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Dagobert L. Brito y Juan Rosellón

A SOLAR POWER EXPORT PROJECT IN MEXICO FOR THE CALIFORNIA ELECTRICITY MARKET

Abstract

We apply the price model in Brito and Rosellón (2002) to a 40 MW solar power project in North West Mexico designed to export electricity to the Californian market. Technology used is thin film photovoltaic solar cells in a 294,000 m2 arid area in Baja California that receives an average annual solar radiation of 2,050 Kwh/m2. Assuming different values for import tariffs and discount rates we confirm that solar electricity price for this project would be competitive with electricity generation based on natural gas priced at $2.50 to $3.50 per Mmbtu. This being true even after assuming a 20% high-risk premium.

Resumen

Aplicamos el modelo de precios en Brito y Rosellón (2002) a un proyecto de energía solar de 40 MW en el Noroeste de México diseñado para exportar electricidad al mercado californiano. La tecnología usada es la de celdas solares fotovoltaicas de película delgada en un área desértica en Baja California de 294,000m2 que recibe una radiación solar anual promedio de 2,050 Kwh/m2. Suponiendo distintos valores para los aranceles de importación y tasas de descuento, confirmamos que el precio de la electricidad solar para este proyecto sería competitivo con generación eléctrica basada en precios de gas natural entre $2.50 y $3.50 por Mmbtu. Este resultado se mantiene aún después de suponer un premio por riesgo del 20%.

*Introduction**

Recent reports in the literature about new developments in thin film solar technology show that this technology has achieved a point where it can be competitive with hydrocarbon based generation. [1] The problems that remain are mostly economic, engineering and political. Solar power is now competitive with natural gas at prices between \$2.50 to \$3.50 per Mmbtu [2] This study is going to compare the cost of electricity produced by solar panels with the cost of electricity produced by combined cycle gas generators in a specific project in Baja California, Mexico, designed to export electricity to California.

Solar cells technology has been traditionally confined to non-ordinary applications such as satellites, microwave transistors, navigation equipments and signaling equipment. It has also been used in other small capacity applications in rural areas, public lightning, air conditioning systems and refrigerating systems. Maybe the more widely known application of solar technology is in watches and calculators, as well as in residential solar systems. Larger applications of solar systems (between 250 and 1,000 KW) have been achieved as peak support for fossil fuel power plants as well as in wider projects above 1MW.[3]

An important break-through in the production of efficient solar cells is thin films technology.[4] Recent developments suggest that the cost of producing these panels is now between \$45 to \$75 a square meter.[5] In this paper we propose 40 MW thin film solar power project in Baja California to sell electricity in the Californian Market. Assuming different values for import tariffs and discount rates we will show that such a project is competitive with natural gas power generation.

The Use of Renewable Energy and Solar Energy

The share of renewable energies in world energy consumption is expected to remain 8% between 1997 and 2020 if fossil fuel prices remain low. [6] Only an unlikely

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[1] Zweibel (1999) and Brito and Rosellón (2002).

[2] First Solar has recently achieved ten percent efficiency by using a coating that enables the panels to use more of the blue spectrum. They expect these panels to be in production by early 2002.

[3] Such as the solar power plants "Solar One" and "Solar Two" in California. This systems are based on "central tower" concentration systems.

[4] Thin films of exotic elements made of such as indium, gallium and selenium (SIGS) or cadmium and tellurium (CdTe) are deposited on glass. See Zweibel (1995).

[5] Zweibel (1995) p. 286. See also Cody and Tiedje (1995) and Brito and Rosellón (2002)

[6] International Energy Outlook (2000).

stringent compliance of the Kyoto protocol could increase the use of renewable energy. Table 1 and table 2 present international installed capacity of renewable energies and consumption of renewable energies, respectively.

Table 1
Installed capacity of renewable energy.
MmKW

Country	1995	1996	1997	1998	1999
Canada	0.044	0.044	0.045	0.045	0.045
Mexico	0.755	0.755	0.746	0.752	0.752
United States	17.162	16.691	16.341	16.686	18.423
Brazil	2.117	2.120	2.232	2.228	2.338
Chile	0.000	0.000	0.000	0.000	0.000
Germany	0.000	0.000	0.000	0.000	0.000
Spain	0.080	0.122	0.218	0.462	0.841
England	0.066	0.086	0.115	0.136	0.140
Philippines	1.100	1.163	1.446	1.886	1.907
Japan	0.386	0.519	0.544	0.535	0.606

Source: Energy Information Administration.

Table 2
International consumption of renewable energies.
(MmKWh)

Pais	1995	1996	1997	1998	1999
Canada	5.3	5.5	5.9	6.1	7.5
Mexico	5.4	5.4	5.2	5.4	5.3
United States	78.7	80.5	76.9	75.3	83.0
Brazil	7.4	8.5	9.5	9.7	9.9
Chile	0.7	0.9	0.8	1.1	1.5
Germany	8.3	9.2	9.9	12.6	15.0
Spain	1.5	1.8	2.8	3.5	3.8
England	5.4	5.7	6.0	6.2	8.2
Philippines	5.8	6.2	6.9	8.5	8.3
Japan	21.8	22.7	24.4	23.8	24.7

Source: Energy Information Administration.

In Mexico, the electricity State sector had an installed capacity of 36,666 MW and faced demand for 3,800 petajoules in 1999[7]. Tables 3 and 4 show data on installed capacity and demand in Mexico for the last 6 years, respectively. Participation of non-hydro renewable energies is marginal. In 1997 the share of combined renewable energies in total energy consumption was 7%. Installed hydro capacity was almost 10,000 MW, while the rest renewable-energy capacity was close to 1,000 MW. Currently, 27% of total power generation is hydro based while 2% is geothermal.

Table 3

Installed State Capacity (MW)

Year	*Total*	*Thermal*	*Hydro*	Carbon	Nuclear	Geothermal	Wind
1994	36,017.80	23,567.30	9,121.00	1,900.00	675	752.9	1.6
1995	33,037.30	19,394.80	9,329.00	2,250.00	1,309.10	752.9	1.6
1996	34,791.00	20,102.10	10,034.40	2,600.00	1,309.10	743.9	1.6
1997	34,814.80	20,120.10	10,034.10	2,600.00	1,309.10	749.9	1.6
1998	35,255.20	20,894.60	9,700.10	2,600.00	1,309.10	749.9	1.6
1999	36,666.30	21,327.40	9,618.80	2,600.00	1,368.00	749.9	2.2
2000p_/	36,268.50	21,825.40	9,618.80	2,600.00	1,364.90	857.2	2.2

Source: Secretaría de Energía

p : projected

Table 4

Electricity Consumption (petajoules)

Year	Total	Rural	Residential, commercial and government	Industry and mines	Transport	Percapita Consumption (Mill.kJ)
1994	3,589.30	91.0	822.9	1,203.90	1,471.70	63.4
1995	3,564.20	93.5	816.1	1,255.40	1,399.10	60.2
1996	3,640.70	101.4	837.9	1,282.50	1,418.80	62.4
1997	3,714.30	106.9	840.8	1,288.50	1,478.10	63.5
1998	3,823.30	106.6	868.9	1,320.60	1,527.30	64.0
1999	3,799.90	109.6	853.3	1,279.50	1,557.50	64.6

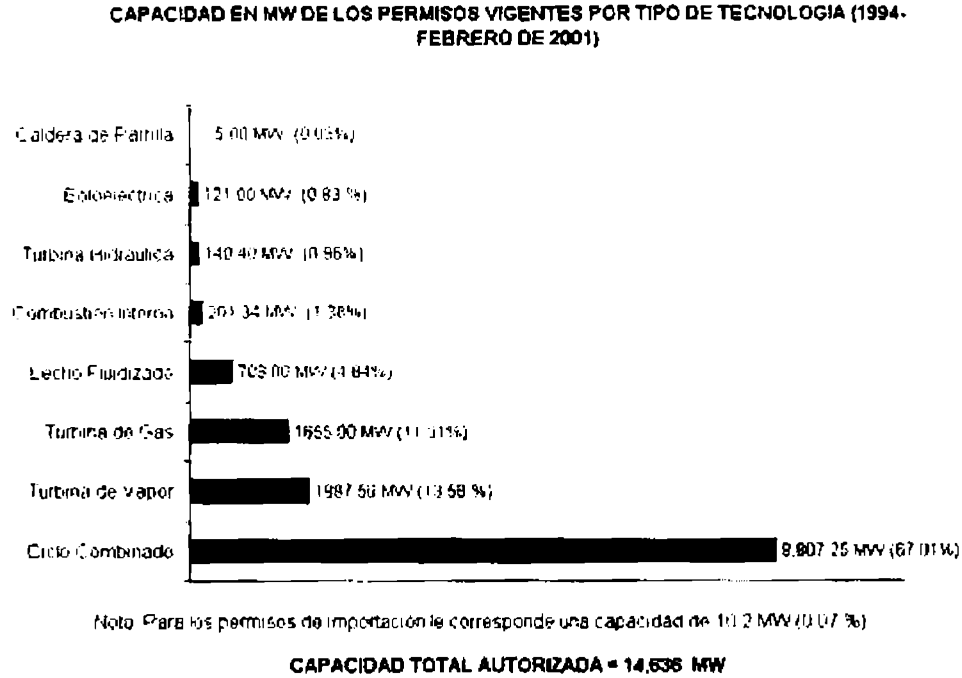
Source: Secretaría de Energía

[7] 3600 Joules = 1 Wh

Figure 1 shows the distribution of the different power plants in Mexico according to the type of technology used. Most generation is hydrocarbon based, and combined-cycle plants will be used to cover most of the additional 13,000 MW required in the next few years. The Comisión Reguladora de Energía (CRE) has granted most generation permits to combined cycle projects and very few permits to renewable (wind and hydro) projects (see figure 2).

Figure 1
Main sources of power generation in Mexico

Figure 2



Source: Comisión Reguladora de Energía

Unlike hydro, wind and geothermal generation, solar energy in Mexico has not developed since its introduction during the seventies. This scenario is not so different to the international scenario.[8] In 1998, solar panels for electricity generation in Mexico added only up to 324,000 m^2, 0.33 m^2 per capita. In 1999, 50,000 modules were installed in rural areas for lightning and water pumping, and a 10% annual increase is expected in the installation of solar collectors. Most of these modules are used for water heating in both urban and rural dwellings.

The current electricity regulatory framework in Mexico does not provide many incentives for a future increase of solar power generation. A hypothetical solar plant that plans to supply the domestic market could sell part of its exceeding power to the vertically integrated State monopoly (and monopsony) Comisión Federal de Electricidad (CFE) so that this company takes care of transportation and distribution. However, the current legal framework would permit cogeneration and self-supply

[8] There have been some international efforts to develop solar power projects, but none of these have reached economic feasibility. For instance, in California, one of the areas with very high solar radiation within the US, there have been 9 solar power plants that have not developed commercially. Other solar projects have developed but in rural areas. In China, there exists a World Bank program to raise a capacity of 10 MW on photovoltaic modules in order to supply electricity to 1 million rural consumers.

solar plants, as well as independent power production solar projects, that export all of their power generation.

A Solar Project for the Californian Electricity Market

We present an application of the model in Brito and Rosellón (2002) to a solar power project in North West Mexico to supply electricity to the Californian market.[9] The chosen location for this project is northern Baja California, Mexico, in an arid area that has a high level of solar radiation and that is close to the transmission lines that export electricity to California from San Miguel and Valle Imperial. It is also close to a turbo gas generation plant in Mexicali and to a geothermal plant in Cierro Prieto (see appendix). It is an area of 294,000 m^2 with a land cost between USD $0.1 and USD $1 per m^2. Annual solar radiation is 2,050 kWh/m^2, a high level when compared with annual radiation averages elsewhere as in Israel (1,592 kWh/m^2), Ecuador (1,397 kWh/m^2), California (1951 kWh/m^2), India (1845 kWh/m^2) and Chile (1485 kWh/m^2). The proposed capacity of the plant is 40 MW.[10] We assume an efficiency level of 15% for thin film solar cells. Table 5 shows a summary of the technical specifications of the project.

Table 5
Technical Specifications of the Project

Variable	Valor
Capacity	40 MW
Solar Radiation	2,050 kWh/m^2 per year
Technology	Thin film solar cell
Efficiency	15%
Location	Northern Baja California
Area	294,000 m^2

We consider the costs of solar panels, system balance[11], import tariffs, land and operation and maintenance. The solar panel cost and the system balance cost are USD 45 per m^2 and USD 35 per m^2, respectively, as in Brito and Rosellón (2002).

[9] There are other models that attempt to analyze the economic feasibility of solar energy in power generation. For example, Chapman and Erickson (1995) present a model for residential projects that shows how photovoltaic technology should be subsidized by the government whenever the decreasing social cost of photovoltaic energy lies below the increasing social cost of fossil fuel generation.

[10] The capacities of the Solar One and Two projects and the SEGS project in the United States are similar to this assumed capacity level. However, as previously noted, these projects use a very different technology to the thin-film photovoltaic technology.

[11] System balance costs includes all the additional equipment required for the installation of thin film solar cells.

The solar power plant requires electrical equipment and electronic equipment as well. Electrical equipment includes transformers, conductors and connectors, while electronic equipment includes solar cells and monitor equipment. We assume that the necessary equipment will be imported from the US or Canada. NAFTA import tariffs in Mexico for this kind of equipment are presented in table 6.

Table 6

Import tariffs

Subheading	Description	Import tariff
85098099	Electronic equipment	0%
85041099	Electric equipment [a]	3.0%

a. Includes transformers and invertors.

Source: Secretaria de Economía, Mexico

We use Caldwell's estimation for operation and maintenance costs of USD 0.8 per kWh or 11.25 per m^2.[12] We finally make an assumption on discount rate given that this is a high-risk project with a probable life of 30 years. Since the US treasury bonds rate is around 5.5%, we will calibrate the project with three different discount rates: 5.5%, 8% and 11%. A summary of the cost assumptions for the project is presented in table 7.

Table 7

Cost Assumptions

Variable	Value
Cost of solar panels	45.0 US\$/m^2
System balance cost	35.0 US\$/m^2
Operation and maintenance cost.	11.25 US\$/m^2
Land cost	1.00 US\$/m^2
Discount rate	5.5%, 8.0%, 11.0%
Import tariff	0.0%, 3.0%

Brito and Rosellón (2002) assume as equilibrium relationship the equality between generation costs and the net present value of the income flow from electricity sales:

$$V = I_p * \alpha * p_s[1 - e^{-rT}] / r = C_s + C_b,$$

where I_p is the solar radiation level [kWh/m^2/year], α is the conversion efficiency, p_s is the price of solar electricity per kWh, r is the discount rate, C_s is the solar panel

[12] Caldwell (1994) argues that this could be an over estimated (but reasonable) value due to lack of field data.

cost, and C_b is the system balance cost. We include in this last expression operation and maintenance costs (C_m), land costs (C_T), as well as import tariff (τ):

$$V - I_p * \alpha * p_s[1 - e^{-rT}] / r = C_s + C_b*(1 + \tau) + C_m + C_T.$$

We then have that price per KWh, p_s, is given by

$$p_s = [(57.25 + 35*(1 + \tau)) / 307.5]* [r / (1 - e^{-30*r})]$$

Table 8 presents the values for p_s for different values of discount rate r and import tariff τ.

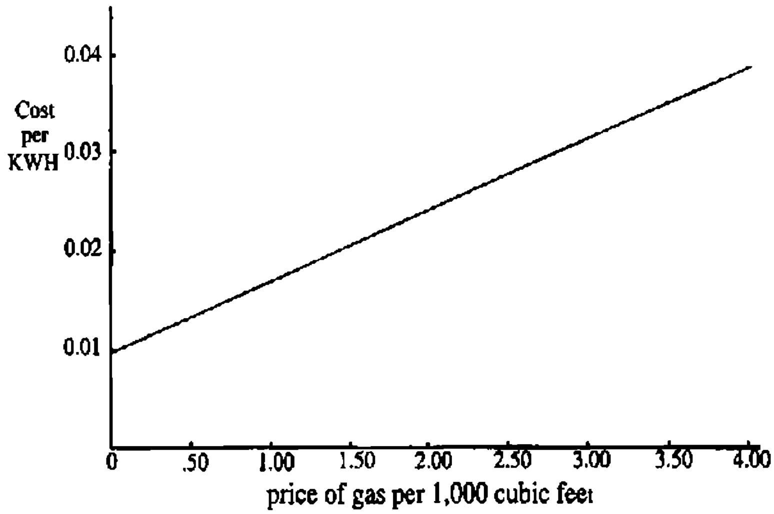
Table 8

Import tariff	Discount rate	p_s [US$/kWh]
3%	5.5%	0.0206
3%	8.0%	0.0267
3%	11.0%	0.0346
0%	5.5%	0.0204
0%	8.0%	0.0264
0%	11.0%	0.0343

Table 8 shows that p_s is practically insensitive to the variation of import tariffs, but very sensitive to changes in the risk-aversion parameter r. Passing from one risk level to another risk level implies a 30% increase in p_s, while moving from the lowest risk level to the highest risk level implies an increase of 68% in p_s.

Brito and Rosellón (2002) present the following relationship between the price of gas and the price of electricity generated by a combined cycle power plant:

Figure 3



The data we obtain in table 8 for the price of solar generation in the North-West Mexico solar project are competitive with gas priced within $2.50 to $3.50 per MmBTU. Even if we assume a high-risk premium of 20% for cost uncertainty, prices for power generated in the solar project would remain competitive with respect to a combined-cycle power plant (See table 9).

Table 9
Values of Ps for a 20% risk premium

Discount rate	p_s [US$/kWh] -20%	p_s [US$/kWh] +20%
5.5%	0.0163	0.0245
8.0%	0.0211	0.0317
11.0%	0.0274	0.0411

Conclusions

In this paper we propose a 40 MW solar power project in northern Baja California, Mexico, to export electricity to the Californian Market. Thin film solar technology is confirmed to be competitive with natural gas priced at $2.50 to $3.50 per Mmbtu even after assuming a 20% high-risk premium.

The practical implementation of solar projects could be more promising if the Mexican electricity sector is reformed so as to permit direct market transactions between producers and consumers. Projects as the one proposed in this paper could probably be connected to the Mexican transmission network and compete with combined-cycle power generation. The environmental and commercial benefits of the use of solar power could even justify some type of government intervention.

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Appendix

Mapa Eléctrico del Norte de Baja California