Source: German Aerospace Center (DLR) and Institute of Technical Thermodynamics, Stuttgart (DLR-TT). *Energy-Specific Solar Radiation Data from Meteosat Second Generation (MSG): The Heliosat-3 Project Example Application no.2: Solar Thermal Power Plants*. Europe: European Commission Community Research - Energy, Environment, and Sustainable Development, 2005, http://www.heliosat3.de/documents/Heliosat3_WP_6020_D15.2_Solar_thermal.pdf (accessed April 2009).

The Concentrating Solar Deployment System Model (CSDS) is similar to STEPS in that it is a multiregional, multi time-period, Geographic Information System (GIS) integrated with detailed CST plant simulation. The key feature and perhaps the most significant difference between CSDS and STEPS is that CSDS also incorporates a linear programming component that models the entire electric sector of the U.S. This means, in addition to highlighting potential areas based on the usual constraints, CSDS will also report the optimal level to operate the currently installed capacity, which type(s) of new capacity and how much new capacity will be the most economical to add in each period, in each region.[99]

The main point is that there exist mature approaches, frameworks, systems, and models that assist in helping developers of CST technology to find the most economically feasible site for concentrating solar thermal power plants. STEPS and CSDS are two good examples. These frameworks and systems are publicly and commercially available and can be adapted for China's custom use. China should take advantage of these tools (to use or to reference in developing their own), which represent the cumulative experience and knowledge of CST implementation.

3.5. Regional Impact of CST in China

As seen thus far, CST is a promising source of clean energy for China with Tibet and Xinjiang consistently identified as regions with the most CST potential. CST power plants will not only benefit a region in terms of providing the electric power needed to fuel regional development, but the large capital investment involved in building CST systems will also have socio-economic benefits to the region(s) that host the solar power plant.

While CST technology is currently emerging in many countries of the world in the form of a parabolic trough, power tower, or some combination of CST and traditional power generation technology,[100] China has yet to pursue any significant CST activity (see section 3.6). Thus, to understand the potential regional economic impact that CST could bring to Tibet and Xinjiang, it is helpful to review lessons learned in the countries where CST deployments have been successful. The United States (mainly SEGS) and Spain (Andasol) are the two most developed CST markets and will serve as the basis of our reference.

In general, the overall economic impact can be categorized into direct effects, indirect effects, and induced effects:[101] direct effects are money directly spent by the project in the host region on labor, materials, and equipments (i.e. the total project price); indirect effects are impact of money spent by the project that stimulates secondary economic activities within the host region and creates new flows of purchase and sale from other sectors of the economy. In other words, one dollar spent by the project in the region is re-spent in the region in other sectors of the economy – also called the multiplier effect of each dollar; and induced effects are related to the expansion of private expenditure the consequent change in consumption pattern of goods and services (e.g. food, transportation, health, services, etc.) from workers in the project.

For the United States, a quick search through NREL's document library reveals a large number of economic impact studies performed for various regions in the Southwest including California, Nevada, New Mexico, and Arizona. Table 31 below presents a summary of results of the economic studies for these four regions. The result of the study shows that the per MW economic impact to Nevada, New Mexico, and Arizona is about

$5M per MW of CST capacity. Please note that California's economic impact assessment only applied to a few counties[102] within the state and which thus explains the glaring outlier – an economy 20x that of Nevada, yielding a GSP benefit only 30% higher than Nevada.

Table 31. Estimated economic impact to region for a 100MW CST station.

Impact to Region	California	New Mexico	Nevada	Arizona
Private Investment	$2.8B	$198.9M	Not Estimated	$400M
Gross State Product	$626M	$465M	$482M	$420M
Earnings	$195M	$75M	$406M	Not Estimated
Jobs	3955 job years	2120 jobs	7170 job years	3400 jobs
Taxes	Not Estimated	$246M	Not Estimated	1.3-1.9B over 30yrs
Size of Economy (M USD)	2,312,968	76,178	127,213	387,028

1: Private investment is the amount of capital flow to the region for plant, transmission facilities, ancillary businesses, and infrastructure. Gross State Output is the total value of goods and services produced within the state. Earnings are the value of wages and benefits earned by workers in the region. Jobs include direct and indirect full and part-time jobs. Taxes are impact to state and local government tax receipts. Size of economy is 2007 Gross Domestic Product for the state.
2: Results may not be completely comparable as different economic impact models were used. For example, California used the Regional Input-Output Model, whereas Nevada studies used the Regional Economic Model (REMI) model of the Nevada economy.
3: California only assessed the economic impact in a few of the counties thus result does not reflect the entire state.

Sources:
(1) Stoddard, L. E., Jason Abiecunas, R. O'Connell, Black & Veatch, and National Renewable Energy Laboratory (U.S.). *Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California*. NREL/SR-550-39291 ed. Golden, CO: National Renewable Energy Laboratory, 2006.;
(2) Schwer, R. K., Riddel, M., National Renewable Energy Laboratory (U.S.), (Researcher), United States, Dept. of Energy, (Sponsor), et al. "Potential Economic Impact of Constructing and Operating Solar Power Generation Facilities in Nevada." Washington, D.C: United States. Dept. of Energy; Oak Ridge, Tenn.: distributed by the Office of Scientific and Technical Information, U.S. Dept. of Energy. http://www.nrel.gov/csp/pdfs/35037.pdf. (Maracas 2008);
(3) Bureau of Economic Analysis. "Regional Economic Accounts - Gross Domestic Product by State." Bureau of Economic Analysis an Agency of U.S. Department of Commerce. http://www.bea.gov/regional/gsp/ (accessed 04/06, 2009).

For Spain, the recent study (Dec 2008) by Caldes et al on the economic impact of CST on Spain also provides useful data for our reference. Caldes et al's study employed the Input-Output methodology and fed the model with detailed sectoral break down and capital, operating, maintenance, and labor costs information.[103] The result of the study showed that the per MW of direct economic impact to Spain using parabolic trough and power tower technologies were $12.77M and $20.60M respectively and the total (direct plus indirect) economic impact is $24.5M and $40.3M respectively. This implies a multiplier effect - which represent the amount of total economic benefit received for every

$1 of direct economic impact invested - of 1.92 and 1.96 respectively. Table 32.

Table 32. Estimated economic impact to Spain for CST implementation.

	Parabolic Trough 50MW	Power Tower 17MW	Parabolic Trough per MW	Power Tower per MW
Impact to GRP				
Direct	$638	$350	$12.77	$20.60
Indirect	$586	$336	$11.72	$19.74
Total	$1,224	$686	$24.48	$40.34
Impact to Employment				
Direct	5,554	3,213	111	189
Indirect	4,030	2,278	81	134
Total	9,584	5,491	192	323

Gross Regional Product (GRP) figure in millions USD. Exchange rate used is 1USD to 1.3163Euro. Spain's size of economy is 1,683,000 million in 2008 nominal or 1,337,000 million in 2006 PPP.
Source:
(1) Caldés, N., M. Varela, M. Santamaría, and R. Sáez. "Economic Impact of Solar Thermal Electricity Deployment in Spain." *Energy Policy* In Press, Corrected Proof;
(2) Central Intelligence Agency (CIA). "The World Factbook." Central Intelligence Agency (CIA). https://www.cia.gov/library/publications/the-world-factbook/index.html (accessed 04/06, 2009).

While the results from the U.S. and Spain are not directly comparable (since economic impact depends on the size, structure, and interconnection of different sectors in the economy), a simple comparison accounting for the size of the economy can provide a rough idea of the degree of economic benefit expected for Tibet and Xinjiang. Excluding California from the comparison and taking the average of Spain's impact with parabolic trough and power tower technologies, the potential economic impact for China can range from $5M to $30M of additional GDP per MW of CST capacity installed depending on the region of CST deployment. For regional comparison, Xinjiang is approximately the same size as New Mexico,[104] based solely on GDP, which suggest that Xinjiang may be able to enjoy $465M of additional GDP or $22.20 of additional per capita GDP[105] if a 100 MW capacity CST is implemented. For Tibet, even using the most conservative estimate of $5M per MW of capacity, building a 50MW CST plant could increase Tibet's GDP by 4% (3% via 2006 PPP).[106]

Ideally, an economic impact assessment with a rigorous methodology similar to that employed by the United States and Spain should be undertaken for China to obtain a more robust assessment of the impact of CST. Importantly, it is also necessary to consider who will benefit from the positive regional economic impacts – the indigenous people or Han corporations from the Coastal regions. It is also crucial to consider the social aspect of the change that CST might bring. Consideration should be given to the indigenous population and their wiliness to change their life style in pursuit of higher standard of living. For example, would farmers and herders be willing to give up their agricultural based lifestyle to become solar engineers.

In addition to modeling, the economic impact assessment should also take into account the current economic profiles of Tibet and Xinjiang and explore the potential of economic captive effects of a CST deployment in this region. For example, Xinjiang is rich in natural resources (minerals, oil, and natural gas) and advantageously located to trade with eight neighboring countries which positions Xinjiang as a major economic growth driver in China's Western region.[107] Rather than solely relying on the sale or export of its natural resource for income, Xinjiang has the potential to move up the value chain and expand its economy by attracting and captivating energy-intensive industries (mining, refining, and chemical) to the region with CST produced electricity thereby further developing Xinjiang's economic base.

In addition to using CST as an anchor to attract industries to the region, the impact of Xinjiang, Tibet, or other parts of China playing a leadership role in CST component manufacturing can also be explored. China is already a world leader in terms of solar thermal heating (size of market and manufacturing capability) and is currently a significant player in solar PV manufacturing. If the transition from solar thermal heating and solar PV to concentrating solar thermal components is possible, CST deployments could be the catalyst needed to give China's government and China's solar industry a unique opportunity to take a leadership position in CST.

3.6. CST Projects and Activities in China

CST technology is currently emerging in many countries of the world in the form of the parabolic trough, power tower, or some combination of CST and traditional power generation technology.[108] China has yet to have any significant CST activity. Currently, there are two demonstration projects and one joint development company in Inner Mongolia looking at the feasibility of CST. In 2005, the first demonstration CST power tower with 75kW capacity was built (and grid-connected) in Nanjing by the Israeli company EDIG Solar – now Aora Solar. By December 2010, a 1MW power tower demonstration projected called DAHAN is expected to go online in the Yanqing district of Beijing becoming the second power tower demonstration project in China. This project is funded by the Ministry of Science and Technology and the Beijing Municipal Science and Technology Commission with the purpose of learning and testing various components of the power tower technology.[109] Promisingly, Solar Millennium, the European leader in CST parabolic trough technology and the proud developer of the world's largest parabolic trough project (Andasol), established a project development company in Hohhot, Inner Mongolia in August 2007. This joint-venture has recently concluded feasibility studies on a 50MW size parabolic trough power plant for the region and is currently presenting the Chinese government with a concrete offer and implementation plan.[110]

3.7. Economics for CST in China

3.7.1. Levelized Electricity Cost – The Yardstick

Levelized electricity cost (LEC)[111] is the cost of producing electricity for a particular system or technology and is often the measuring stick used when comparing different electricity producing technologies. LEC evaluation considers two major components: 1) it considers all costs associated with the investment of a particular technology and takes into account the time-value of money by standardizing the analysis using present value; 2) it considers at what price (today) a unit of electricity generated must be sold for to ensure that all costs (across project lifetime) will be covered. Thus, LEC is the minimum price that the electricity must be sold at for an energy project to break even or the price per unit of electricity that will make the technology a zero NPV project. Below is the equation form of LEC:

$$LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t + O_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

LEC = Average life time levelized electricity generation cost
I_t = Investment expenditures in the year t
M_t = Operations and maintenance expenditures in the year t
F_t = Fuel expenditures in the year t
O_t = Other incomes or expenditures in the year t
E_t = Electricity generation in the year t
r = Discount rate used
n = Estimated life of the system

The strength of LEC is its ability to include all the costs over the lifetime of the project including initial investment, operations and maintenance (O&M), insurance, cost of fuel, cost of capital, expected return, and, if so desired, even tax, subsidy, carbon cost, or other monetized environmental effect can be included under the O_t term. The weakness of the LEC is the flexibility to include virtually any cost element associated with the project into the assessment. Thus, understanding exactly which elements are included in an LEC evaluation is critical when making comparisons between systems using LEC. With the usual project life extending between 20 and 40 years, all future parameters are questionable and present value calculations are highly sensitive to the discount rate used (which is affected by cost of capital and financing mix). Thus, reasonable scenarios should be calculated to try to bound the result.

3.7.2. Drivers of CST Economics

If levelized electricity cost is the primary yardstick used by the world to determine CST's economic feasibility, then it is worthwhile to take a look at the drivers of LEC. Recall the equation for LEC from section 3.7.1, LEC is driven by I+M+F+O (IMFO costs), E - amount of electricity it can generate, and r – the discount rate applied. Decomposing these three elements further reveals a clearer picture showing the activities and factors that drives the LEC. Figure 35.

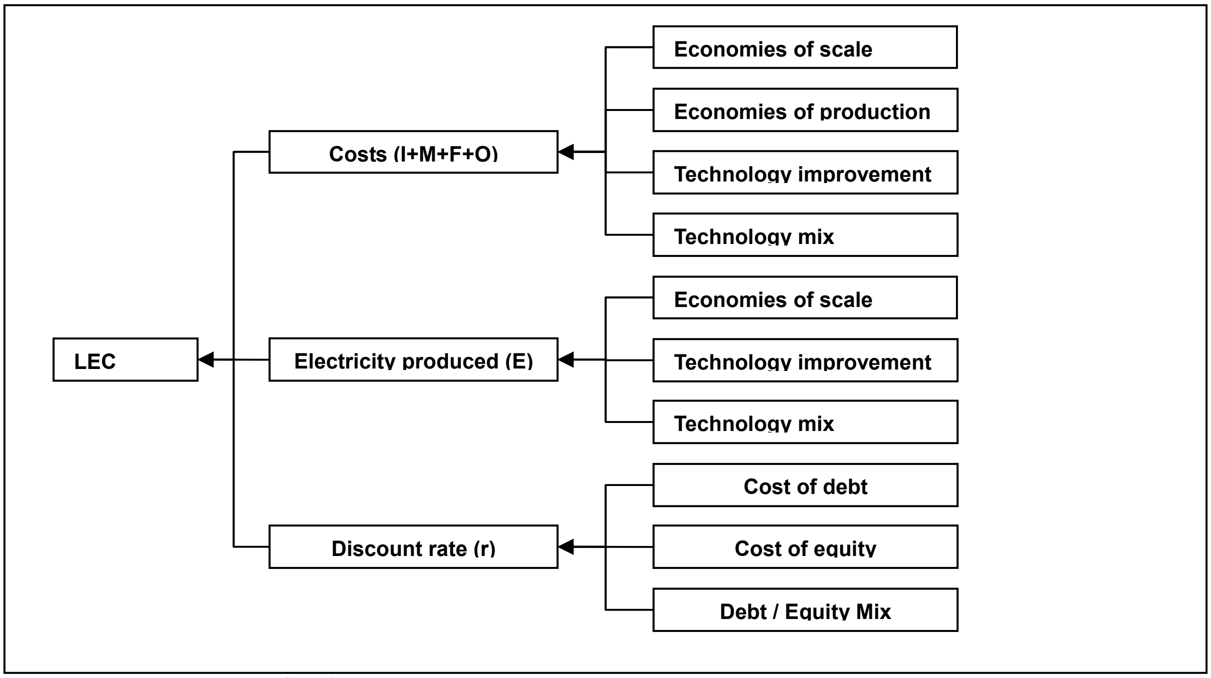


Figure 35. Activity drivers of LEC

Based on the figure above, improvements in economies of scale, economies of production, and technology all drive down the costs of CST. For electricity production (E), economies of scale, technology improvement, and technology mix are significant drivers. For discount rate (r), the cost of debt, cost of equity, and the capital structure used to finance the project will have a direct impact.

Economies of scale refer to effects achieved through having large CST plants. For example, larger CST plants will require a larger number of components (e.g. mirrors, collectors, tubes, etc) and thus through large-scale manufacturing lower per unit costs of these components. In addition, to components, the large scale CST will also benefit from decreasing per unit costs of capital intensive components (e.g. electric power generating system, other auxiliary systems), [112] non-recurring charges (e.g. feasibility studies, one-time grid connection, infrastructure work, and other fixed overhead), and O&M labor savings. Furthermore, studies show that larger the CST plant, specifically the size of the solar collector field, the more electricity it can produce.[113] Thus, all things equal, economies of scale not only lower the numerator, but can also increase the denominator of the LEC equation yielding a lower LEC.

Economies of production refer to the number of CST deployed regardless of the size. So, all things equal, a larger number of CST plants will also yield lower cost components through large scale manufacturing of the components, but unlike economies of scale, there will be no other costs or electricity generation benefits associated with economies of production. Thus, all things equal, economies of production will only lower the numerator of the LEC equation.

Technology improvements refer to the continued innovation of CST technology through R&D and real-life implementation learning. Innovations can be in the form of efficiency (e.g. a higher temperature limit on heating fluid) which will allow for greater electricity yield per unit of investment. Innovations can also be in the form of cost reduction (e.g. an improved manufacturing technique that lowers cost or a better material for solar collectors). Thus, all things equal, technology improvements will lower the numerator and increase the denominator of the equation yielding a lower LEC.

Technology mix refers to the type of CST technology and subsystems chosen for the CST implementation. For example, adding a thermal storage subsystem allows surplus energy to be stored during the day and time-shifted to produce electricity during hours where solar energy is not available. Effectively, thermal storage extends the number of hours per day that the CST plant can produce electricity. Of course, the thermal storage subsystem will increase the overall cost of the system, but experts believe that the additional amount of electricity generated will more than compensate and thus lower the overall LEC of CST.[114]

Cost of debt and cost of equity refer to the financial costs of obtaining debt and equity capital. Cost of debt is the interest rate charged by the lender for the amount borrowed to finance the project. There are well-established debt rating systems and agencies (Moody, Standard and Poor) that can be used as proxies for estimating the cost of debt. Cost of equity is the rate of return required by equity participants of the project. This rate of return is usually the risk-free rate plus a required risk premium demanded by equity investors. Since the discount rate is the weighted average of both cost of debt and equity, the interest rate on debt, return demanded on equity investment, and capital structure of the project combined will all impact the LEC. Specifically, a lower discount rate will yield a lower LEC and vice versa for a higher discount rate.

Thus, the cost of CST produced electricity is dependent on many factors including overall costs, electricity producing potential, and financing decisions. Through decomposition, the activity drivers of these factors are identified and can help in highlighting the path toward an economically competitive CST system.

3.7.3. Nominal and True Cost of Electricity Production (LEC Comparison)

To get an idea of how LEC compares to CST and other electricity generating technologies (both conventional and renewable), Table 33 below (mainly from Sovacool's compilation[115]) presents the average nominal LEC for each technology. Specifically, Sovacool referenced Michael Karmis et al's study[116] for biomass, nuclear, onshore wind, IGCC, scrubbed goal, advanced gas and oil combined-cycle, gas and oil combined-cycle, IGCC with carbon capture, advanced gas and oil combined-cycle with carbon capture, advanced combustion turbine, combustion turbine, and solar PV data.

Table 33. Nominal 2007 Levelized Electricity Costs

Rank	Electricity Generation Technology	Nominal LEC, $2007 (¢/kWh)	% +more/-less expensive CST is to the other technologies
1	Biomass (Landfill Gas)	4.1	230%
2	Advanced Nuclear	4.9	176%
3	Onshore Wind	5.6	141%
4	Hydroelectric	6.0	124%
5	Geothermal	6.4	111%
6	Integrated Gasification Combined-Cycle (CC)	6.7	102%
7	Biomass (Combustion)	6.9	96%
8	Scrubbed Coal	7.2	88%
9	Advanced Gas and Oil Combined-Cycle	8.2	65%
10	Gas Oil Combined-Cycle	8.5	59%
11	Adv Gas and Oil CC with Carbon Capture	12.8	6%
12	Solar CST (parabolic trough)	13.5	0%
13	Advanced Combustion Turbine	32.5	-58%
14	Combustion Turbine	35.6	-62%
15	Solar Photovoltaic (panel)	39.0	-65%

Source: (1) Sovacool, Benjamin K. "Renewable Energy: Economically Sound, Politically Difficult." *The Electricity Journal* 21, no. 5 (6, 2008): 18-29.; (2) Badr, Magdy, Benjamin, Richard, United States, Dept. of Energy, (Sponsor), United States, Dept. of Energy, et al. "Staff Final Report. Comparative Cost of California Central Station Electricity Generation Technologies." Washington, D.C. : United States. Dept. of Energy ; Oak Ridge, Tenn. : distributed by the Office of Scientific and Technical Information, U.S. Dept. of Energy. http://www.energy.ca.gov/reports/2003-06-06_100-03-001F.PDF.

These estimates assume a 25-year system life; All federal tax incentives and credits as of 2007; accelerated depreciation with half-year convention (MACRS); a discount rate of 7.0 percent; current costs and capacity factors (no cost and performance improvements over time); inflation rate of 2.5 percent per year; fixed and variable operations and maintenance costs escalated at the inflation rate; capital costs associated with the connection of centralized systems to the electricity grid are not included; fixed and variables costs associated with electricity distribution and transmission are not included. For detailed assumptions, please refer to Michael Karmis et al's study.

For Geothermal, Sovacool's reference ultimately points to California Energy Commission's Final Staff Report on the comparative costs of California's electricity generation technologies (CEC 2003).[117] This report provided estimates for two types of geothermal technology (binary and flash) which Sovacool averaged and adjusted from 2002 base dollar to 2007. The main assumptions used by CEC 2003 report include 30 year system life, loan term of 12 years, inflation of 2%, Federal depreciation using MACRS 5 years, State depreciation using full system life, with investment tax credit, debt-equity ratio of 2.02, and a discount rate (weighted average cost of capital) of 10.8%. Capital costs associated with the connection of centralized systems to the electricity grid and fixed and variables costs associated with electricity distribution and transmission are not included. Detailed assumptions on both geothermal technologies can be found on Appendix J & K of the CEC 2003 report.

For hydro power and solar thermal technology, Sovacool's references did not provide the assumptions behind the estimates used in Sovacool's paper. In light of CEC 2003's comprehensive assumptions used, this paper will use the LEC estimate of hydro power and solar thermal technology from CEC 2003. Main assumptions are the same as ones described above. Detailed assumptions for hydro power can be found on Appendix L of the CEC 2003 report. Detailed assumptions for solar thermal (parabolic with gas) can be found on Appendix O of the CEC 2003 report.

Based on this ranking, CST parabolic trough is ranked at 12th place at 13.5 cents per kWh electricity. Compared to renewables sources with major focus in China's plan, CST is 124% more expensive than hydroelectric, 141% more expensive than onshore wind, and 230% more expensive than biomass. Compared to non-renewable sources with a significant influence in China, CST is 176% more expensive than nuclear. Compared to China's dominant technology of electricity generation, CST is about 194% more expensive than coal-fired power plants located in Xinjiang (not listed in table) which have a cost of electricity of 4.6 cents per kWh.[118] Thus, based on this ranking alone, the economics of CST seems LEC challenged in China.

However, some experts argue that nominal LEC does not represent the true cost of producing electricity. Different technologies will have different environmental impacts during the time of plant construction and over the lifetime of plant operation and as such, these environmental externalities must be priced in as well. These externalities can include GHG emissions, solid waste, toxic wastes, emissions of mercury, other noxious pollutants, and even social inequity (e.g. Three Gorges dam). Because the pricing of externalities can result in a wide range of values depending on the assumptions used, it is useful to look at Sundqvist's study[119] on the disparity of externality estimates to 1) understand some causes of these disparities and 2) get a better feel for the range of the data by looking at Sundqvist's aggregated study.

Applying statistical analysis to 38 studies and 132 estimates of electricity externalities, Sundqvist's results indicate that the methodology used (e.g. abatement cost approach, damage cost approach top-down, damage cost approach bottom-up) and the fuel stages used (i.e. whether the individual studies have addressed the full fuel cycle or not) have statistical significance (at the 1% level) with the disparity of externality estimates. Specifically, the results show that the bottom-up approach produces the lowest external cost estimates compared to abatement and top-down and studies using full fuel cycle produces higher estimates than studies using just generation. See Table

34a for complete descriptive statistics. While Sundqvist is the first to admit that his analysis is not sufficient to explain all the variability in externality estimates, his study provides good insight into the some of the explanatory variables in the disparity.

Table 34a. Descriptive statistics of electricity externality studies in 1998 dollar

(US cents/kWh)	Coal	Oil	Gas	Nuclear	Hydro	Wind	Solar	Biomass
Min	0.0600	0.0300	0.0030	0.0003	0.0200	0.0000	0.0000	0.0000
Max	72.42	39.93	13.22	64.45	26.26	0.80	1.69	22.09
Mean	14.87	13.57	5.02	8.63	3.84	0.29	0.69	5.20
SD	16.89	12.51	4.73	18.62	8.40	0.20	0.57	6.11
N	29	15	24	16	11	14	7	16

SD = standard deviation; N = sample size
Source: Sundqvist, Thomas. "What Causes the Disparity of Electricity Externality Estimates?" Energy Policy 32, no. 15 (10, 2004): 1753-1766.

With the large standard deviations, it is hard to pinpoint with certainty the best externality estimate to use. However, taking Sundqvist data at the aggregated level and using the MIN and MAX to define the range, it may be reasonable to assume that the correct externality estimate lies somewhere in between. For purpose of comparison, Sovacool's study used the mean value (averaged across studies) of the externality cost for each technology and added them to the nominal LEC to obtain what he called the true LEC.[120] Table 34b.

Table 34b. True Cost of Generating Electricity. Nominal + Externality = True LEC (2007)

Rank	Electricity Generation Technology	Nominal LCOE, $2007 (¢/kWh)	Nominal External Cost, $2007 (¢/kWh)	True Cost, $2007 (¢ /kWh)	% +more/-less expensive CST is to the other technologies
1	Onshore Wind	5.6	0.4	6.0	140%
2	Geothermal	6.4	0.7	7.1	103%
3	Biomass (Landfill Gas)	4.1	6.7	10.8	34%
4	Hydroelectric	6.0	4.9	11.0	31%
5	Biomass (Combustion)	6.9	6.7	13.6	6%
6	Solar CST (parabolic trough)	13.5	0.9	14.4	0%
7	Advanced Nuclear	4.9	11.1	16.0	-10%
8	Advanced Gas and Oil Combined-Cycle	8.2	12.0	20.2	-29%
9	Gas Oil Combined-Cycle	8.5	12.0	20.5	-30%
10	Adv Gas and Oil CC with Carbon Capture	12.8	12.0	24.8	-42%
11	Integrated Gasification Combined-Cycle	6.7	19.1	25.8	-44%
12	Scrubbed Coal	7.2	19.1	26.3	-45%
13	Advanced Combustion Turbine	32.5	6.5	39.0	-63%
14	Solar Photovoltaic (panel)	39.0	0.9	39.9	-64%
15	Combustion Turbine	35.6	6.5	42.1	-66%

Source: Sovacool, Benjamin K. "Renewable Energy: Economically Sound, Politically Difficult." The Electricity Journal 21, no. 5 (6, 2008): 18-29.

Based on this calculation and ranked by true LEC, CST moves up six places to number 6 with LEC of 14.4 cents per kWh. Compared to renewable sources with major focus in China's plan, CST is now only 31% more expensive than hydroelectric, 140% more expensive than onshore wind (about the same as nominal), and now 34% more expensive than biomass. Compared to the non-renewable sources with a significant influence in China, CST is now 10% cheaper than nuclear. Compared to scrubbed coal, a cleaner version of China's dominant coal-fired electricity, CST is 45% cheaper. Notably, hydro electricity externalities in the above table most likely did not include the social disturbance of large scale resettlement and environmental damages such as reduced biodiversity, degradation of water quality, fragmentation of the ecosystem, land erosion, and other geological damages. If accounted for, these externalities would raise the true cost of hydro generated electricity and in turn, make it more expensive than CST technology. In sum, when costs of externalities are included in the calculation of true costs, CST becomes a very competitive electricity generation alternative.

3.7.4. Predicting CST's Future with Experience Curve

Including the cost of externalities is not the only way to make CST competitive. The experience curve for CST suggests that continued market expansion of CST technology can also make CST economically competitive. The experience curve incorporates the effects of economies of scale, economies of production, and technology and summarizes the effects as the relationship between historical cumulative production versus the price variation (usually decrease).[121] As California (SEGS) has the longest operating history in the world with CST technology, the experience curve from SEGS has the potential to provide a reasonable roadmap to CST's future. Figure 36.

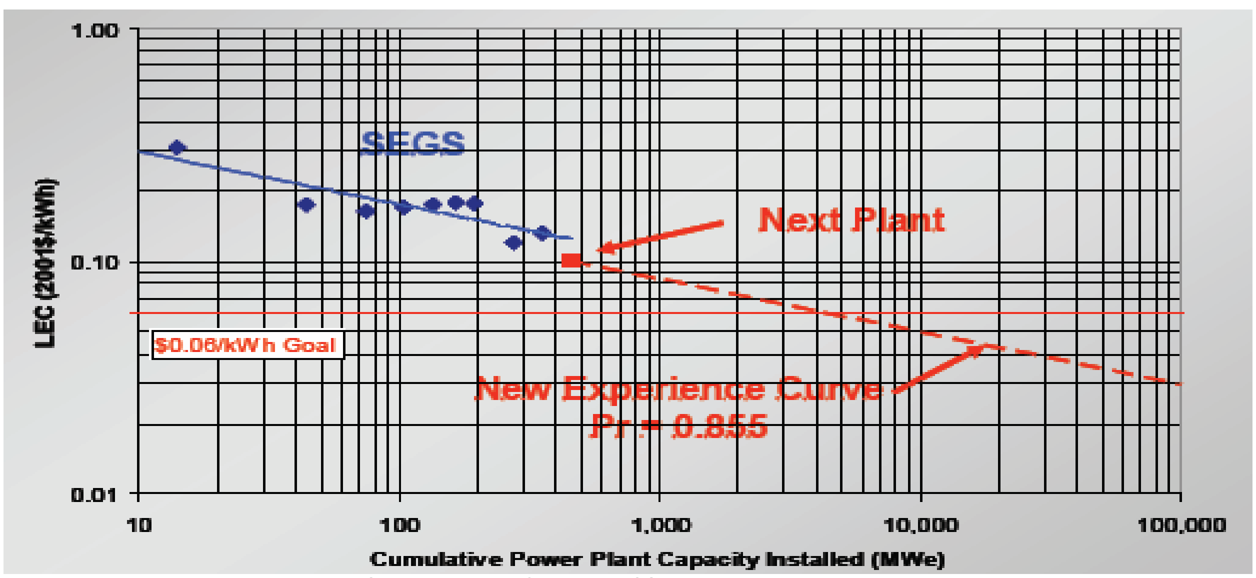


Figure 36. Relationship between LEC and amount of installed CST capacity
Source: (Cohen et al. 2005)

Figure 36 shows the relationship between LEC and the cumulative installed CST capacity. As the historical experience curve (in blue) shows, the LEC of CST plants started around 30 cents per kWh and steadily decreased to around 13 cents per kWh once 400MWe capacity was installed. The decreasing cost trend represents the maturation of the technology as more CST capacity is built and comes online. In addition, the extrapolated new learning curve (in red) suggests the LEC will continue to decrease as CST capacity continues to expand. For example, the next CST project is expected to have a LEC of 10 cents per kWh. At about the 4,000 MWe of capacity, the curve suggests that the LEC for CST will be around 5 cents per kWh which would be competitive on a nominal basis with the cost of coal-fired electricity in Xinjiang. The law of diminishing return is evident in the new curve as it takes significantly more installed capacity to lower the same amount of LEC. This can be explained by the notion that the "low hanging fruits" have been picked early on and the remaining obstacles are the toughest ones to tackle. However, it is important to note that there could be step functions in the curves if major technology improvements are attained.

While SEGS experts readily admit that the new experience curve currently lacks the support of empirical evidence,[122] the trend, nonetheless, suggests that there is a huge potential for CST cost reduction. If the IEA outlook of 20,150 MWe of installed CST in 2020 is correct, then based on this curve, a very competitive LEC of around 4 cents per kWh can be realized. Thus, the CST technology will be able to compete with traditional peak and base load, fossil fuel based electric power within ten years.[123]

3.8. The Path to CST Commercialization in China

Although the CST potential for commercialization is high, the current nominal levelized cost of electricity from CST is still 100% higher than conventional coal-fired generation. To realize a cost that is competitive with China's coal-fired electricity, CST will need to develop rapidly to unleash the benefits of the experience curve. In the immediate term, this can only happen with the government's public policy support. While China's Ministry of Science and Technology has identified CST as an important research area in the Summary of National Mid & Long-Range Science and Technology Development Plan (2006-2020)[124], against the backdrop of other renewable alternatives, CST is inadequately considered in China and more should be done to push this technology forward.

Jun Li's paper, titled "Scaling up concentrating solar thermal technology in China" suggests the best way forward is through a holistic approach of 1) harnessing of current intra-China technology; 2) creating an environment for the innovation and diffusion of CST technology; 3) articulating a concrete renewable energy policy portfolio; and 4) creating government supported financing packages.[125] While these are all well-meaning and reasonable words, solid quantitative support is required for the strategy to have real impact.

Harnessing the current technology available in China means to leverage China's leadership in solar thermal and advanced development in solar PV for scaling up in CST component technology. As discussed previously, one of the regional economic benefits that CST can bring is the opportunity for China (or specific region) to take on a leadership role in the CST technology niche. In terms of the LEC drivers, harnessing China's solar thermal and solar PV capabilities is a way to speed through the experience curve.

Moreover, the Chinese government, through policies, should encourage not just R&D in a particular area of CST, but "embrace the innovation in the whole supply chain".[126] Some possible policies include: indicating credible government commitment to investments in CST, funding for commercial-scale demonstration projects, and investing in solar technology education. In terms of LEC drivers, these policies will accelerate technology improvements (improve efficiency, lowering cost) and lower the LEC of CST as a faster rate. For this to happen, the government must obtain a solid quantitative analysis showing how money should be spent relative to other alternatives. Of course, governments don't necessarily have to follow such recommendations as they can do things purely based on political reasons.

Also, as proven in the developed countries such as the United States and Spain, a comprehensive renewable energy policy is needed to facilitate renewable energy technology adoption. Policies such as capital subsidy, feed-in tariffs, and tax incentives can all act to lower the LEC of CST electricity: 1) tax incentives can lower the overall costs of the project; 2) capital subsidies can come in the form of low-cost loans thus lowering the overall discount rate; 3) whereas tax affects the right-hand side of the LEC equation (section 3.7.1), feed-in-tariffs look to the left-side of the equation by guaranteeing a payment level significantly above the current LEC for CST. Spain's world leadership position in CST development via a feed-in-tariff of around 0.27Euro per kWh for CST power is a case in point.[127] Additionally, a government can enact policies that account for externalities which effectively raises the LEC of non-renewable power generating technology against the LEC of CST.

Concurrently, government supported financing packages are needed in order to provide an acceptable internal rate of return to attract private investors. As described previously in section 3.7.2 - *Drivers of CST Economics*, there is 1) an inverse relationship between the level of debt in the project capital structure and the LEC of the project (higher debt level, lower LEC); 2) a direct relationship between cost of debt and the LEC of the project (higher interest rates, higher LEC). Thus, governmental support that effectively allows investors to finance CST projects with a high debt level and low interest rates will have a greater chance of success. In addition, to spread the benefits and the risks of CST projects, government should encourage investments from diverse backgrounds including foreign investors, domestic investors, and private equity investors with a focus on the development of the Western region.[128]

While not mentioned in Jun Li's paper, another key factor to rapid adoption of CST technology is in generating and promoting greater awareness of CST technology in China. By educating investors, politicians, and the general public about the facts of CST, the Chinese will be better informed to make the appropriate decisions and enact a framework of policies to make CST a reality.[129]

4. Summary and Conclusion

In summary, this paper presents China's challenge as it continues to grow and propose concentrating solar thermal (CST) electric power as a viable renewable energy alternative that can solve China's three-headed problem by: (1) fueling China's growing need, (2) bridging regional income disparity, (3) reducing carbon emissions and move China towards a low-carbon economy.

In part one, the paper presented data showing China's unprecedented economic growth in the last 30 years. The paper then established a positive relationship between China's economic growth, energy consumption (specifically electricity), and GHG emission contribution to the world. In effect, China's unparalleled economic growth is the direct cause of China's unmatched GHG pollution contribution to the world. The paper also looked at how China's economic development has benefited its 1.3 billion people. While economic reform lifted hundreds of millions out of poverty, the rising tide did not raise all boats evenly. The paper shows that China's uneven growth created regional disparity which left unchecked would cause severe social and political repercussion. With the goal of quadrupling GDP by 2020, China will only intensify the severity of both these problems. In light of these challenges, the paper examines China's current renewable energy policy and argues that the lack of investment and policy focus on solar (specifically solar thermal CST) is a mistake as it can play an important role in China's renewable energy portfolio that that can simultaneously solve China's 3-headed problem. The paper accounts for the rich solar potential in China, makes comparisons between solar energy (CST) and other clean energy options (including nuclear) in China's plan, and propose that CST be seriously considered due to its many benefits – proven technology, clean power generation, enabling Western regions, and virtually zero environmental hazards.

In part 2, the paper introduces CST technology with a brief discussion on its theory, reality, and benefits and shortcomings. The paper also discusses and compares the different types of CST systems with respect to advantages/disadvantages, operating characteristics, and summary cost information and what this details means for China. The paper then moves forward to assess the potential of CST in China. The assessment includes review of: 1) solar resource using satellite DNI data; 2) land slope, space, and availability; 3) power grid in terms of proximity and availability; and 4) natural gas and water access. The paper also reviewed literatures on previous CST assessment and together concluded that: 1) Xinjiang and Tibet are the two regions with the best potential for CST due to their abundant solar resources and availability of large desert area; 2) Xinjiang and Tibet are also the only two regions not currently interconnected with China's nationwide power grid, but both are expected to be connected by 2011; 3) ambient temperature should be a factor of consideration in assessing CST sites as below freezing temperature will significantly reduce the electricity output potential of CST plants; and 4) while more in-depth feasibility studies should be performed in Xinjiang and Tibet using a comprehensive framework or system of assessment, results show that CST has a great potential in China. Next, the paper assesses the potential economic impact of CST in China by observing the results of the world's two largest markets for CST – U.S. and Spain. While the results show that Xinjiang and Tibet can benefit significantly from CST implementation, the paper recommends a more thorough analysis of this topic using a model that properly represents China's economic dynamics. The paper, then, moves to the economics of CST using LEC as a starting point and derives the activities that drive this yardstick. With these drivers in mind, the paper looks at studies on the nominal and true costs of electricity generation by different technologies and compares them to CST. The paper shows that with externalities accounted for and with the benefit of the experience curve, CST has commercial potential. Lastly, also with the LEC drivers in mind, the paper looks at the public policy support necessary to make CST commercialization a reality in China. The paper shows that a holistic policy approach is the best way forward and any policy that can lower costs, lower discount rates, or raise the bar of electricity payments (feed-in-tariff) above that of the current LEC of CST produced electricity will move CST closer to commercialization in China.

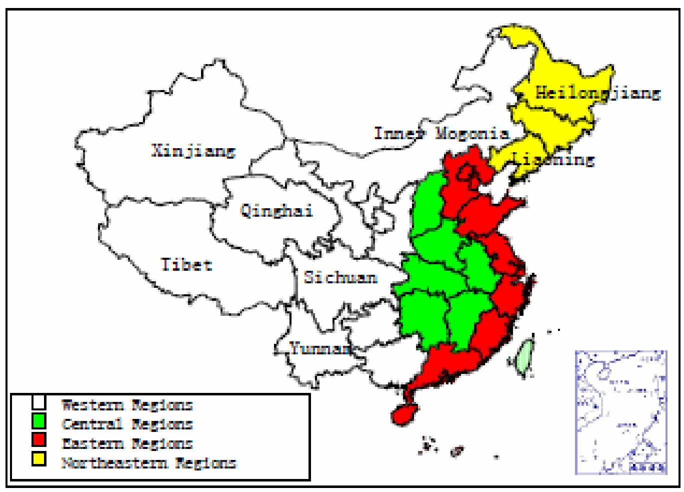
In conclusion, CST should be part of China's renewable energy supply because of the following: 1) With over two-thirds of China's land surface areas receives more than 5.02 x 10^6 kJ/m^2 per year of solar radiation and DNI resources ranging from 5 kWh/m^2 per day to 9 kWh/m^2 per day in China's Western region (mainly Xinjiang and Tibet), China has the key prerequisite to making CST power generation economical. 2) With Western regions characterized by mostly flat and unproductive desert lands and concrete plans to connect Tibet and Xinjiang into the national power grid by 2011 with HVDC lines, China also has the land and grid infrastructure needed for successful CST deployment. 3) While CST is dependent on an intermittent source for fuel, CST system can provide non-intermittent electricity generation (firm capacity) or to satisfy peaking or intermediate load capacity demands (dispatchability) when equipped with heat storage systems and/or fossil fuel backups (hybridization). 4) With demonstrated capacity factor of 24%, name plate capacity at 100s of MW scale, 20 years of operational experience, and virtually emissions free, CST is can be a good utility-scale clean energy power plant option for China. 5) While the CST parabolic trough's cost of producing electricity is 13.5 cents per kWh (predicted for the next trough plant based on California SEGS experience curve), this is still about 194% more expensive than coal-fired power plants located in Xinjiang which has a cost of electricity of 4.6 cents per kWh. However, when costs of externalities are considered, CST becomes 45% cheaper than scrubbed coal (a cleaner version of China's dominant coal-fired electricity) and 10% cheaper then nuclear according to Sovacool's study. Thus, while externalities vary greatly due to different assumptions, the key point is that if externalities are accounted for CST becomes a very competitive electricity generation alternative. 6) Externalities aside, CST also has great potential for continued cost savings from both economies of scale and technological improvements in efficiency. If IEA's CST outlook of 20,150 MWe of installed capacity in the year 2020 is realized, based on California SEGS experience curve, CST can realize a LEC of around 4 cents per kWh which makes CST competitive with traditional fossil fuel based electric power within ten years. 7) Using economic impact assessments of select U.S. regions and Spain (two most developed markets for CST) as reference, the potential economic impact for China can range from $5M to $30M of additional GDP per MWe of CST capacity installed. On a regional basis, this could mean an additional $465M of GDP or $22.20 of additional per capital GDP for Xinjiang if a 100 MWe capacity CST is implemented there. For Tibet, even using the most conservative estimate of $5M per MW of capacity, building a 50MW CST plant could increase Tibet's GDP by 4% (3% via 2006 PPP). Of course, two key factors that should also be taken into consideration are how the regional economic benefit is calculated and how it will be split up (i.e. who will benefit from the additional income). While the results from the U.S. and Spain are not directly comparable (since economic impact depends on the size, structure, and interconnection of different sectors in the economy), simple comparison accounting for size of the economy can provide a rough idea on the size of regional economic benefit that China can expect to receive from CST implementation. Thus, CST should be incorporated and have a greater focus in China's renewal energy plan as it can play an important role is meeting China's energy demand cleanly while helping to bridge regional income disparity.

APPENDIX A – Classification of Regions per PRC's 11th Five Year Plan

Regions	Provinces/Municipalities
Central	Shanxi
Central	Anhui
Central	Jiangxi
Central	Henan
Central	Hubei
Central	Hunan
Eastern	Beijing
Eastern	Tianjin
Eastern	Hebei
Eastern	Shanghai
Eastern	Jiangsu
Eastern	Zhejiang
Eastern	Fujian
Eastern	Shandong
Eastern	Guangdong
Eastern	Hainan
Northeastern	Liaoning
Northeastern	Jilin
Northeastern	Heilongjiang
Western	Inner Mongolia
Western	Guangxi
Western	Chongqing
Western	Sichuan
Western	Guizhou
Western	Yunnan
Western	Tibet
Western	Shaanxi
Western	Gansu
Western	Qinghai
Western	Ningxia
Western	Xinjiang

Source: Compiled by author from Li, Shantong, and Zhaoyuan Xu. 2008, China Economic Information Network, and National Development and Reform Commission (NDRC)

Source: China Economic Information Network
http://www1.cei.gov.cn/ce/region/Chinamap.htm



Source: Li, Shantong, and Zhaoyuan Xu. 2008 citing NDRC's 11th Five-Year Plan

Appendix B – Survey of leading papers on economic growth and energy consumption

Increased Energy Consumption Leads to Increased GDP Growth	Increased GDP Growth Leads to Increased Energy Consumption	Bi-directional Causality
Yu and Hwang (1984)[1]	Kraft and Kraft (1978)[4]	Masih and Masih (1996)[12]
Erol and Yu (1987)[2]	Yu and Choi (1985)[3]	Masih and Masih (1997)[14]
Masih and Masih (1996)[4]	Masih and Masih (1996)[12]	Glasure and Lee (1997)[5]
Masih and Masih (1997)[6]	Masih and Masih (1997)[14]	Asafu-Adjaye (2000)[7]
Asafu-Adjaye (2000)[15]	Cheng and Lai (1997)[8]	Yang (2000)[9]
Stern (2000)[10]	Soytas and Sari (2003)[19]	Soytas and Sari (2003)[19]
Soytas and Sari (2003)[11]	Jumbe (2004)[12]	Oh and Lee (2004)[13]
Lee (2006)[14]	Lee (2006)[22]	Paul and Bhattacharya (2004)[15]
Huang et al. (2008)[16]	Huang et al. (2008)[24]	Lee (2006)[24]

Source: Li, Chien 2008

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Appendix C – SEGS Land Assessment Criteria for CST Siting

The following data are requirements used by the SEGS and was used to assess flood potential and soil characteristics for grading, foundation design, and flood diversion channels. Source: (Cohen et al. 2005), pg 65

- Topography and Surface Hydrology
- Site land area (1.5-3.0 km^2 depending on configuration)
- Topographical maps (1:200,000-1:500,000 for overview, 1:25,000-1:50,000 for site selection) showing slopes as a function of direction; (0.5% slope is preferable; higher slopes up to 3% may be acceptable depending on cost of grading; slope in the north-south direction is preferred)
- 50-year and 100-year flood data; height, duration, and season of flooding
- Aerial photographs (oblique or low-angle views)
- Data on natural drainage and flood runoff flow paths
- Information on streams, ravines, obstructions, or other special features
- Soil Characteristics (at various locations on site)
- Soil type and composition as a function of depth (e.g., sand, clay, loam, sedimentary; grain size, density)
- Water table data (well depths, level of water in wells)
- Resistance to penetration (standard blows per foot)
- Lateral modulus of elasticity
- Minimum stress capacity
- Geological formation of the area
- Seismic records (magnitude and frequency data, maximum probable and maximum credible seismic events). This is needed for plant design, including buildings and solar collector field.
- Geological or man-made features that would shadow the solar field in early morning or late afternoon (features lower than 10 degrees above the tangent horizon will not shadow the solar field)
- Site elevation and geographic coordinates (longitude/latitude)
- Legal description of property (location, etc.)
- Land ownership and current land use
- Land use priorities or zoning restrictions applicable to this site
- Existing rights of way (water, power line, roads, other access)
- Land cost
- Existence of dust, sand, or fumes carried to site by winds (constituents, quantity or rate, duration, direction, velocity)

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