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Economic impact of solar thermal electricity deployment in Spain

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ABSTRACT

The objective of the work is to estimate the socio-economic impacts of increasing the installed solar thermal energy power capacity in Spain. Using an input–output (I–O) analysis, this paper estimates the increase in the demand for goods and services as well as in employment derived from solar thermal plants in Spain under two different scenarios: (a) based on two solar thermal power plants currently in operation (with 50 and 17 MW of installed capacity); (b) the compliance to the Spanish Renewable Energy Plan (PER) 2005–2010 reaching 500 MW by 2010.

Results show that the multiplier effect of the PER is 2.3 and the total employment generated would reach 108,992 equivalent full-time jobs of 1 year of duration. Despite this is an aggregated result, this figure represents 4.5% of current Spanish unemployment.

It can be concluded that the socio-economic effect of the PER's solar thermal installed capacity goal would be remarkable.

1. Introduction

During the next decades, solar energy is likely to be one of the most promising sources of clean energy. This fact is especially relevant in countries like Spain, where solar radiation is high and solar electricity generation potential is remarkable. There are several solar thermal power technologies – parabolic trough, central tower and parabolic dish – and despite the fact that most of them are in a development stage, their future potential decline in costs and technological advances are striking.

A remarkable promotion of the solar thermal industrial activity has taken place in Spain, partly due to the favourable current Spanish regulatory scheme. The Royal Decree (RD 661/2007) fixes a 0.27€/kWh feed-in tariff[1] for the electricity generated by solar thermal technologies which, combined with the possibility of constructing mixed plants with gas,[2] has generated a great interest for solar concentration technologies among investors and the Spanish industrial sector. This favourable environment has brought forth an upsurge in solar projects – mainly using either a central receiver or a parabolic trough – , and it is expected that the total potential capacity will exceed more than 500 MW_e, which coincides with the Spanish Renewables Energy Plan (PER)'s goal for solar thermal installed capacity by 2010.

The goal of this study is to estimate the socio-economic impacts derived from the construction of solar thermal power plants in Spain. As Kulišić et al. (2007) note, most renewable energy feasibility studies account, at most, for direct effects, underestimating indirect socio-economic revenues in terms of economic activity and job creation. In this sense, this study attempts to enlarge the current body of literature in two ways: first, by gathering cost data regarding construction and operation of solar thermal power plants currently in operation and second, by taking into account both direct and indirect effects on the demand of goods and services as well as employment generation.

In order to estimate such impacts in Spain, two different scenarios were considered:

(I) The *first scenario* considers the individual impact derived from the construction and operation of two solar thermal power plants with the following specifications:
- A power plant consisting of 624 parabolic trough collectors with 50 MW of installed capacity. This plant uses synthetic oil as transfer fluid and molten salts to create a 7 hours storage system. In line with the current regulatory framework, 15% of total output is generated by natural gas.
- A central solar tower power plant consisting of 2750 heliostats with 17 MW of installed capacity. This plant uses molten salts both as a transfer fluid and storage system. This power plant occupies 150 Has. As in the previous case, the power plant generates 15% of the total electricity from natural gas.

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[1] RD 661/2007 establishes that solar thermal electricity producers can choose between: (i) obtaining a feed-in tariff of 0.27 €/kWh for the electricity or (ii) selling the electricity for the market price. Plus a 0.25 €/kWh premium – with a minimum guaranteed revenue (considering the price of the market and adding the premium) of 0.25 €/kWh and a maximum limit of 0.34 €/kWh.

[2] Mixed plants may combine between 12% and 15% of gas to compensate for any heat losses during the process.

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(II) The *second scenario* contemplates the PER installed capacity goal for solar thermal power, which would lead to 500 MW installed capacity by 2010. According to this hypothetical scenario, it was assumed that 80% of such capacity would be met by parabolic trough plants while 20% would be met by solar tower power plants.

2. Input–output methodology

Since the Russian economist Wassily Leontief started to develop the input–output (I–O) methodology in the late 1930s, these models have been widely used in order to analyse the existing links between different sectors within an economy. This analytical tool can gather information about the productive relations between the different sectors in the economy in a systematic way. The advantage of the I–O methodology is its apparently simple framework, in which each column of the I–O table contains the amount of inputs provided from each sector to the rest of the sectors in the economy. Constructed based on the I–O symmetric table, the matrix of technical coefficients summarizes the interdependencies between production sectors (Ten Raa, 2005). In this way, based on the I–O account it is possible to determine a system of linear equations using the technical or productive coefficients that describe the relation between inputs used by a sector and the final demand (Kulišić et al., 2007). Moreover, tracing out a portrait of the whole national economic structure, it is possible to analyse the economic activity and employment impacts induced by an increase in the demand of one particular economic sector. Finally, the I–O models are also used to estimate the multiplier effect that a certain investment generates in the production of different goods and services as well as in employment (Leontief, 1966). Appendix A shows a more detailed description of the I–O analytical steps.

When conducting an input–output study, three types of effects may be analysed: (i) *direct effects* – accrued due to the increase in the demand of those industries that directly provide the goods and services required to construct, operate, maintain and dismantle a plant,[3] (ii) *indirect effects* – originated due to the effect that this new investment has on new flows of purchases and/or sales among other productive sectors in the economy, and (iii) *induced effects* – related to the expansion of private expenditure in goods and services (food transportation, health, services, etc.) from workers – in a direct or indirect way – by the project.[4]

Since the oil price shocks of the 1970s, the input–output analysis has been commonly applied to the field of energy in order to determine the impact of personal consumption decisions, through the so called *dollar–energy–labour* (DEL) (Folk and Hannon, 1973; Hannon, 1972; Herendeen and Sebald, 1974; Chapman, 1974). The DEL impact characterizes the energy and inputs required to produce the output that is needed to meet consumer demand.

One of the most recent applications of the I–O analysis focuses on the environmental consequences of energy use. For example, Lainer et al. (1998) use I–O analysis to measure emissions, employment and other macroeconomic impacts derived from energy efficiency and low-carbon technologies.

In terms of employment, the impact of renewable energies has been widely studied in both the USA and Europe. While in the USA focus has been on photovoltaic technologies (Cook, 1998; US DOE, 1992), in Europe there have been various studies aiming to show the positive impacts derived from the deployment of other renewable energy technologies. (Ciorba et al., 2004; Kulišić et al., 2007; Madlener and Koller, 2007; Allan et al., 2008). Germany is the leading country in this regard, with several studies which have analysed the whole energy planning system in an integrated framework (Pfaffenberger et al., 2003; Umweltbundesamt, 2004; BMU, 2004; Hillebrand et al., 2006; Lehr et al., 2008). Similarly, the European Commission supported a study focusing on the employment effects of renewable energy in Europe to 2020 (ECOTEC, 1999).

Compared to other analytical methods, the main advantages of the I–O methodology are its simplicity and intuitive understanding. Moreover, the implementation of this methodology does not require the use of sophisticated statistical packages and is widely accepted. Nevertheless, there are some limitations that are worth mentioning and should be taken into account when interpreting the results. One of the greatest limitations of this method is that the coefficients used to obtain the results are constant or static and not always account for technological improvements, import substitution, change in consumption patterns, or relative price variations over time (Holland and Cooke, 1992). Another limitation is that, when using this methodology, homogeneity among sectors is assumed. This assumption implies that the different activities within a certain sector are considered equal (in terms of consumption of goods and services during the production process as well as later use of its production). Another assumption upon which this methodology is based is the absence of production capacity limitations. This assumption implies that there are no limits to the amount that a certain sector can produce in response to an increased demand (either in a direct or indirect way) generated by a new investment.

3. DATA

3.1. Solar thermal plants costs

3.1.1. Parabolic trough power plant

Table 1 shows the details of the investment costs associated to a 50 MW solar thermal power plant[5]: solar field accounts for 46% of the total investment cost, power block for 21%, storage for 12%, construction for 10%, and the remaining 10% accounts for engineering costs and contingencies.

In order to determine the operation and maintenance costs, an exploitation timeframe of 30 years with an annual discount rate of 8%[6] was considered. Both total annual operation and maintenance costs and those accumulated during 30 years[7] are showed in Table 2. Regarding fixed operation and maintenance costs, 80% of such costs are assumed to account for the payment of employees' wages while the rest accounts for administration services, insurance, etc. Similarly, the expenses associated to natural gas and electricity consumption were accounted for. The estimation of the financing expenses has been computed considering a 12-year repayment loan with a 7% interest rate.

In order to estimate the effect on employment, the following steps and assumptions were made: as mentioned before, it was assumed that 80% of the operation fixed costs were assigned to

[3] Due to the lack of actual data regarding the dismantling phase of the project, this last phase will not be considered in this analysis.

[4] It must be noted that in this work, due to the lack of precise data on employment and salary figures, induced effects were not estimated.

[5] According to ECOSTAR, the investment cost would be split in the following manner: solar field (51%), power block (22%), storage (8%), land (2%) and contingencies (17%).

[6] An annual discount rate of 8% is commonly used in commercial energy projects in Spain. This rate includes a minimum risk premium due to legal and economic uncertainties.

[7] Our selection of 30 years lifespan is in line with the literature (DLR/BMU, 2002) which considers a lifespan of 20–30 years for this type of projects.

Table 1
Breakdown of investment costs associated to the parabolic trough plant.

Concept	Investment (k€)	Investment (%)	% of imports
Solar field	123,487	46	
Solar field	105,163	40	34
HTF field	14,437	5	30
Spare parts and other expenses (50%)	3887	1	0
Power block	55,690	21	
Natural gas boiler	3051	1	0
Vacuum generator	4767	2	100
BOP	13,173	5	40
Generation plant	30,811	12	40
Spare parts and other expenses (50%)	3888	1	0
Terrain	1211	0	0
Storage	33,187	12	
Storage system	19,837	7	0
Salts	13,350	5	100
Construction	26,584	10	0
Engineering	12,839	5	0
Contingencies	12.839	5	0
Total	265,837	100	29

Table 2
Parabolic trough plant operation and maintenance costs.

Concept	Annual cost (k€)	Annual cost (%)	Total cost[a] (k€)
Fixed operation	1292	11	25,250
Maintenance	2761	22	53,958
Financing[b]	5432	44	106,158
Natural gas	1563	13	30,546
Electricity	1252	10	24,468
Total	12,300	100	240,380

[a] The exploitation period considered was 30 years and the annual discount rate used when discounted future operation and maintenance costs was 8%.

[b] It has been assumed that the investment will be financed over 12 years with an annual interest rate of 7%. Only the payment of the interests of the loan were considered as financial costs.

pay employees, so that salaries amount to 1033.6 k€/year. According to the National Statistics Institute (INE) data, the average salary of a Spanish employee working in the electricity generation and distribution sector amounts 46.3 k€/year, and the estimated number of employees annually working in the operation of this plant would amount to 22 people.

The increased direct demands – in the form of investment, operation and maintenance costs – were later assigned to the different sectors in the economy that are contemplated in the reduced Input–Output table that was constructed for this purpose.

The increase in the total direct demand associated to the construction and operation of the parabolic trough plant amounts 486 M€, which represents an annual demand of 17.2 M€/year (assuming a construction period of 3 years and a lifetime of 30 years). This direct demand can be expressed as a function of the size of the solar thermal plant, which amounts to 9.7 M€ for every MW installed.

Table 3
Breakdown of investment cost associated to the solar tower plant.

Concept	Investment (k€)	Investment (%)	% of imports
Solar field	62,384	42	
Heliostats	54,186	37	34
Piping system	2826	2	30
Cables	2021	1	0
Spare parts and other expenses	3351	2	0
Tower	23,753	16	
Tower	3821	3	0
Receiver	19,932	14	0
Power block	29,686	20	
Natural gas boiler	1973	1	0
Vacuum generator	2438	2	100
BOP	6814	5	40
Generation plant	15,110	10	40
Spare parts and other expenses	3351	2	
Land	1423	1	
Storage	9412	6	
Storage	4126	3	0
RT pump	1358	1	0
ST pump	591	0	0
Salts	3337	2	100
Construction	9414	6	
Engineering	5472	4	0
Contingencies	5472	4	0
Total	147,016	100	23

3.1.2. *Solar tower power plant*

According to the original cost data provided by ECOSTAR (2004), Table 3 shows the detail of the total investment cost associated to a 17 MW tower plant. When disaggregating the total investment cost of the plant, it was assumed that construction works represent 6% of such investment. According to this assumption, total investment can be further disaggregated in the following manner[8]: solar field accounts for 42% of the investment, power block for 20%, tower and receptor for 16%, storage system for 6%, construction for 6%, and the remaining 8% accounts for engineering and contingencies costs.

In terms of the operation and maintenance costs associated to a solar tower plant, it was assumed that the operational period lasted 30 years and an 8% annual discount rate was used. Table 4 provides the detail of the annual and the total aggregated operation costs for a period of 30 years. As in the previous plant, within the fixed operation costs, 80% of such costs are assumed to cover employees' wages and the rest accounted for administrative services, insurance, etc. Both gas and electricity costs required to operate the solar plant were taken into account. Finally, it was assumed that investments cost were financed with a loan to be repaid over 12 years with an annual interest rate of 7%.

[8] According to ECOSTAR, the investment breakdown of a scaled solar tower power plant of 50 MW would be the following: solar field (36%), power block (24%), receiver (15%), tower (3%), storage (3%), land (2%) and contingencies (17%).

Table 4
Operation and maintenance costs of the solar tower power plant.

Concept	Annual cost (k€)	Annual cost (%)	Total cost (k€)
Fixed operation	1292	18	25,250
Maintenance	1455	20	28,435
Financing	2812	39	54,955
Natural gas	771	11	15,068
Electricity	824	12	16,103
Total	7154	100	139,811

Table 5
Sectoral breakdown for the I–O analysis of solar thermal plants.

TSIO code	New sector code	Sector name
1; 2; 3	1	Agricultural products, livestock, hunting, forestry and fishing
4;5;6;7	2	Fuels and extractive activities
8	3	Carbon, refinery products and nuclear fuel
9;10;11	4	Electricity, gas and water production and distribution services
12; 13; 14; 15; 16; 17; 18; 19	5	Foodstuffs, drinks, textiles, clothes and footwear
20; 21; 22	6	Wood, paper, cardboard, edition products
23; 24	7	Chemical products, plastics and rubber
25; 26; 27; 28	8	Cement, lime, plaster, glass and other no-mineral products
29	9	Metallurgical products
30	10	Metal products, except machinery and equipments
31	11	Machinery and equipments
32; 33	12	Office equipment, computing devices and electronic material
34; 35	13	Electronic devices, radio, precision, TV and communication equipments
36; 37	14	Motor vehicles and trailers
38; 39	15	Furniture, other manufactured products and material recovering
40	16	Construction: building and civil engineering
41; 42; 43; 44	17	Hotel industry, commerce and vehicle and motorcycle repairing, and fuel selling to small consumers
45; 46; 47; 48; 49	18	Transport services
50; 51; 52; 53	19	Telecommunication services, financial services, insurance and auxiliary services to financial mediation
54; 55; 56; 57	20	Building services, machinery renting, computing and R&D
58; 59; 60; 61; 62	21	Other business and service activities (health and social work, recreational activities, etc.)
63; 64; 65; 66; 67; 68; 69; 70; 71	22	Other no market personal services and public administration services

As in the previous case, 80% of the fixed costs accrued to employees' wages, amounting 1033.6 k€/year for 22 permanent employees per year. Once again, the direct demands generated by the construction, operation and maintenance of the tower plant were later assigned to the different sectors of the economy included in the reduced form of the Spanish input–output table.

3.2. National economy data

The most recent official Spanish input–output table dates from the year 2000 and was published by the National Statistics Institute in 2007. This table reflects the transactions taken place across economic sectors in the form of increased demands as well as intermediate and final production across 73 national economic sectors. Based on the 73 sectors included in the original table, a reduced table consisting of the 22 most relevant economic sectors for this analysis was constructed (Table 5).

As shown in Tables 6–9, total investment and operation costs of both solar thermal power plants had to be broken down and associated to the different sectors of the reduced I–O table constructed for this analysis.

4. Scenario results

4.1. Individual impacts

4.1.1. Parabolic trough plant

Table 10 shows the total effect associated to the parabolic trough plant, which amounts to 930 M€, equivalent to 18.6 M€ for every MW installed. The total indirect effect generated during the construction and operational phase would reach 445 M€, of which 285 M€ are indirect national demands and 160 M€ are indirect demands generated outside the Spanish territory. The associated multiplier effect is 1.92 which means that for every euro invested during the construction and operation phase, an aggregate demand of 1.92 euros would be generated. The national multiplier would be 1.70 while the foreign multiplier would be 3.14.

At the same time, the above mentioned increased demand of goods and services in the economy would generate 9583.7 additional 1-year jobs – of which 5553.5 and 4030.2 are direct and indirect, respectively – implying that for every 19.8 thousand euros directly invested during the construction and operation phases of the parabolic trough plants, one new job would be created.

4.1.2. Solar tower power plant

As shown in Table 10, total economic effect generated by the solar tower plant would amount to 521.9 M€ – which is equivalent to 30.7 M€/MW – and the total indirect effect generated during the construction and operation phase of the plant would amount to 255 M€. This figure includes 163 M€ which would account for the national indirect demand and 92 M€ which would account for an indirect increase in the demand of goods and services generated outside the Spanish borders. The multiplier effect would be 1.96 while the national and foreign multiplier effect would be 1.70 and 3.73, respectively. Similarly, Table 11 shows that during both the construction and operation phase, 5491 1-year jobs would be created – 3213 directly and 2278 indirectly – implying that one new job is created for every 20.6 thousand euros invested.

4.2. Compliance with the PER objectives

Based on these results, in order to estimate the socio-economic impact derived from the compliance with the 500 MW solar thermal installed capacity goal described in the Spanish Renewable Energy Plan 2005–2010 (PER), it was assumed that the 2010 PER solar thermal installed capacity goal would be met through the installation of 400 MW of parabolic trough plants (80% of the total power) while the rest (20%) would be met with the installation of 100 MW solar tower plants.

It was also considered that during the period under consideration, operation and investment costs would remain constant. This assumption is supported by the literature which does not foresee any major cost decline in the technology over the next 5 years (DLR, 2005).

Table 6
Hypothesis for the distribution of the investment costs to the economic sectors included in the reduced I–O table.

Sector code	Solar field (%)	Power block (%)	Terrain (%)	Storage (%)	Construction (%)	Engineering (%)	Contingencies (%)
1			13.4				
4			10.6				
7	3.3			28.6			
8	19.2						
9	22.5			20.0			
10	20.6			1.4			
11	6.2	67.4		20.0			
13	11.5	5.0					
16	8.6	25.4	22.1	22.0	100.0		
18	8.1	2.2		8.0			
20			22.1				
21			31.8			100.0	100.0

Parabolic through plants.

Table 7
Hypothesis for the distribution of the O&M costs to the economic sectors included in the reduced I–O table.

Sector code	Fixed operation (%)	Maintenance (%)	Financing (%)	Natural gas (%)	Electricity (%)
4				100	100
7		10			
8		10			
12		10			
19	10	20	100		
20		20			
21	10	30			
	20	100	100	100	100

Parabolic through plants.

Table 8
Hypothesis for the distribution of the investment costs to the economic sectors included in the reduced I–O table.

Sector	Solar field (%)	Tower (%)	Power block (%)	Terrain (%)	Storage (%)	Construction (%)	Engineering (%)	Contingencies (%)
1				13				
4				11				
7					36			
8	36							
9		17			6			
10	20	41			1			
11	20	41	72		29			
12	7							
13	7	1						
16	10		25	22	25	100		
18			2		2			
20				22				
21				32			100	100

Solar tower plants.

Table 9
Hypothesis for the distribution of the O&M costs to the economic sectors included in the reduced I–O table.

Sector code	Fixed operation (%)	Maintenance (%)	Financing (%)	Natural gas (%)	Electricity (%)
4				100	100
7		10			
8		10			
12		10			
19	10	20	100		
20		20			
21	10	30			

Solar tower plants.

Table 10
Total effect on the demand of goods and services derived from the construction of an individual plant.

CONCEPT	Demand ratio (M€/MW)	Total effect (M€)
Parabolic trough power plants (PTP)		
Direct demand (Inv.+Oper.)	9.7	485
National	8.2	410
Exterior	1.5	75
Indirect demand	8.9	445
National	5.7	285
Exterior	3.2	160
Total PTP		930
Tower power plants (TP)		
Direct demand (Inv.+Oper.))	15,7	266
National	13.7	232
Exterior	2.0	34
Indirect demand	15.0	255
National	9.6	163
Exterior	5.4	92
Total (TP)		522

Table 11
Total effect on the employment from the construction of an individual plant.

CONCEPT	Employment ratio (Emp/MW)	Total employment
Solar trough power plant (50 MW)		
Direct employment	111	5553.5
Indirect employment	81	4030.2
Solar tower (17 MW)		
Direct employment	189	3213
Indirect employment	133	2278

Table 12 shows the total effect that accomplishing the PER objectives would have on both the National and foreign demand of goods and services as well as employment. The increase in both demands would amount to 10,538 M€, which is equivalent to an average 21 M€ for every MW installed. When considering only the parabolic trough plants, the effect would amount 7467 M€, (18.7 M€ for every MW installed). When considering the solar tower plants, the increase would amount to 3071 M€ (30.7 M€ for every MW installed).

In terms of increased demand, the most benefited sector would be the financial services sector (sector 19), followed by the electricity production sector (sector 4) and the other business and service activities- health and social work, recreational activities, etc.- (sector 21). Other sectors specially benefited would be machinery and equipment (sector 11) as well as construction (sector 16).

Finally, Table 13 shows the effects on employment that would be generated as a result of the accomplishment of the PER's solar thermal power objectives. The direct employment generated would amount to 63,485 jobs while the indirect employment would result in 45,508 equivalent jobs of 1 year of duration. So, the total employment generated would reach 108,992 equivalent full-time jobs of 1 year of duration. Despite this being an aggregated result (as it is the sum of the employments generated along the time horizon up to 2040), when taking into account the Spanish unemployed persons registered in July of 2008 (2,381,500), this figure represents 4.5% of current unemployment.

5. Conclusions

When compared with conventional fossil fuel technologies, renewable technologies often have several environmental and socio-economic benefits which are seldom internalized. Support policies are therefore needed in order to make renewable technologies competitive in the energy market. In a world of scarce resources, the type of analysis presented in this work is a convenient tool for policy makers which helps them analyze whether the public budgetary resources spent in subsidising the cost of renewable technologies are justified in terms of social welfare, considering not only their environmental benefits but also their contribution to increasing GDP, reducing foreign dependency and employment generation.

Solar energy is likely to play a key role in the future energy scene and Spain will most likely become one of the leading countries in terms of its implementation, expertise and development of new technologies. The recently published Spanish Renewable Energy Plan 2005–2010 states that solar thermal installed capacity by 2010 should reach 500 MW. The current portfolio of projects under development as well as the solar thermal power plants under construction already exceeds the PER goal. In order to evaluate the socio-economic impacts that would be generated when accomplishing the PER's solar thermal installed capacity objective, the increase in the demand of goods and services as well as the employment generated have been quantified.

In order to carry out the analysis, it was necessary to first compute the economic impact derived from the construction and operation of two different power plants: a 50 MW parabolic trough plant and a 17 MW tower plant. Based on the data and information provided by similiar investment projects currently underway, it was possible to estimate their socio-economic impact using the input–output methodology. Based on this methodology, the impact of both direct and indirect effects on the demand of goods and services – inside and outside the Spanish borders – as well as the employment were estimated.

The second analysis consisted in estimating the socio-economic impacts generated by the construction and operation of 500 MW solar thermal plants. This analysis was based on the previously obtained results at an individual scale. Moreover, it was assumed that solar thermal parabolic trough would represent 80% of such installed capacity while the remaining 20% would be met with tower plants. The total effect on the national and foreign demand of goods and services would amount 10,538 M€ which is equivalent to an average 21.1 M€ for every MW installed. The total direct employment generated would be 63,485 while the indirect employment generated would reach 45,508 equivalent jobs of 1 year of duration.

The possible impacts of playing a leadership role in international markets is one of the most valuable intangible effects omitted in this study. Spain can be considered today as one of the pioneers in solar thermal deployment, which could present a unique opportunity for Spanish technological and engineering enterprises to position themselves in this new niche in international markets. There are certainly other possible omitted effects which should be considered by policy makers. Examples of such effects inlcude the extension of the transport electricity grid to absorb energy from dispersed plants and the modifications to the power plant fleet required to soften the electricity system in order to guarantee the electricity supply in peak times.

Although the results should be interpreted with caution because the I–O methodology's limitations, it can be concluded

Table 12
Total effect on the demand of goods and services derived from PER.

Sector	Effect of parabolic trough plants planned in PER (400 MW)						Effect of tower plants planned in PER (100 MW)					
	National demand			International demand			National demand			International demand		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
1	1	14	15	0	6	6	1	5	7	0	2	2
2	0	171	171	0	706	706	0	70	70	0	287	287
3	0	89	89	0	24	24	0	35	35	0	9	9
4	441	146	587	0	2	2	184	62	246	0	1	1
5	0	28	28	0	6	6	0	12	12	0	2	2
6	0	96	96	0	26	26	0	38	38	0	10	10
7	111	150	260	41	93	134	30	61	91	7	38	45
8	171	87	258	62	12	73	108	34	142	41	5	45
9	182	138	320	94	76	170	26	78	104	1	43	44
10	140	116	256	68	23	90	109	55	163	23	11	34
11	253	84	336	162	77	239	197	41	238	76	38	114
12	43	69	112	0	66	66	34	32	66	8	31	39
13	90	32	122	46	50	95	19	11	30	8	16	24
14	0	15	15	0	9	9	0	6	6	0	3	3
15	0	39	39	0	10	10	0	14	14	0	4	4
16	375	157	532	97	0	97	119	55	174	33	0	33
17	0	126	126	0	2	2	0	52	52	0	1	1
18	73	161	234	38	25	64	3	65	68	2	10	12
19	956	228	1184	0	15	15	372	91	463	0	6	6
20	88	107	196	0	13	13	35	43	78	0	5	5
21	358	226	584	0	47	47	132	96	228	0	20	20
22	0	14	14	0	0	0	0	5	5	0	0	0
Total	3282	2293	5575	606	1286	1892	1369	960	2330	199	542	741

Table 13
Total effect on employment (PER goal for thermo solar power generation).

Sector	Solar trough power plant			Solar tower plant		
Cod	Direct	Indirect	Total	Direct	Indirect	Total
1	39	408	446	33	162	196
2	0	1686	1686	0	686	686
3	0	91	91	0	36	36
4	1662	548	2210	694	234	928
5	0	281	281	0	114	114
6	0	1298	1298	0	518	518
7	896	1214	2110	240	497	738
8	2338	1185	3523	1475	467	1942
9	1003	763	1766	143	429	572
10	2785	2310	5095	2164	1090	3254
11	4004	1324	5328	3120	653	3773
12	461	735	1195	368	339	707
13	1081	389	1470	230	129	359
14	0	124	124	0	50	50
15	0	919	919	0	317	317
16	7745	3244	10,989	2464	1132	3596
17	0	3295	3295	0	1358	1358
18	1347	2995	4342	59	1211	1270
19	11,049	2636	13,685	4295	1052	5347
20	424	513	936	169	206	375
21	9419	5937	15,356	3473	2512	5985
22	0	523	523	0	203	203
Direct jobs on plant	176	0	176	129	0	129
Total	44,428	32,418	76,845	19,057	13,395	32,452

that the socio-economic effect derived from the accomplishment of the PER's solar thermal installed capacity goal would be remarkable, in terms of both the increase in the demand of goods and services and in employment.

Appendix A. Input–Output analysis: methodological steps

A.1. Impacts in the demand of goods and services

According to the I–O methodology, the relationship between the expenditure generated by a certain project (ΔD) and its impact in the economy in terms of increased demand of goods and services (ΔQ) is depicted by the following relation:

$$\Delta Q = (I - A)^{-1} \Delta D, \quad \text{(A.1)}$$

where I is the identity matrix, A is the matrix of technical coefficients (which reflects the percentage of production from each sector consumed by each of all the productive sectors) and $(I–A)^{-1}$ is the Leontief inverse, that represents the total (direct and indirect) requirements per unit of final demand.

A.2. Impacts on employment

The development of any type of energy project generates impacts on the employment. On the one side, there is a direct effect on employment in those economic sectors that provide inputs consumed by the solar thermal project. On the other side, the indirect effect on employment consists in all those jobs created in those other sectors in the economy that supply inputs to the industries that directly provide goods and services to the project.

The total direct and indirect employments created in each sector (L_y) will be estimated by multiplying the number of employed people per unit of output produced in each sector (vector L_s[9])) by the total final demand (direct and indirect)

[9] Vector L_s is constructed based on the employment information published by the Spanish National Statistics Institute.

generated by the project:

$$L_s\Delta Q_y = L_y. \quad (A.2)$$

Based on this estimation, the number of direct (DL_s) and indirect (IL_s) employments is estimated using the following expressions:

$$DL_s = L_s\Delta D_y, \quad (A.3)$$

$$IL_s = L_s(\Delta Q_y - \Delta D_y). \quad (A.4)$$

A.3. Impacts on commercial flows

It is often the case that during the construction phase of any power plant, part of the goods and services required are imported from outside the national territory. Therefore, when estimating the economic and employment impact of the project analyzed in this work, it is possible to distinguish the national from the exterior effects.

$$\Delta D_y = \Delta ND_y + \Delta ID_y, \quad (A.5)$$

where ΔD_y is the increase in the demand of goods and services; ΔND_y is the increase in the demand of national goods and services; and ΔID_y is the increase in imports of goods and services which can be decomposed in the following manner:

$$\Delta D_y = \Delta ND_y + (\Delta dID_y + \Delta iID_y), \quad (A.6)$$

where ΔdID_y is the direct imported demand; ΔiID_y is the indirect imported demand.

In order to obtain [6], the following steps should be taken: first, when computing the total national effect, one must multiply the Leontief's inverse matrix by the investment vector that accounts only for those investments made within the Spanish territory (national direct demand generated by the project). It is worth noting that the direct national demand (dND) has been estimated by making several assumptions – showed in Tables 1 and 3.

$$\Delta ND_y = (I - A)^{-1}\Delta dND. \quad (A.7)$$

From the resulting vector from expression (A.7) – which accounts for the total effect on the national demand – one must subtract the direct increase in the national demand in order to obtain the indirect increase in the Spanish demand.

$$\Delta iND_y = \Delta ND_y - dND_y. \quad (A.8)$$

In order to compute the exterior or foreign effect of the project – which is made of the total sum of the direct and indirect imports – the following steps must be taken:

$$\Delta ID_y = \Delta dID_y + iID_y. \quad (A.9)$$

The direct import demand vector is obtained from the information regarding the country of origin of all goods and services purchased during the construction and operation phase of the project. Put it in another way, it is possible to identify what part of the directly increased demand related to the project is purchased from outside the Spanish territory.

$$\Delta dID_y = \Delta dD_y - \Delta dND_y. \quad (A.10)$$

Finally, in order to compute the increase in indirect imports, one must identify (from the symmetric I–O table) what is the percentage of the indirectly generated demand that is imported. From this information, the indirectly imported demand vector will be obtained by multiplying the indirect demand vector by the percentage rate that is imported in each sector of the economy (data obtained from the INE).

$$\Delta iID_y = \Delta iND_y \frac{I_i}{D_i}, \quad (A.11)$$

where I_i is the imports of sector i, D_i is the demand of sector i.

A.4. Multiplier effect

Finally, and based on the previous results, it is then possible to compute the multiplying effect of a certain project. The multiplier effect is a number that indicates by how much a certain economy is going to grow due to a certain project development taking into account both direct and indirect effects. That is, for every monetary unit invested in the project, how much money is generated economy as a whole. The general formula to compute the multiplying effect (M) is:

$$\text{Multiplier} = \text{Total effects}/\text{Direct effects}.$$

Therefore, from the results obtained, three different multipliers can be computed:

Total multiplier:

$$M = \frac{\Delta Q}{\Delta D}.$$

National multiplier:

$$NM = \frac{\Delta ND}{\Delta dND}.$$

Foreign multiplier:

$$FM = \frac{\Delta ID}{\Delta dID}.$$

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