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Economic impacts of solar thermal electricity technology deployment on Andalusian productive activities: a CGE approach

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Abstract Solar thermal electricity is a type of renewable energy technology of special interest for Andalusia (southern Spain) because of the large number of annual sunshine hours. This paper estimates the impact on productive activities of increasing the production capacity of the installed solar thermal plants in Andalusia. Using a computable general equilibrium (CGE) approach, estimates of the changes in the economic sectors' activity under two different scenarios are obtained: i) based on two types of solar thermal electricity plants currently in operation and ii) based on an increase from 11 MW in 2007 to 800 MW installed capacity by 2013 to comply with the 'Plan Andaluz de Sostenibilidad Energética (PASENER)—Sustainable Energy Plan for Andalusia'. For the case of a parabolic trough solar collector power plant, results show that compliance with the PASENER goal would increase the level of the productive activities by around 30%. For the alternative technology—a solar tower power plant—results show that activities would increase by around 5% for 30 years, the estimated lifetime of this type of plant. Thus, the impact of the solar thermal

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electricity plants on the productive activities of the PASENER compliant production goal would be remarkable.

JEL Classification Q28 · C63 · Q43

1 Introduction

The view that renewable energy can be an engine of regional growth and development has been firming slowly, with its recognition in EU law since 2001. Directive 2001/77/EC (EP & C 2001) establishes, as one of the objectives of the Community, the policy on renewable electricity, its contribution to employment generation, especially local employment, and to the promotion of regional development. On the other hand, the European Commission Communication of 2005 related to renewable energy stated as one of its objectives the improvement in economic and social prospects, especially for rural regions (European Comission 2005). Recently, the Renewable Energy Policy (EP & C 2009) emphasized the benefits of new renewable energy plants to rural development because they can generate, among other benefits, opportunities for the development of small- and medium-sized enterprises. Thus, promotion of new renewable energy technologies in Andalusia (southern Spain), and therefore solar thermal electricity technology deployment, can be seen as an opportunity for growth and regional development.

This paper estimates the changes in productive activities in Andalusia due to the solar thermal electricity deployment.[1] Using a computable general equilibrium (CGE) approach, the estimation is carried out under two different scenarios. In the first scenario, the paper estimates the impact on productive activities from the deployment of two types of solar thermal electricity plants.[2] Impacts of each type of plant are obtained by comparing results from the model with the benchmark. For this scenario, the paper follows technological assumptions made in Caldés et al. (2009). In the second scenario, to estimate the impact on the same productive activities, we consider compliance with the 'Plan Andaluz de Sostenibilidad Energética (PASENER) 2007–2013' (Consejería de Innovación, Ciencia y Empresa 2007) requiring an installed capacity of 800 MW by 2013 starting from 11 MW in 2007. Impacts of this increase are obtained by comparing results from the model in case of PASENER compliance with the same benchmark. The economic activity values for the Andalusian economy updated to 2008 define the benchmark.

In case of renewable energy sources such as solar energy, their economic impact has been usually estimated using Input–Output (I–O) models. For the USA, I–O analysis has been reported in Cook (1998); US DOE (1992) and Ciorba et al. (2004); for the European area in Kulisic et al. (2007), Madlener and Koller (2007) and Allan et al.

[1] The Andalusian electricity sector is deeply integrated with the rest of the Spanish sector. Spain has a regulated electricity market. It is a free market for the power plants but with wholesale and retail customers. Prices are fixed by authorities.

[2] Solar energy is an intermittent energy source, making energy storage an important issue in order to provide energy continuously. However, solar thermal power plants generate heat using lenses and reflectors to concentrate the sun's energy. As the heat can be stored, these plants are unique because they can generate power when it is needed, i.e. during day or night. We assume that solar thermal energy is part of the Andalusian mix.

(2008) developed a similar approach. Caldés et al. (2009), Calzada et al. (2009) and the European Commission (MITRE) (2009) recently used an I–O model to estimate the economic impact of renewable energy sources in Spain.

Besides the estimation of the economic impacts of solar thermal electricity deployment, this paper aims to expand the literature using a computable general equilibrium (CGE) approach based on a social accounting matrix (SAM) instead of the I–O models used in similar works. In the last 25 years, the CGE has been widely used to analyse government economic policies, both in developed and developing countries (Shoven and Whalley 1992; Arndt et al. 2009). In general terms, these models translate the theoretical Walrasian general equilibrium system into fully operational tools, including an endogenous output and price system, substitutability in production and demand, and the optimization behaviour of individual agents. A CGE analysis allows one to study the changes in the spheres of production and consumption as well as in income distribution, in response to changes in a given economic policy, as these models explicitly include a representation of the framework of interdependencies among all markets in an economy.

Section 2 explains the CGE methodology. Section 3 describes the economic database used. Results are contained in Sect. 4. Section 5 gives conclusions and discussion.

2 Computable general equilibrium methodology

In this section, we give a general overview of the CGE methodology and the associated SAM used for the modelling and computation.

2.1 The social accounting matrix (SAM)

Table 1 shows a standard framework of a social accounting matrix (SAM). According to Stone (1962), a SAM model is a representation of all the transactions made in the setting of an economy in a certain period of time. The Input–Output Tables define the relation between the final demand and production, whereas the SAM describes how the production process influences and determines the demand. Thus, they extend the Leontief model and the relations shown by the Input–Output Tables because they describe the flows between the value added and the final demand and, therefore, represent the circular flow of the income.

The SAM rows show the incomes for different accounts, whereas the columns show the expenses. The cells show monetary values.

Following the early work on SAM in Stone (1962) and Pyatt and Round (1979) among others, its first applications in Spain[3] can be found in works such as Kehoe et al. (1988). Recently, SAM at a regional level has been developed,[4] and this paper follows this trend.

[3] To read more about SAM applied to the Spanish economy, see Polo and Sancho (1993), Uriel et al. (1998, 2005), Fernandez and Polo (2001), Cardenete and Sancho (2003) and Sanchez-Choliz et al. (2007).

[4] See, for example, Manresa and Sancho (2004), and Llop and Manresa (1999) for Catalonia; Mainar and Flores (2005) for Aragon; Crámara and Marcos (2009) for Madrid; De Miguel and Manresa (2004) for Extremadura; and Cardenete (1998), and Cardenete and Moniche (2001) for Andalusia.

Table 1 Social accounting matrix (SAM) for Andalusia, 2008

	Production	Productive factors	Institutional sectors	Capital	Foreign sector
Production	Intermediate consumption		Public sector and domestic consumption	Gross capital formation	Export
Productive factors	Payment of VA to the factors				
Institutional sectors	Taxes on activities and goods & services	Factors income allowance to institutional sectors	Common transfers among institutional sectors	Taxes on capital goods	Transfers from the rest of the world, taxes on export
Capital		Fixed capital consumption	Institutional sectors saving		Foreign saving
Foreign sector	Import		Transfers to the rest of the world		

Source Symmetrical matrix IOFAN95 (IEA) and Cardenete and Moniche (2001)

The SAM describes an economy in great detail as in Fernandez and Gonzalez (2004). Therefore, SAM becomes a very useful instrument for public policy evaluation, allowing an investigator to overcome some of the statistical limitations. Starting with some hypothesis related to the behaviour of the economic agents, their economic environment and the structure of the economy, SAM are used as databases which allow one to develop a range of multisectoral models such as the computable general equilibrium models (CGE) (Shoven and Whalley 1992) described in the following subsection.

2.2 Computable general equilibrium model

A static CGE model has been developed for the Andalusian economy, following the structure of Andre et al. (2005), who presented the first CGE applied to environmental issues for Andalusia. This model allows us to determine the effects on resource allocation under the two scenarios considered. In our case, we have not used the environmental taxes and we have focused on the purely economic CGE model as detailed in the following. This model involves a set of equations that reflect equilibrium conditions and the behaviour of the different economic agents. For that reason, the producers, the households, the public sector and the foreign sector are considered in general terms.

In this subsection, a detailed analysis of each sector or agent is given (Sects. 2.2.1 to 2.2.4), including some observations in relation to the labour market (Sect. 2.2.5) and the notion of equilibrium used (Sect. 2.2.6).[5]

2.2.1 Activities

The model for the Andalusian economy incorporates 27 productive activities. It is assumed that each productive activity generates a homogeneous product, according to

[5] The main equations of the model are shown here. The full listing of equations is available upon request.

a nested production function. At the first nested level, following the Armington (1969) hypothesis, the total production of each activity (Q_j) is obtained as a Cobb–Douglas aggregate of domestic output (Qd_j) and imports (Qm_j). At the second level, the domestic production for each activity is obtained with a fixed-coefficients technology between intermediate inputs (X_{ij}) and value added (VA_j). Finally, at the third nested level, the value added of each activity is obtained by combining the primary factors of capital (K_j) and labour (L_j), according to a Cobb–Douglas technology function. The expressions used at these three levels are given in Eqs. (1), (2) and (3), respectively:

$$Q_j = \beta_{Aj} Qd_j^{\delta dj} Qm_j^{1-\delta dj} \tag{1}$$

$$Qd_j = \min\left\{X_{1j}/a_{1j}\ ,\ X_{2j}/a_{2j}, \ldots, X_{27j}/a_{27j}\ ,\ VA_j/v_j\right\} \tag{2}$$

$$VA_j = \beta_j K_j^{\alpha_j} L_j^{1-\alpha_j}, \quad j = 1, 2, \ldots, 27 \tag{3}$$

In these expressions, β_{Aj} and β_j are scale parameters; δd_j are parameters which reflect the share of domestic output of j in j's total production; parameters a_{zj} express the minimum amount of z needed to obtain a unit of j; v_j is the technical coefficient of value added; and, finally, α_j and $(1-\alpha_j)$ are parameters which represent the participation of the primary factors, namely capital and labour, with regard to value added.[6] We have chosen these two types of methodology—Leontief and Cobb–Douglas—because we have used a calibration method to give values to overall parameters and coefficients in the model, avoiding the need to estimate any value following econometric estimations, as CES (Constant Elasticity of Substitution) technology requires.

Finally, it is assumed that firms obtain their demand functions for inputs and supplies of outputs by maximizing profits under the specified technological constraints.

2.2.2 Consumption

The model assumes only one consumer. The following Cobb–Douglas utility function (U), defined in terms of saving and consumption, is considered:

$$\text{maximize } U_h\left(C_{jh}, S_{jh}\right) = \left(\prod_{j=1}^{27} C_{jh}^{\phi_{jh}}\right) S_h^{(1-\phi)_h} \tag{4}$$

$$\text{such that } p_j C_{jh} + invpS_h = YD_h \tag{5}$$

In Eq. (4), the parameters ϕ and $(1-\phi)$ represent the share coefficients corresponding to consumption goods and savings, respectively. S represents the saving, C expresses the private consumption of commodity, and j and h is the representative consumer. Recall that the economy is divided into 27 activities. Equation (5) shows

[6] For the simulations considered in the paper, a sensitivity analysis for functional forms has been done. Specifically, a Cobb–Douglas function between intermediate inputs and value added has been introduced instead of the Leontief function of Eq. (2). The results obtained in both cases are very similar—qualitatively and quantitatively—and, therefore, those from the Cobb–Douglas specification have not been included in the paper.

the budget constraint for this representative household account, where p_j are present consumption prices and *invp* is the price index of savings/investment goods.

Thus, the disposable income of the only household group[7] is given by Eq. (6):

$$YD = (1-\tau)\,[rK + wL(1-u) + cpi\ TPS + rowpTFS - ess\ wL(1-u)]\,. \tag{6}$$

The representative consumer derives the consumption demand functions by maximizing the utility function subject to the budget constraint shown in (4) and (5). The right-hand side of Eq. (6) shows disposable income, *YD*. This income comes from the sale of its endowments of capital (K) and labour (L), at the prices r and w, respectively, which are our *numerarie* in the model. In addition, households receive transfers from the public sector (*TPS*), indexed by the consumer price index (*cpi*), and receive transfers from the foreign sector (*TFS*) indexed by rest-of-the-world price index (*rowp*), although their total quantitative importance is minimal. Finally, households have to pay employees' social contributions and income tax, whose rates are *ess* and τ, respectively. The unemployment rate is represented by u.

2.2.3 Government

The activity of the government consists, on the one hand, of producing public services, using the technology of "Non-sales oriented services" (j_{27}), while, on the other hand, of demanding public services (public consumption, C^G_{j27}) and investment goods (C^G_i). In this sense, this agent can be considered to maximize a Leontief utility function (U^G), defined by Eq. (7):

$$U^G = \min\left\{C^G_{j27},\ \gamma^G C^G_i\right\} \tag{7}$$

where γ^G is an economic policy parameter reflecting the existence of a fixed proportion between public consumption and public investment.

The budget constraint that the government confronts can be expressed by inequality (8):

$$p_{j27}C^G_{j27} + p_i C^G_i \le R^G + p_i w^G_i - cpi\ TPS. \tag{8}$$

The left-hand side of this inequality reflects government spending on consumption and investment. On the right-hand side, tax revenues are (R^G), from which transfers paid to households have to be subtracted. w^G_i represents the stock of debt that the government issues when it is in budgetary deficit. The rest of the activities could buy this debt at the same price as saving/investment, p_i.

With respect to the total tax revenues R^G, the model includes net taxes on production, employers' social security contributions, import taxes and the previously

[7] As will be discussed later, u is an endogenous variable that reflects the unemployment rate.

mentioned value added tax as indirect taxes. As direct taxes, employees' social security contributions and income tax are considered. The tax revenue components (a) to (f) are specified in Eqs. (9) to (14), respectively.

a) Taxes on production (*Rt*):

$$Rt = \sum_{j=1}^{27} t_j \left[\sum_{z=1}^{27} p_z X_{zj} + w(1 + esc_j)L_j + rK_j \right]. \tag{9}$$

That is, the domestic output of each activity is subject to a tax at a rate t_j. The production price for activity z is p_z. Finally, esc_j stands for the employers' social contributions rate.

b) Employers' social security contributions (*resc*):

$$resc = \sum_{j=1}^{27} esc_j wL_j. \tag{10}$$

c) Import taxes (*Rtarif*):

$$Rtarif = \sum_{j=1}^{27} tarif_j p_m Qm_j \tag{11}$$

where $tarif_j$ is the import tariff rate for activity j, while p_m is the weighted price index of imported products.

d) Value Added Tax (*Rvat*):

$$Rvat = \sum_{j=1}^{27} vat_j p_j C_j. \tag{12}$$

e) Employees' social security contributions (*ress*):

$$ress = esswL(1 - u). \tag{13}$$

f) Income tax ($R\tau$):

$$R\tau = \tau \left[rK + wL(1 - u) + cpi\, TPS + TFS - esswL(1 - u) \right]. \tag{14}$$

2.2.4 Foreign sector

Following the Armington (1969) hypothesis, since our analysis is based on the Andalusian regional economy, the foreign sector is modelled in a simple, aggregated way, as a single sector that includes the rest of Spain, the European Union and the rest of the world.

$$ROWD = \sum_{j=1}^{27} rowpIMP_j - \sum_{h=1}^{1} TFS_h - \sum_{j=1}^{27} rowpEXP_j \tag{15}$$

where IMP_j represents the import activity j, EXP_j the export activity j, and TFS_h the transfers which come from the foreign sector to the representative consumer h. The foreign deficit or surplus is represented by *ROWD*.

2.2.5 Labour market

Capital and labour demands are obtained from conditional factor demand functions, thus minimizing the cost of obtaining value added. For the capital factor, we assume perfectly inelastic supply and therefore, this factor is always fully employed. However, the model allows possible rigidities in the labour market, so the unemployment rate may be positive. More precisely, we consider the relationship in Eq. (16) between the real wage and the unemployment rate:

$$\left(\frac{w}{cpi}\right) = \left(\frac{1-u}{1-u_0}\right)^{1/\beta_d}. \tag{16}$$

This formulation of the labour market in CGE modelling is due to Kehoe et al. (1988), following the precepts established in Oswald (1982). The variable *(w/cpi)* represents the real wage, u is the unemployment rate, u_0 is a parameter that reflects the unemployment rate at the benchmark equilibrium and β_d is a parameter that expresses the sensitivity of the real wage to the unemployment rate. This last parameter can have values between zero and infinity. If $\beta_d = 0$, the real wage will adjust sufficiently so that the unemployment rate remains constant and equal to the benchmark equilibrium rate. If $\beta_d \to \infty$, the situation is exactly the opposite, that is to say, the real wage remains constant and the unemployment rate varies. For intermediate values, higher values of this parameter represent greater wage rigidity. In other words, the sensitivity of the real wage to the unemployment rate diminishes. In the simulations presented below, calculations are carried out for different values of this parameter. Specifically, the extreme values $\beta_d = 0$ and $\beta_d \to \infty$ are used, as well as the value from econometric literature, $\beta_d = 1.25$ (see Andrés et al. 1990).

2.2.6 Equilibrium

The notion of equilibrium that is used in the model is that of the Walrasian competitive equilibrium, extended to include not only producers and households, but also the government and foreign sectors (see, for instance, Shoven and Whalley 1992). Specifically, economic equilibrium is determined by a price vector, an activity-level vector and a set of macro variables such that supply equals demand in all markets, with the sole exception of the labour market, as previously discussed. Further, each one of the economic agents included in the model attains its corresponding optimal choices under the respective budget constraint, i.e., the agents implement their optimal equilibrium solutions.

We assume full employment for capital and unemployment in labour factor in the benchmark equilibrium. Additionally, the level of activity of government and the foreign sectors will be fixed, allowing relative prices, activity levels, public deficit and foreign deficit work as exogenous variables as mentioned before.

Therefore, the equilibrium will be an economic state in which the representative consumer will maximize his utility, the productive activities will maximize their profits after taxes and the public revenues will be equal to the payments to the different economic agents. In this equilibrium, total sales will be equal to total demands in every market. Formally, the model achieves the equilibrium state of the Andalusian economy where the supply and demand functions for every good and service will be obtained as the solution of maximization of utility and profit problems. The result will be a price vector of goods and factors, utility level and tax revenues which satisfy the given conditions.

Following these specifications, we reproduce the data contained in the SAM as a *benchmark equilibrium* in which all prices (endogenous and exogenous) are normalized to be equal to 1 at the initial time. From this initial condition, we introduce the increase in demand associated with the solar thermal power activity implied in the PASENER goal provoking an *exogenous shock*. This will allow us to evaluate the changes by comparing benchmark equilibrium with the simulation equilibrium. The model has been implemented using *GAMS* software (Brooke et al. 1988) with *MINOS* as the solver. The CGE model has been calibrated using the SAM for Andalusia, avoiding econometric estimations for coefficient and parameters included in the technological functions developed in the model. For more information about SAM and CGE structures, see Cardenete et al. (2010) and Cardenete and Sancho (2003), respectively.

Similar to Caldés et al. (2009), the model used in this paper assumes an absence of production capacity limitations for produced goods. This assumption implies that there are no limits to the amount that a certain activity can produce in response to an increased demand (either in a direct or indirect way) generated by a new investment. It is also assumed that during the period under consideration, operation and investment costs remain constant. But unlike in Caldés et al. (2009), primary factors act as a disciplining constraint since their levels, being elastic within limits, are subject to the labour market constraints as specified in Eq. (16).

The model allowed us to analyse two types of productive impacts:

(i) Direct impacts caused by the expansion of production in other productive activities that need intermediate inputs of the manufacturing process from another branch of activity. In this case, the construction, operation and dismantling (which is ignored in this analysis as stated in footnote 8) of a solar thermal power plant requires inputs of other activities and this requirement causes effects on production.[8]

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

(ii) Induced impacts that occur in the productive structure, derived from the productive cycle by the relationships between consumption and intermediate demand among productive activities. To satisfy the input requirements of the solar thermal power plant, remaining activities require other inputs. The use of the SAM also allows us to capture the effects from the generation of income that assumes a circular flow of income. The production of each activity generates a feedback process from the income of the production factors through to the expenditure of the institutional sector and finally to each activity's own productive process.

This simulation focuses on estimating both direct and induced impacts. To develop both analyses, we use the CGE model as a Leontief model. This means that we shock the final demand of the Andalusian economy as an impact demand model. Later, to look for the benchmark equilibrium of the economy, we develop an impact assessment modifying the structure of the final demand following the requirements of PASENER compliance. After that, we run the CGE model again looking for the new equilibrium.

The analysis carried out only reports gross economic impacts. Further investigations must consider the possibility that the output gains identified in the analysis might come at the expense of other states' output possibly from, for example, the crowding-out effect of power generation.

3 Data

This Section discusses the costs and other data related to solar thermal plants and the general data related to the Andalusian economy.

3.1 Solar thermal plant data

The data used in the CGE simulation come from SAMAND00[9] and from Caldés et al. (2009) which consider two types of technologies: a power plant consisting of 624 parabolic trough collectors with 50 MW of installed capacity and a central solar tower plant consisting of 2750 heliostats with 17 MW of installed capacity. Caldés et al. (2009) assumed that the market quota of every technology which would meet the PASENER goal consists of 80% parabolic trough plants and 20% tower power. This paper uses the same assumption. Due to the fact that the number of productive activities considered in Caldés et al. (2009) is less than the 27 activities included in the SAMAND00, we disaggregated some of those in Caldés et al. (2009) to obtain comparable figures between those results and ours.

Tables 6, 7, 8 and 9 in the Appendix show the investment costs and operation & maintenance (O & M) costs associated with every power plant.

From the aforementioned data on investment and operation & maintenance (O & M) costs, we obtain the increase in demand, associated with the solar thermal power

[9] SAMAND is the SAM used for the modelling and computation referred to Andalusian economic data. SAMAND00 refers to Andalusian economic data of the year 2000.

Table 2 Increase in demand associated with the solar thermal power activity (in percentage)

No.	Activity	Parabolic trough power plants technology	Solar tower power plant technology
1	Agriculture	0.04	0.08
7	Electricity	13.44	13.73
13	Chemicals	3.37	2.22
14	Mining, iron and steel industry	5.54	1.93
15	Metal products	4.26	8.07
16	Machinery	7.70	14.66
18	Construction materials	5.22	8.05
20	Other manufacturing	4.06	3.90
21	Construction	11.42	6.97
24	Transport and communications	31.34	27.90
25	Other services	2.70	2.63
26	Services oriented to Sales	10.91	9.84
	Total	100.00	100.00

Source Own elaboration

activity implied in the PASENER goal, which provokes the exogenous shock.[10] Table 2 shows activities involved in the increase in demand, and their percentages share for parabolic and tower technologies. The larger initial increase in demand occurs in the activity of transport and communications in both cases. Others activities with important initial increase in demand are electricity, machinery, construction and services oriented to sales. This information is relevant to assess the role that the initial impact plays in generating the set of indirect effects and helps in explaining the way equilibrium results shift after the change.

3.2 Andalusian economic data

The most recent SAMAND dates from 2000 and is due to Cardenete et al. (2010) constructed from Andalusian Input–Output Tables dating from 2000 as the basic source. This matrix has been adapted for the year 2008 using a cross-entropy method[11] and the overall available information about production and GDP. We refer to it as SAMAND08.

As for the degree of disaggregation of the activities in the SAMAND08, it is a 39 × 39 matrix, so it contains 39 activities, where the flows realized in the Andalusian economy for the year 2000 are described.

The productive activities have been reduced to 27 (account numbers 1 to 27); two productive factors—labour and capital—are numbered 28 and 29, respectively; the saving/investment account is sector (31); public administration (38); the consumption (30) and indirect taxes, employers' social security taxes, net taxes on production,

[10] We assume a Return-on-Assets (ROA) rate of 8% as in Calzada et al. (2009).

[11] For more information about the cross-entropy method see Robinson et al. (2001).

Table 3 Economic activity sectors in SAMAND08

SAMAND08 code	Activity	IOFAND00* code
1	Agriculture	1 to 3
2	Animal products and Forestry	4 and 5
3	Fishing	6
4	Coal	7
5	Rest of Extracts	8 and 9
6	Oil and natural gas	26
7	Electricity	46
8	Gas	47
9	Water	48
10	Food industry	10 to 19
11	Textile and leather	20 to 22
12	Wood products	23 and 24
13	Chemicals	27 and 28
14	Mining, iron and steel industry	33
15	Metallic products	34
16	Machinery	35 to 39
17	Vehicles	40
18	Construction materials	30 to 32
19	Other transport elements	41 and 42
20	Other manufacturing	25, 29, 43 to 45
21	Construction	49 and 50
22	Commerce and repairing	51
23	Rest of Commerce	52 to 56
24	Transport and communications	57 to 60
25	Other services	61 to 63, 66 to 71, 73, 83 and 84
26	Sales services	64, 65, 72, 76, 78, 80, 81, 85 and 86
27	Non-sales services	74, 75, 77, 79 and 82

* IOFOAND00 (Input–Output Framework of Andalusia 2000)
Source Cardenete et al. (2010)

tariffs and valued added tax (VAT); and direct taxes, income tax and employees' social security taxes are sectors 32 to 3, respectively; the last one is the foreign sector (39).

Table 3 shows the productive activities considered and the correspondence between IOFAND00 (Input–Output Framework of Andalusia 2000) codes and SAM codes.

4 Scenario results

From CGE model described above, and based on SAMAND08, this section records the increase in production of various activities that results from the investment in, and the operation and maintenance of, a solar thermal energy plant, depending on the technology used.

Table 4 Productive impacts of parabolic trough power plants technology

No.	Activity	Benchmark production (k€)	Scenario 1 one plant effects			Scenario 2 compliance with PASENER goal effects, 80%		
			Simulation production (k€)	Variation (%)	Weight of total variation	Simulation production (k€)	Variation (%)	Weight of total variation
1	Agriculture	9,360.93	9,346.57	−0.15	−0.57	10,284.04	9.86	0.88
2	Animal products and forestry	2,240.88	2,246.16	0.24	0.21	2,289.25	2.16	0.05
3	Fishing	961.21	966.39	0.54	0.20	893.69	−7.02	−0.06
4	Coal	2,855.65	2,880.14	0.86	0.96	4,552.35	59.42	1.62
5	Rest of extracts	2,590.45	2,607.26	0.65	0.66	3,080.96	18.94	0.47
6	Oil and natural gas	12,271.30	12,355.46	0.69	3.32	17,254.52	40.61	4.75
7	Electricity	4,706.44	4,807.70	2.15	3.99	14,828.47	215.07	9.65
8	Gas and water steam	506.28	510.46	0.82	0.16	724.99	43.20	0.21
9	Water	1,082.83	1,089.67	0.63	0.27	1,209.54	11.70	0.12
10	Food industry	31,299.09	31,390.68	0.29	3.61	27,788.02	−11.22	−3.35
11	Textile and leather	7,265.36	7,308.42	0.59	1.70	6,128.50	−15.65	−1.08
12	Wood products	4,460.81	4,485.27	0.55	0.96	5,155.03	15.56	0.66
13	Chemicals	13,347.20	13,429.32	0.62	3.23	16,054.12	20.28	2.58
14	Mining, iron and steel industry	5,580.48	5,641.01	1.08	2.38	6,929.59	24.18	1.29
15	Metal products	4,419.72	4,466.63	1.06	1.85	5,530.17	25.12	1.06

Table 4 continued

No.	Activity	Benchmark production (k€)	Scenario 1 one plant effects			Scenario 2 compliance with PASENER goal effects, 80%		
			Simulation production (k€)	Variation (%)	Weight of total variation	Simulation production (k€)	Variation (%)	Weight of total variation
16	Machinery	16,080.16	16,232.89	0.95	6.02	19,409.46	20.70	3.17
17	Vehicles	7,059.81	7,093.97	0.48	1.35	6,287.73	−10.94	−0.74
18	Construction materials	7,208.83	7,270.86	0.86	2.44	9,499.73	31.78	2.18
19	Other Transport elements	2,322.26	2,327.06	0.21	0.19	2,493.76	7.38	0.16
20	Other manu-facturing	9,306.62	9,389.02	0.89	3.25	11,769.98	26.47	2.35
21	Construction	48,650.64	48,850.31	0.41	7.87	53,310.98	9.58	4.44
22	Commerce and Repairing	2,147.20	2,158.12	0.51	0.43	2,285.05	6.42	0.13
23	Rest of Commerce	39,031.29	39,165.67	0.34	5.29	33,338.79	−14.58	−5.43
24	Transport and communica-tions	19,593.29	19,905.09	1.59	12.28	52,838.65	169.68	31.69
25	Other services	28,924.04	29,143.55	0.76	8.65	56,004.90	93.63	25.81
26	Services oriented to Sales	31,082.10	31,818.04	2.37	28.99	47,808.76	53.81	15.94
27	Services not oriented to Sales	26,174.92	26,182.63	0.03	0.30	27,682.44	5.76	1.44
	Total	340,529.82	343,068.36	0.75	100.00	445,433.51	30.81	100.00

Source Own elaboration

Table 4 contains the effects of parabolic trough power plants on Andalusian production over the lifetime of the plant (30 years), in the two scenarios analysed. The third column shows the situation of production by activity in 2008 (the Benchmark). Fourth to sixth columns illustrate effects of one plant on productive activities (Scenario 1), while seventh to ninth columns show these effects in compliance with PASENER goal (80%).

In the first scenario, fourth and fifth columns show the final production of each sector estimated by the model when a new plant is introduced and the percentage variation that represents the level of production compared to the production that each activity has in the benchmark framework (third column), respectively. The last row of these columns shows the final production for the whole economy and the total increase percentage, which amounts to 0.75%. The largest increases are linked to productive activities of services oriented to sales (2.37%), electricity (2.15%), transport and communications (1.59%), mining, iron and steel industry (1.08%) and metal products (1.06%). Column six shows the weight of each activity on the total production increase, i.e. the percentage ratio of the increase in production observed in each activity (for each activity, the fourth column minus the third) on the increased production of the whole economy (for total, the fourth column minus the third). These weights show the importance of each increase in the overall economy of Andalusia. The activity with the largest weight on the total variation is again the service-oriented sales activity, which is almost 29%. Overall, it is worth noting that activities 23, 24, 25 and 26, all of these being tertiary activities, account for 55.21% of the weight on total variation.

From the eighth column, it can be seen that the total percentage increase in production resulting from reaching PASENER goals with this technology (i.e. the percentage variation of the production level reached in compliance with PASENER goals compared to the production that each activity has in the benchmark framework), amounts to 30.81%, despite the remarkable increases in the activities of electricity (215.07%), transport and communications (169.68%) and other services (93%). It must be noted, that although there are sectors that have significantly increased production starting from the level they had before introducing the new plant, the final increase in production for the whole regional economy may not be as significant. The final increase depends on the contribution of each economic activity to the total production of the Andalusian region.

The production increases in the activities mentioned above seem logical. On the one hand, production of electrical activity will be reinforced by the operation of new plants, because the initial production level is low. Therefore, small production increases lead to significant additions. On the other hand, the increased production of transport and communication activities and other services is due to increase in the initial demand for these activities for the construction and operation of new plants, as can be seen in Table 2. Also, although it seems that intensive energy industries should increase their production, in fact they are not significantly affected. This can be explained by the fact that an increase in energy supply does not necessarily lead to increased production in these industries. Their increase in production will depend mainly on the demand for their goods, which among other things in turn depends on the product price. This price could fall if the increased energy supply would translate into a decrease in energy prices. However, this does not usually happen, as the cost of renewable energy is high.

The activities that have the biggest weight on total production variation (column nine), in compliance with PASENER (i.e. the effect increased production of each activity has on the increase in the total economy), are transport and communications, other services and services oriented to sales. Together, they add up to around 73.44% of the production increase in the whole economy, due to these technologies.

We now assess the role of direct and indirect equilibrium results after the first shock is introduced and absorbed. Comparing weights on total production variation (column nine of Table 4) with data from the third column of Table 2, we observe that activities with the greatest weights on total production variation are the same as those shown in Table 2. This shows the importance of direct effects. Nevertheless, percentage values in the two Tables 2 and 4 are different. This is due to the multiplier effects in the economy. Weights on total production variation of activities 24, 25 and 26 are substantially higher than the initial increases in demand shares. In particular, that occurs in activity 25 (other services). These three activities considered together account for 45% of the initial increase in demand (sum of transport and communications, other services and services oriented to sales in third column of Table 2), while the share of total production variation is 73.44% (sum of transport and communications, other services and services oriented to sales in column nine of Table 4). As the other activities included in Table 2 have declined in value in Table 4, the multiplier effects work mainly on these three services activities. On the other hand, weights on total production variation of activities not present in Table 2 represent the indirect effects of the initial demand on these activities. In general, these values are small, indicating that they have small multiplier effects. It is worth noting the impacts of activities 4, 6 related to the energy sector and 27 non-oriented services sales.

Table 5 shows the productive effects of solar tower power plants. Columns four to six show again one plant effects (Scenario 1) and columns seven to nine the effects obtained in compliance with the PASENER goal (20%) (Scenario 2). Column three represents the benchmark. For one plant, the increase in total production is shown in column five and amounts to 0.68%. Activities with the largest increases are productive services oriented to sales (2.03%), electricity (1.45%), metal products (1.11%), construction materials (1.05%), and transport and communications (1.07%). In terms of their share in total increases in production, column six shows that service-oriented sales activity accounts for 27.07% of the increase in total production and construction activity 16.04%. Also noteworthy is the weight of total variation of machinery's activity, rest of commerce, transport and communications, and other services. Overall, as in case of the technology discussed above, it is worth noting that activities 23, 24, 25 and 26 represent together 49.98% of the total production variation caused by the plant.

Table 5 also shows the effects associated with PASENER compliance. The total production increase due to solar tower power plant is 4.57%, with the most notable activity increases, compared to its benchmark production level, in service-oriented sales (14.20%). The three activities with the biggest weight are transport and communications, other services and facilities for sales. The total increase in these is 47.78%.

Table 5 Productive impacts of a solar tower power plant technology

No	Activity	Benchmark production (k€)	Scenario 1 plant effects			Scenario 2 compliance with PASENER goal effects, 20%		
			Simulation production (k€)	Variation (%)	Weight of total variation	Simulation production (k€)	Variation (%)	Weight of total variation
1	Agriculture	9,360.93	9,347.85	−0.14	−0.56	9,372.90	0.13	0.08
2	Animal products and forestry	2,240.88	2,245.59	0.21	0.20	2,277.89	1.65	0.24
3	Fishing	961.21	965.81	0.48	0.20	990.83	3.08	0.19
4	Coal	2,855.65	2,874.48	0.66	0.81	2,998.34	5.00	0.92
5	Rest of extracts	2,590.45	2,607.61	0.66	0.74	2,690.56	3.86	0.64
6	Oil and natural gas	12,271.30	12,338.71	0.55	2.90	12,766.40	4.03	3.18
7	Electricity	4,706.44	4,774.46	1.45	2.92	5,278.12	12.15	3.68
8	Gas and water steam	506.28	509.69	0.67	0.15	531.02	4.89	0.16
9	Water	1,082.83	1,088.75	0.55	0.25	1,124.43	3.84	0.27
10	Food industry	31,299.09	31,377.91	0.25	3.39	3,209.16	2.27	4.57
11	Textile and leather	7,265.36	7,303.74	0.53	1.65	7,492.63	3.13	1.46
12	Wood products	4,460.81	4,485.74	0.56	1.07	4,599.49	3.11	0.89
13	Chemicals	13,347.20	13,406.48	0.44	2.55	13,820.39	3.55	3.04
14	Mining, iron and steel industry	5,580.48	5,608.71	0.51	1.21	5,819.78	4.29	1.54
15	Metal products	4,419.72	4,468.99	1.11	2.12	4,797.50	8.55	2.43
16	Machinery	16,080.16	16,25.73	0.91	6.26	17,340.16	7.84	8.11
17	Vehicles	7,059.81	7,088.10	0.40	1.22	7,743.66	9.69	4.40
18	Construction materials	7,208.83	7,284.62	1.05	3.26	7,707.82	6.92	3.21
19	Other transport elements	2,322.26	2,325.98	0.16	0.16	2,352.58	1.31	0.20
20	Other manufacturing	9,306.62	9,371.75	0.70	2.80	9,806.40	5.37	3.21

Table 5 continued

No	Activity	Benchmark production (k€)	Scenario 1 plant effects			Scenario 2 compliance with PASENER goal effects, 20%		
			Simulation production (k€)	Variation (%)	Weight of total variation	Simulation production (k€)	Variation (%)	Weight of total variation
21	Construction	48,650.64	49,023.91	0.77	16.04	49,753.89	2.27	7.10
22	Commerce and repairing	2,147.20	2,156.62	0.44	0.40	2,224.97	3.62	0.50
23	Rest of commerce	39,031.29	39,166.61	0.35	5.82	39,331.33	0.77	1.93
24	Transport and communications	19,593.29	19,803.09	1.07	9.02	21,255.22	8.48	10.69
25	Other services	28,924.04	29,111.92	0.65	8.07	30,275.34	4.67	8.69
26	Services oriented to sales	31,082.10	31,711.97	2.03	27.07	35,497.15	14.20	28.40
27	Services not oriented to sales	26,174.92	26,181.70	0.03	0.29	2,617.61	0.16	0.27
	Total	340,529.82	342,856.55	0.68	100.00	356,075.59	4.57	100.00

Source Own elaboration

The composition of the induced equilibrium shifts associated with PASENER is now discussed. When we compare weights on total production variation with data from the fourth column of Table 2, we observe that activities shown in Table 2 have the greatest weight of total variation. However, there are other activities that have significant weights of total production variation. These include activities 6, 10, 11, 17 and 23. This shows that there are significant indirect effects. On the other hand, it is worth noting that weights on total production variation of activities 25 and 26 are far higher compared to their shares in initial demand increases. This shows that these activities are also significantly affected by indirect effects in the economy.

Adding the effects of both technologies used in the assumed proportion (80% & 20%) shows that the increase in production is 35.37%. Most significant increases are associated with three activities: transport and communications, other services and services oriented to sale, which together total just over 70% of the variation of production, and basically are associated with the maintenance and repair of technical plants, which requires the employment of well-trained workforce. In rural areas where these plants are most likely to be located, this may be an opportunity to promote new economic activities and new local companies. Finally, the impact on regional GDP would be an increase of 7.99% for solar tower power plants and of 41.77% for parabolic trough power plants. In both cases, the figures refer to the total lifetime of the plants in Scenario 2.

5 Remarks

The gradual penetration of renewable energy sources (RES) like solar thermal technology in electrical power production is shown to directly contribute to two of the four objectives of the EU's energy strategy: to reduce the energy dependence on primary energy consumption (solar energy is an indigenous source) and to reduce the demand stress on the primary energy resources. It also contributes to the climate change policy due to lower greenhouse gas emissions associated with the use of RES. These objectives are also considered in the PASENER.

The total increase in the economic activity due to a parabolic trough power plant amounts to 0.75%. The largest increases are linked to activities of services oriented to sales, electricity, transport and communications, mining, and the iron and steel industry and metal products. The total increase in the economic activity due to parabolic trough power plants in compliance with the PASENER goal is 30.81%, with remarkable increases in electricity. The activities with the biggest weight of total production variation are transport and communications, other services and services oriented to sales.

The increase in the economic activity due to the solar tower power plant is 0.68%. The activities experiencing the largest increases are productive services oriented to sales, electricity, metal products, construction materials, and transport and communications. The total increase in the economic activity due to solar tower power plants is 4.57%. The transport and communication activities have the biggest weight. Adding the effects of both technologies used in the assumed proportion, the increase due to compliance with the PASENER goal is 35.37%. The variation of production is basically associated with the maintenance and repair of technical plants located in rural areas (70%), so it can be an opportunity for the development of these areas in Andalusia. Finally, as the regional GDP variation is positive, the net benefit of introducing the technologies considered in the paper is also positive.

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Appendix

See Tables 6, 7, 8 and 9.

Table 6 Investment costs of the parabolic trough power plant

Item	I	II (I/Total)	III	IV (100%–III)	
	Investment (k€)	Investment (%)	Imports (%)	Domestic (%)	Domestic investment (k€)
Solar field	123,487	46.45	32.46	67.54	83,403.12
Power block	55,690	20.95	40.15	59.85	33,330.46
Land	1,211	0.46	0	100.00	1,211.00
Storage	33,187	12.48	40.22	59.78	19,839.18
Construction	26,584	10.00	0	100.00	26,584.00
Engineering	12,839	4.83	0	100.00	12,839.00
Contingencies	12,839	4.83	0	100.00	12,839.00
Total	265,837	100.00	28.51	71.49	190,046.87

Source Own elaboration from Caldés et al. (2009)

Table 7 Operation and maintenance (O&M) costs of the parabolic trough power plant

O& M Cost item	Annual cost (k€)	Cost (%)	Total cost over 20 years (k€)
Fixed costs	1,292	10.50	25,250
Maintenance	2,761	22.45	53,958
Financing	5,432	44.16	106,158
Natural gas	1,563	12.71	30,546
Electricity	1,252	10.18	24,468
Total	12,300	100.00	240,380

Source Own elaboration from Caldés et al. (2009)

Table 8 Investment costs of the solar tower power plant

Item	I	II (I/Total)	III	IV (100%–III)	
	Investment (k€)	Investment (%)	Imports (%)	Domestic (%)	Domestic (k€)
Solar field	62,384	42.43	30.89	69.11	43,113.58
Tower	23,753	16.16	0	100.00	23,753.00
Power block	29,686	20.19	37.75	62.25	18,479.54
Land	1,423	0.97	0	100.00	1,423.00
Storage	9,412	6.40	34.45	65.55	6,169.56
Construction	9,414	6.40	0	100.00	9,414.00
Engineering	5,472	3.72	0	100.00	5,472.00
Contingencies	5,472	3.72	0	100.00	5,472.00
Total	147,016	100.00	23.00	77.00	113,296.68

Source Own elaboration from Caldés et al. (2009)

Table 9 Operation and maintenance (O&M) costs of the solar tower power plant

O&M Costs item	Annual costs (k€)	Costs (%)	Total costs over 20 years (k€)
Fixed costs	1,292	18.06	25,250
Maintenance	1,455	20.34	28,435
Financing	2,812	39.31	54,955
Natural Gas	771	10.78	15,068
Electricity	824	11.52	16,103
Total	7,154	100.00	139,811

Source Own elaboration from Caldés et al. (2009)

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