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Procedia Computer Science 83 (2016) 1150 – 1156

Procedia Computer Science

International Workshop on Hybridisation of CSP with Other Energy Sources

(HCSP_OES 2016)

Socio-economic effects of a HYSOL CSP plant located in different countries: An Input Output Analysis

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Abstract

The aim of this paper is to estimate the socioeconomic effects associated with the production of electricity by a CSP plant with HYSOL configuration, using Input Output Analysis. These effects have been estimated in terms of production of Goods and Services (G&S), multiplier effect, value added, contribution to GDP, employment creation and labor intensity. The analysis has been performed considering that the plant was established in four countries contemplated as suitable for HYSOL technology: Spain, Mexico, Chile and Kingdom of Saudi Arabia. The results indicate that producing electricity in a HYSOL CSP plant generates positive impacts on the economy and the employment in every country, producing the following ranges of socio-economic effects: a 0.05 %-0.38 % increment of the national GDP, creation of 11662-21053 jobs-year and production of 1412-2565 M$ of domestic G&S. The economic results are particularly favorable for Spain and Chile, which has been associated with higher multiplier effects (2.05 and 2.01 respectively) and higher demand of G&S in the Operation and Maintenance phase. In the case of Chile, favorable results are also due to the national production of nitrate salts employed in the thermal energy storage system. Employment results are more favorable in Mexico and Chile, which has been associated with the higher labor intensity of its national economies.

Peer-review under responsibility of the Conference Program Chairs

Keywords: Concentrated Solar Power; HYSOL; Employment; value added; GDP;

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Peer-review under responsibility of the Conference Program Chairs
doi:10.1016/j.procs.2016.04.236

1. Introduction

Concentrating Solar Power (CSP) plants are often criticized for their limited capacity factor and inability to produce on demand due to the cyclic, seasonal and stochastic nature of the solar resource. These aspects determine the economic viability of this technology, its environmental performance and also its integration into existing power networks. To mitigate these limitations, modern commercial scale plants usually incorporate energy backup systems in the form of thermal energy storage (TES) systems and/or auxiliary fuels. In conventional CSP plants, natural gas (NG) is usually burnt in gas furnaces to supplement solar when needed. However, this strategy is strongly questionable due to the low thermal efficiencies achieved in single thermodynamic cycles (usually below 40 %). An alternative under investigation involves the hybridization of CSP with gas fuels using combined cycle technology[1]. HYSOL is a research project lead by the Spanish engineering company ACS-COBRA and funded by the European Commission (FP7-ENERGY-2012-1, CP 308912) intended to provide a response to this matter by incorporating a combined cycle concept to the hybridization of solar energy with gas fuels. The use of biogas or biomethane as auxiliary fuel would result in electricity that is 100 % renewable.

It is widely accepted that energy use/generation has a notable impact on the macro-economic performance of regions. This needs to be taken into consideration when designing strategies intended to promote the deployment of alternative energy technologies like those based on renewable resources. These decisions should be based not only on direct economic viability indicators but also on an in depth analysis of macro-economic, socio-economic and environmental performance. Input/Output (IO) analysis is used by policy makers to quantify the effect of an investment on the economy of a region. This is done by using IO tables produced by recognised institutions that quantify the interdependence between economic sectors within an area[2]. In addition to economic, IO analysis may also be extended to cover socio/economic parameters such as employment, social metrics, international exchanges, energy consumption and environmental pollution.

The aim of this study is to evaluate the macro-economic impact of a CSP HYSOL plant and its effect on a series of domestic and non-domestic indicators including: generation of Goods and Services (G&S, direct, indirect and induced), employment creation, labour intensity and the contribution to the Gross Domestic Product (GDP). The analysis has been conducted using IO methodology in four geographic locations including Spain, Mexico, Kingdom of Saudi Arabia (KSA) and Chile. The sites were selected considering technical, economic and market information provided by engineering companies involved in the design and commercialization of CSP technology.

2. Methodology

2.1. Description of the CSP plant

The CSP plant used as a reference in this analysis is representative of HYSOL technology, incorporating a 100 MWe steam turbine and a 80 MWe gas turbine operating in combined cycle configuration. The solar field is based on tower technology and consists of between 9000 and 9500 heliostats (depending on location) with a surrounding layout. Direct Normal Irradiation (DNI) is reflected by the heliostats to an external central receiver to heat a Heat Transfer Fluid (HTF) consisting of binary nitrate molten salts. This HTF fulfils two objectives: transporting the heat to the steam generation system, and storing thermal energy using a Thermal Storage System (TES). The plant incorporates a 14 hours indirect two-tank TES used to support dispatchability and increase electricity generation. The thermal energy accumulated by the HTF is used to drive the Rankine thermodynamic cycle based on air cooling technology for reduced water consumption (at the expense of lower electricity generation efficiencies and higher economic costs). The aero-derivative gas turbine is used to support electricity generation when TES is empty or to increase electricity generation when the plant operates at peak-base load. Exhaust gases from the gas turbine are driven to a Heat Recovery System (HRS) where the HTF is reheated, thus improving fuel utilization efficiency and storage dispatchability.

The characteristics of the power plant and the amount of electricity generated and sold to the market for each location were calculated by IDIE S.L. (a partner in the HYSOL project) considering national power demand curves, plant characteristics and availability of solar resources in each location. Table 1 shows technical information about each of the locations considered in this analysis including availability of solar resource, main design and operating features and gas consumption. Power generation has been calculated taking into consideration onsite power requirements, efficiency losses due to grid availability and curtailment, annual degradation of components and parasitic electricity consumption.

Table 1 Power plant characteristics and electricity poured into the grid for each location.

Characteristics of the power plant	Spain (Talarrubias)	Chile (Copiapó)	KSA (Riad)	Mexico (La Paz)
Direct Normal Irradiation, KWh/m	2086	2687	2393	2026
Installed capacity	180	180	180	180
Peak design power	150	100	130	150
Heliostats, units	9151	9237	9494	9059
Tower height, m	201	201	203	200
Annual electricity poured into the grid, MWh/yr	797,423	735,732	702,026	800,647
Solar fraction, %	45	71	66	46
Consumption of gas, MJ/yr	3.40E+09	1.62E+09	1.87E+09	3.32E+09

2.2. Input Output Modeling

IO Analysis is based on the A matrix[3,4], which represents the monetary amount required from each sector to produce one monetary unit of products or services in every sector, according to Equation (1):

$$X = (I - A)^{-1} Y \qquad (1)$$

where X is the production of Goods and Services (G&S) measured in monetary units, $(I - A)^{-1}$ is the Leontief inverse matrix describing direct and indirect monetary effects per unit of final demand, and Y is the final demand. The analysis is based on a monetary inventory of the demand for G&S throughout the lifetime of the CSP HYSOL project including two stages: initial investment (design and construction) and Operation and Maintenance (O&M). The economic data has been modelled using national IO tables to generate the following results:

- Direct effect (Y): changes in the economy derived from direct demand for G&S from the project.
- Indirect effect (X-Y): intermediate financial outcomes required to satisfy changes in the final demand.
- Induced effect (X_{induced}): consumption of G&S derived directly from the economic compensation of employees.
- Non-domestic effects (Xn): domestic effects refer to those taking place in the national economy, while non-domestic effects are those affecting the economies of third countries due to the consumption of imported G&S. Direct non-domestic effects are calculated using Equation (2), where Xn is the non-domestic effect and An is the technical coefficient matrix corresponding to imports of the national IO table. Non-domestic effects derived from G&S which are known to be imported from specific countries were calculated using the corresponding national IO table.

$$Xn = An * Y \qquad (2)$$

- Multiplier effect: represents how the direct demand for G&S is amplified in the form of total national income. The multiplier effect is calculated from Equation (3), which provides the relationship between total (direct, indirect and induced) and direct effects on the production of G&S.

$$Em = \left(X + Xinduced\right)/\,Y \tag{3}$$

- Value added: represents the additional economic value that every good or service acquires when it is created or transformed by the productive activity of each sector. This value can also be defined as the contribution of a private company or an economic sector to the national Gross Domestic Product (GDP). This analysis is based on the value added IO vector which describes the value added per monetary output unit for each of the sectors considered in the IO table, as described in Equation (4):

$$Et = eX = e\left(I - A\right)^{-1} * Y \tag{4}$$

where E_t represents the effect on the value added and e is the vector describing the amount of value added per monetary unit and economic sector. The amount of value added generated by the system represents the contribution of the project to the national GDP.

- Employment created: represents the number of jobs (in terms of man×year, considering the average number of hours per year worked in each country) created throughout the life cycle of the project. This includes not only direct jobs in the power plant, but also direct and indirect jobs derived from indirect and induced economic activities. The value is calculated from Equation (4) when using the employees per monetary output unit vector for each of the sectors considered in the IO table. Labour intensity of the project is calculated as the ratio between direct and indirect employment created over direct plus indirect generation of G&S.

The IO tables used were obtained from two sources: WIOD and OECD. The World Input Output Database (WIOD) was developed within the WIOD project funded by the European Commission[5]. This public database provides time-series of world IO tables for thirty five economic sectors of forty countries worldwide, and a model for the rest-of-the-world, for the period 1995-2011. These tables are standardized according to the European System of Accounts 2010[6] and have been constructed based on officially published IO tables together with national accounts and international trade statistics. WIOD was the best option for Spain and Mexico as it includes social accounts (employment vector) and it is updated to 2011. Since data for Saudi Arabia and Chile was not available in the WIOD database, the corresponding OECD IO database 2015 edition[7] was used for these countries. The OECD IO database provides time-series of IO tables for thirty four economic sectors of 62 countries worldwide. This database does not contain the information to build the employment vector. Hence, this data was obtained for Chile from ILOSTAT database (2011) and for KSA from the Central Department of Statistic & Information of KSA (http://www.cdsi.gov.sa/english) (2011). For harmonization purposes, monetary data from the economic inventory and the IO tables was transformed into local currency in 2011 considering national Consumer Price Index (PCI) published by OCDE[8]).

2.3. Hypothesis and main data

The economic inventory on which this analysis is based was supplied by IDIE S.L. and refers to 2015. Construction of the HYSOL CSP plant is assumed to take place during year 1, while the O&M phase takes place between years 2 and 26. Cash flows were actualized for a discount rate of 4 %. Every component is assumed to be purchased in the country where the project is located except for the gas turbine, steam turbine and nitrate salts, which are imported from Italy, Germany and Chile, respectively. For those components, direct, indirect and induced effects were calculated in the country of origin. Table 2 shows a summarized economic inventory. All locations have similar investment costs (with minor differences due to the solar field design). A discount has been applied to the Thermal Energy Storage system in Chile due to the fact that molten salts are produced locally. Gas and labour costs represent local prices.

Table 2 Summarized economic costs considered in the study for each country, in USD2015

		Mexico	Chile	KSA	Spain
Initial investment costs (M$)	Power block	124.2	124.2	124.2	124.2
	Solar field	475.1	441.2	469.8	462.2
	Others (BoP, contingencies)	109.4	107.0	109.0	107.0
	EPC and Owner cost	70.87	67.24	70.30	67.22
	TOTAL	**779.5**	**739.6**	**773.3**	**739.4**
O&M costs (M$/year)	Water and gas consumption	12.72	22.63	7.095	35.03
	Staff	1.052	1.166	2.852	2.327
	Others (Spare parts, insurance, land rental)	6.523	6.197	6.454	5.825
	TOTAL	**20.30**	**29.99**	**16.40**	**43.19**

Labour costs were assumed to produce induced effects due to the demand for G&S generated by employees of the power plant during the O&M phase. This demand is distributed into the different sectors according to a pattern of "*consumption expenditure by households*" included in the corresponding IO table. The amount of money spent by employees was calculated considering a household saving rate of 9.6 %, and the national average tax wedge reported for each country (Tax wedge is defined as the ratio between the amount of taxes paid by an average single worker a single without children and the corresponding total labour cost for the employer) [9]. Tax wedge for KSA was assumed to be 9 %[10] (corresponding only to social security contribution from the employer, since there is no tax on employment in KSA). The percentage of labour cost corresponding to taxes and social security contributions was added to the corresponding economic sector (Public Admin and Defence; Compulsory Social Security) in the demand vector (Y) used for G&S calculations.

3. Results and discussion

The economic activity generated by the investment and the O&M phases of the HYSOL CSP project when deployed in different locations is described in Table 3. The total production of G&S, including domestic effects (direct, indirect and induced) and non-domestic effects, ranges between 1907 and 2786 M$, while the total domestic effects range between 1607 and 2484 M$, with the lowest value corresponding to KSA and the highest to Spain. The multiplier effect of the HYSOL project when calculated for different locations ranges between 1.75 (KSA) and 2.01 (Spain). The investment phase is the one contributing the highest to the production of G&S in every location, while the multiplier effect is higher in the O&M phase in every case.

Table 3 Production of G&S throughout the investment and O&M phases of the HYSOL CSP plant, located in different target countries.

Generation of goods and services	Mexico		Chile		KSA		Spain	
	Invest.	O&M	Invest.	O&M	Invest.	O&M	Invest.	O&M
Direct (M$)	603	265	608	406	617	193	658	578
Indirect (M$)	298	168	383	411	266	110	598	425
Induced (M$)	216	58.0	143	78.1	150	84.4	139	86.0
TOTAL DOMESTIC EFFECTS (M$)	1607		2029		1421		2484	
Non-domestic : Italy (M$)	55.6	-	55.6	-	55.6	-	55.6	-
Non-domestic: Germany (M$)	66.4	-	66.4	-	66.4	-	66.4	-
Non-domestic: Chile (M$)	44.6	-	-	-	44.6	-	44.6	-
Non-domestic: Rest of the World (M$)	95.4	37.1	65.3	50.2	112	56.9	62.5	94.8
TOTAL NON-DOMESTIC EFFECTS (M$)	299		238		336		324	
TOTAL G&S	1907		2266		1757		2786	
Multiplier effect	1.85		2.00		1.75		2.01	

The country showing the most favourable economic results is Spain, whose total domestic effects are significantly higher than those observed in all the other countries (2484 M$). These superior economic results for Spain are primarily attributable to two reasons: (1) the direct demand of G&S during the O&M phase is significantly higher in Spain than in other countries, due to the comparatively higher cost of the gas fuel in this country (0.5071 $/Kg[11]), and (2) this country produced the highest multiplier effect of all locations (corresponding with 2.05), which contributes to increasing indirect effects. The second best economic results were produced by Chile (2029 M$), due also to its high direct demand of G&S during the O&M phase (cost of gas fuel in Chile was assumed to be 0.6592 $/kg[12]), high multiplier effect (2.01) and also due to the fact that the demand for nitrate salts is met by the national market (it has been assumed that this product is produced in Chile , thus resulting in increased domestic demand for G&S). The contribution of non-domestic effects to the total effects of the CSP project in different locations is 16, 10, 19 % and 11 % for Mexico, Chile, KSA and Spain, respectively. The non-domestic effects are lowest in Chile due mainly to the national production of nitrate salts.

Table 4 describes the value added (direct, indirect and induced) produced during the investment and O&M phases of the project in each of the countries under study. The results show that 35 %, 44 %, 50 % and 42 % of the domestic effect corresponds to value added for Mexico, Chile, KSA and Spain, respectively. This percentage is higher than the average share of value added in the national “Electricity, Gas and Water Supply” sector for Mexico, Chile and Spain (33.8, 30.1 and 33.6 % respectively), which suggests that the contribution of a CSP HYSOL project to the GDP of the nation would be higher than for the average technology for electricity production in each country. Although the highest contribution of domestic effects corresponding to value added is associated with the KSA economy (50 %), this percentage is lower than the average in the “Electricity, Gas and Water Supply” sector (61 %), which could be explained by the high domestic production of natural gas in that country. As described in Table 4, the contribution of a HYSOL project to the economies of the countries considered represents between 0.05- 0.38 % of their total GDP.

Table 4 Contribution to GDP and value added produced by the demand of Goods and Services throughout the investment and O&M phases of the HYSOL CSP plant, located in different target countries.

Value added	Mexico		Chile		KSA		Spain	
	Invest.	O&M	Invest.	O&M	Invest.	O&M	Invest.	O&M
Direct (M$)	208	80.8	303	139	307	58.4	227	226
Indirect (M$)	125	66.9	189	160	163	67.1	241	205
Induced (M$)	64.5	20.3	63.8	28.8	91.6	30.5	74.8	38.9
TOTAL (M$)	565		883		714		1041	
NATIONAL GDP at basic prices* (M$)	1,117,801		232,000		651,096		1,376,830	
Contribution of the project to the national GDP (%) of 2011	0.05		0.38		0.11		0.08	

*Calculated for year 2011 with the corresponding IO table as the sum of the value added produced by every economic sector.

Table 5 describes the employment generated in each country (including direct, indirect and induced) by the investment and O&M phase of the HYSOL CSP project. The total number of jobs (measured as one year jobs) created during the life cycle of the plant range between 21,053 and 11,388 jobs×year, of which approximately 70 % are created during the initial investment phase and only 30 % during O&M. Direct employment represents more than half of the employment generated. The amount of employment created in Mexico and Chile almost doubles the value obtained for Spain. This difference has been associated mainly with the labour intensity of the country, which represents the rate of labour per G&S generation. The labour intensity in the Spanish economy (according to the IO table and employment data for 2011) amounts to 5.7 jobs /M$, while the same value in Mexico, Chile and KSA amounts to 16.0, 16.4 and 10. 4 jobs/M$ respectively.

The labour intensity of the “Electricity, Gas and Water Supply” sector in each of the countries investigated (4.5, 2.5, 9.2 and 0.9 jobs/M$ for Mexico, Chile, KSA and Spain respectively) is considerably lower than that determined for the HYSOL project (14.0, 9.59, 10.5, 4.48 jobs/M$ respectively) expect for KSA, which is slightly higher. This implies a positive influence from the HYSOL technology in the generation of employment in the corresponding economic sector for every location.

Table 5 Domestic direct, indirect and induced employment created during the investment and O&M phases of the HYSOL CSP plant, located in different target countries.

Employment	Mexico		Chile		KSA		Spain	
	Invest.	O&M	Invest.	O&M	Invest.	O&M	Invest.	O&M
Direct (jobs)*	10265	3496	7144	2593	6679	2591	3105	2449
Indirect (jobs)*	3366	1592	4524	3079	2321	844	2952	1605
Induced (jobs)*	1637	706	1971	1100	1728	975	791	485
TOTAL (jobs)*	21063		20412		15138		11388	
HYSOL Labor intensity (jobs/M$)[a]	14.0		9.59		10.5		4.48	

*Measured in one year job for one person, considering de average annual working hours for each country.

[a] Calculated considering only direct and indirect domestic effects.

4. Conclusions

The IO Analysis applied to the HYSOL technology suggests that implementing one 180 MW CSP plant in different countries would produce the following socio-economic effects: a 0.05 %-0.38 % increment of the national GDP, creation of 11388-21053 jobs-year and production of 1421-2484 M$ of domestic G&S. The economic results are particularly favorable for Spain and Chile, which can be explained by the higher multiplier effect of these economies, the higher cost of natural gas (producing a higher demand of $ in the O&M phase) and, in the case of Chile, the domestic production of nitrate salts. The country for which the HYSOL project would have the lowest effect on its economy (in terms of production of G&S) is KSA, due mainly to a lower multiplier effect and a lower investment in the O&M phase (associated with a lower cost and consumption of natural gas). Mexico presents the lowest contribution to its GDP (0.05 %) due to a lower share of value added obtained throughout the project, and a higher absolute value of GDP in the country. The country showing the highest employment benefits from the deployment of the HYSOL plant is Mexico, followed closely by Chile. These improved employment figures are attributed to a higher labor intensity of these economies. Results regarding labor intensity indicate that the HYSOL CSP technology has a higher employment generation capacity than that observed in the “Electricity, Gas and Water Supply” sector of each of the locations considered.

Acknowledgements

Thanks are due to the European Commission for funding under HYSOL Project (Innovative Configuration for a Fully Renewable Hybrid CSP Plant, FP7-ENERGY-2012-1 CP 308912). The authors are also grateful to the engineering companies ACS-COBRA and IDIE for technical inventories of the CSP plants.

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