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The economic influence of photovoltaic technology on electricity generation: A CGE (computable general equilibrium) approach for the Andalusian case

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ABSTRACT

This paper provides an estimation of the socio-economic impacts of increasing the production capacity of installed solar parks in Andalusia (southern Spain). Solar parks use photovoltaic technology for electricity generation. A CGE (computable general equilibrium) approach is used to capture impact assessments of an increased roll out of solar parks in Andalusia on production activities, employment and other macroeconomic variables as a consequence of increasing power output by this means to 400 MW by 2013 as stipulated in the program named as 'PASENER (Plan Andaluz de Sostenibilidad Energética) 2007–2013' implemented by the Andalusian Regional Government.

Results show that compliance with the PASENER goal would increase the activity level of the economic sectors considered by 3.1 %, and total employment generated would reach 215,148 equivalent fulltime jobs lasting one year. The other macroeconomic variables considered would also increase.

The deployment of the photovoltaic technology would provide up to 527,573 tonnes of CO_2 abatement if it displaces an equivalent installed capacity of thermal plants.

1. Introduction

The large number of annual sunshine hours in Andalusia (southern Spain) makes some renewable energy technologies like solar thermal technology (for electricity generation and for heating use) and photovoltaic technology of special interest for this large area. This paper focuses on the use of photovoltaic technology for electricity generation that is promoted through a public funding program.

Initiatives in EU countries to promote the use of RES (renewable energy sources) have been justified on the basis of environmental benefits – due to the abatement of GHG (green-house gas) emissions- and for the security of energy supply [37,38]. The power generation sector is one of the main sources of CO_2 emissions which, in the Spanish electricity sector, amounted to 73 million tonnes[1] of CO_2in 2011. However, not all power generation technologies are pollutants, and photovoltaic energy in particular is a clean technology.

Solar parks use photovoltaic technology for electricity generation. A remarkable increase in the number of solar parks has taken place in Spain due to two main policy measures. First, a promotion system based on feed-in tariffs.[2] Second, solar parks enjoy tax incentives [12] and are part of the EU energy policy for Member States and their regions. In the region of Andalusia, the 'PASENER (Energy Sustainability Plan Andaluz) 2007–2013' [22] was the instrument via which RES targets were set for each technology. For the specific case of photovoltaic technologies, the objective was to move from 64.1 MW installed capacity in 2007 to 400 MW in 2013. In spite of the global financial crisis, it is expected that the PASENER target of an increase of 335.9 MW of installed capacity would be reached by 2013.

The purpose of this paper is to estimate the socio-economic impacts that would be derived by adding up to 335.9 MW of photovoltaic electricity generation to the electricity grid in Andalusia and to assess the CO_2 abatement associated with this deployment. Results allow policy makers and citizens to know

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[1] Red Eléctrica Española [44]. No separate data is available for the Andalusian area.

[2] R.D. 661/2007, in force since May 25, 2007, had set up a tariff of 44.04 c€/kWh, but this was set to decline following the passing into law of R.D 1578/2008 September 28, which implemented an important reform to the feed-in tariffs framework for photovoltaic plants.

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about the way that PASENER promotes the deployment of this clean technology. A CGE (computable general equilibrium) model is used for this analysis.

Although CGE models have been used to analyze energy systems from an economic point of view, the economic impact of renewable energy has been usually estimated by using I–O models.[3] For example, for the USA economy, I–O analysis has been used by Cook [23], US DOE [49] and Ciorba et al. [21]; for the European area Kulisic et al. [36], Madlener and Koller [39], and Allan et al. [4], developed a similar approach. Caldés et al. [9], Calzada et al. [10] and the European Commission (MITRE) (2009) [25], recently used an I–O model to estimate the socioeconomic impact of renewable energy in Spain. However, Fuentes et al. [27], Cansino et al. [12,13] and Cardenete et al. [20] have recently developed a CGE approach to analyse the economic impact of RES.

This present work aims to extend the literature in four ways: first, by gathering cost data on the construction, operation and maintenance of solar parks; second, by taking into account both direct and induced effects on the economic sectors' activity as well as other macroeconomic variables; third by using a CGE approach based on a SAM (Social Accounting Matrix) instead of the I–O models that have been used in similar works, and fourth by the assessment of CO_2 emissions abatement in Andalusia associated with the photovoltaic technology deployment. In this sense, the aim of this article is to broaden the research mentioned above and to contribute to improve the design of public programs.

Over the past 25 years, CGE models have been used widely to analyse government economic policies, both in developed and developing countries[4] [46]. 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 demands, and the optimization behaviour of individual agents. A CGE analysis allows one to study changes in the domains 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. The policy measure in which this paper focuses on is the PASENER. It implies to put in production 335.9 MW of photovoltaic technology before the end of 2013. As this goal will provoke a shock on economic activity, the CGE developed is used to assessment the main economic impacts.

In order to estimate the socio-economic impacts of photovoltaic energy use in Andalusia, this paper assumes compliance with the PASENER installed capacity goal for photovoltaic technology that would lead to 400 MW of installed capacity by 2013.

The structure of this paper is as follows. After this introduction, Section 2 shows the structure of the CGE model and database (SAM) used. In Section 3, we discuss the costs and other data related to the use of solar parks to generate electricity and the general data related to the Andalusian economy. Section 4 shows the results obtained with the relevant scenarios considered and includes a discussion. Finally, Section 5 offers conclusions.

2. Computable general equilibrium methodology

In this section, a general outline of the CGE methodology and the associated SAM used for the modelling and computation are given.

2.1. SAM (the social accounting matrix)

The beginnings of analyses with SAMs can be found in Stone [48], Pyatt and Round [42] among others, having its first applications in Spain in works such as Kehoe et al. [32]. Recently, SAMs have also been developed at a regional level in Spain as also used in this paper.[5]

According to Ref. [48]; a SAM model is a representation of all the transactions made in the setting of an economy in a certain period of time. The I–O Tables define the relation between the final demand and production, whereas the SAM describes how the productive process influences and determines the demand. Thus, a SAM extends the Leontief model and the relations shown by the I–O Tables; these describe the flows between the value added and the final demand and, therefore, represent the circular flow of income. The SAM is a database that collects and organises in a square matrix the economic and social information of all the transactions made by the different economic agents within an economy at a specific moment in time [26]. SAMs are used as databases that allow one to develop a range of multisectorial models like the CGEs described in the following subsection [46].

Fig. 1 presents the structure of an standard SAM employed in this study. Rows represent income and columns represent uses of income. Shaded cells correspond to the main blocks (intermediate consumption, primary inputs, and final demands) of a standard IO table, and distribution and income spending transactions appear in the other nonempty cells. Every account draws its income from production, primary factors, resident sectors, and the foreign sector; every account uses income to finance production, resident sectors, the capital account, and the foreign sector. If we take the resident sectors, for example, they use production taxes, net resident incomes, current and capital transfers, and wages and property income to finance private and public consumption, current and capital transfers, net resident financial capacity, and foreign current and capital transfers.

2.2. Computable general equilibrium model

A static CGE model has been developed for the Andalusian economy. This model allows us to determine the effects on resource allocation caused by the deployment of photovoltaic technology in Andalusia. This model involves a set of equations that reflect equilibrium conditions and the behaviour of the different economic agents. Therefore, the producers, the consumers, the public sector and the foreign sector are considered in general terms.

In this subsection, the paper shows a detailed analysis of each sector or agent (subsections 2.2.1–2.2.4), including some observations in relation to the labour market (subsection 2.2.5) and the notion of equilibrium used (subsection 2.2.6).[6]

2.2.1. Production

The model for the Andalusian economy incorporates 19 production sectors. It is assumed that each production sector generates a homogeneous product, according to a nested production function. Sectors appear listed in Table 1.

At the first nested level, following the Armington hypothesis [5], the total production of each sector (Q_j) is obtained as a

[3] However, a previous investigation employed a computable general equilibrium model in the Austrian economy to quantify the impacts of fostering the use of distinct biomass energy technologies [47].

[4] See Ref. [6].

[5] See Ref. [17] for a review of this approach in Spain.

[6] The main equations of the model are shown here. The full listing of equations is available upon request and can also be found in Ref. [16].

	PRODUCTION	PRIMARY FACTORS	RESIDENT SECTORS	CAPITAL ACCOUNT	FOREIGN SECTOR
PRODUCTION	Intermediate consumption		Private and public consumption	Gross capital investment	Exports
PRIMARY FACTORS	Gross value added				Wages and property income
RESIDENT SECTOR	Production taxes	Net resident income	Current and capital transfers	Taxes on capital	Current and capital transfers
CAPITAL ACCOUNT		Fixed capital consumption	Net resident financial capacity		Foreign savings
FOREIGN SECTOR	Imports	Wages and property income	Current and capital transfers		

Fig. 1. Simplified structure of a SAM. Source: own elaboration.

Cobb–Douglas aggregate of domestic output (Qd_j) and imports (Qm_j).[7] At the second level, the domestic production for each sector 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 sector 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)–(3) respectively:

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

$$Qd_j = \min\{X_{1j}/a_{1j}, X_{2j}/a_{2j}, \ldots, X_{19j}/a_{19j}, \mathrm{VA}_j/v_j\} \tag{2}$$

$$\mathrm{VA}_j = \beta_j K_j^{\alpha_j} L_j^{1-\alpha_j}, \quad j = 1, 2, \ldots, 19 \tag{3}$$

In these expressions, β_{Aj} and β_j are scale parameters; δd_j is a parameter which reflect the share of domestic output of j in j's total production; $1 - \delta d_j$ is a parameter which reflect the share of imports of j in j's total production; a_{zj} expresses 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, capital and labour, with regard to value added.[8]

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

2.2.2. Consumption

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

$$U = \sum_{j=1}^{19} \gamma_j \ln C_j + \gamma_s \ln S \tag{4}$$

In Eq. (4), the parameters γ_j and γ_s reflect the share of disposable income for goods j and/or for private savings respectively. S represents the saving and C_j expresses the private consumption of good j of the representative consumer. Recall that the economy is divided into 19 sectors.

Inequality (5) shows the budget constraint for this representative consumer[9]:

$$\sum_{j=1}^{19} p_j (1 + \mathrm{vat}_j) C_j + p_i S = \sum_{j=1}^{19} p_j^{\mathrm{F}} C_j + p_i S \le \mathrm{YD} \tag{5}$$

The sum on the left hand side is the expenditure on final consumption. The parameter vat_j is the value added tax rate for the good j, and p_j^{F} is its final consumption price inclusive of taxes. Private saving is also included in the expression, being valued at the saving/investment price, p_i.

The right hand side of the inequality (5) shows disposable income, YD. This income is derived from the sale of its endowments of capital (K) and labour (L), at the prices r and w, respectively. In addition, consumers receive transfers from the public sector (TPS), indexed by the consumer price index (cpi), and receive transfers from the foreign sector (TFS), although their total quantitative importance is minimal. Finally, consumers have to pay employees' social contributions and income tax, whose rates are ess and τ, respectively.

Thus, the disposable income of the only representative consumer[10] is given by (6):

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

The representative consumer derives the consumption demand functions by maximising the utility function subject to the budget constraint shown in (5).

2.2.3. Government

The activity of the government consists firstly in the production of public services by using the technology of “Non-sales-oriented

[7] Cobb–Douglas function is a particular functional form of the production function, widely used to represent the technological relationship between the amounts of two or more inputs, particularly physical capital and labor, and the amount of output that can be produced by those inputs. In our case for combination of domestic outputs and imports.

[8] For the simulations considered in this paper, a sensitivity analysis for functional forms has been performed. 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.

[9] Due to the nature of consumer's utility function – monotonically increasing – this weak inequality must be satisfied as an equality at the equilibrium. The same comments are valid for expression (8) for the government budget constraint.

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

Table 1
Production sectors considered.

Production sector number	Production sector name
1	Primary sector
2	Extracts of primary sources of energy
3	Remaining extractives
4	Coke, Refined Petroleum and Nuclear Fuel
5	Electricity power and Electricity Supply
6	Gas generation and Gas supply
7	Water generation and water supply
8	Food industry
9	Textile and Leather
10	Wood products
11	Chemicals
12	Mining, Iron and Steel industry
13	Metallic products
14	Manufacturing
15	Construction
16	Commerce and transport
17	Other services
18	Sales Services
19	Non- Sales Services

Source: own elaboration.

services" (j_{19}), and secondly in the demand of public services (public consumption, $C^{G}j_{19}$) and investment goods ($C^{G}{}_{i}$). In this sense, this agent can be considered to maximise a Leontief utility function (U^{G}), defined by (7):

$$U^{G} = \min\left\{C^{G}_{j19}, \gamma^{G} C^{G}_{i}\right\} \tag{7}$$

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):

$$p_{j19}C^{G}_{j19} + p_i C^{G}_{i} \leq R^{G} + p_i w^{G}_{i} - \text{cpi}\cdot\text{TPS} \tag{8}$$

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 consumers have to be subtracted (cpi·TPS) and the stock of debt that the government issues when it is in budgetary deficit and evaluated at the same price as saving/investment, p_i ($p_i w^{G}_{i}$).

With respect to the total tax revenues R^{G}, the model includes net taxes on production (a), employers' social contributions (b), import taxes (c) and the previously mentioned value added tax (d), taxes, employees' social contributions (e) and income tax (f). The tax revenue components (a) to (f) are specified in Eqs. (9)–(14) respectively:

a) Taxes on production (Rt):

$$Rt = \sum_{j=1}^{19} t_j \left[\sum_{z=1}^{19} p_z X_{zj} + w\left(1 + \text{esc}_j\right) L_j + rK_j\right] \tag{9}$$

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

b) Employers' social contributions (Resc):

$$\text{Resc} = \sum_{j=1}^{19} \text{esc}_j wL_j \tag{10}$$

c) Import taxes (Rtarif):

$$\text{Rtarif} = \sum_{j=1}^{19} \text{tarif}_j p_m Qm_j \tag{11}$$

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

d) Value Added Tax (Rvat):

$$\text{Rvat} = \sum_{j=1}^{19} \text{vat}_j p_j C_j \tag{12}$$

e) Employees' social contributions (Ress):

$$\text{Ress} = \text{ess}\ wL(1-u) \tag{13}$$

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

$$R\tau = \tau[rK + wL(1-u) + \text{cpi TPS} + \text{TFS} - \text{ess}\ wL(1-u)] \tag{14}$$

Eqs. (9)–(14) show the taxes included in the model benchmark.

2.2.4. Foreign sector

The model considers only one foreign sector, this being the combination of the rest of Spain, the EU and the rest of the world:

$$\text{ROWD} = \sum_{j=1}^{19} \text{tarif}_j \quad Qm_j - \text{TFS} - \sum_{j=1}^{19} \text{tarif}_j Qx_j \tag{15}$$

where Qm_j represents sector j imports, Qx_j sector j exports and TFS 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:

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

This formulation of the labour market in CGE modelling is due to Kehoe et al. [33]; following the precepts established in Ref. [40]. The variable (w/cpi) represents the real wage, u is the unemployment rate, u_0 is a parameter that reflects the unemployment rate in the benchmark equilibrium, and β_d is a parameter that expresses the sensitivity of the real wage to the unemployment rate.

The parameter β_d can have values between zero and infinity. If $\beta_d = 0$, the real wage would adjust 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 salary rigidity. In other words, the sensitivity of the real wage to the unemployment rate diminishes. In the simulations, we have not introduced an "*a priori*" condition, and calculations are carried out using an average value for the labour market elasticity, that is, $\beta_d = 1$.

2.2.6. Equilibrium

The notion of equilibrium used in this model is that of the Walrasian competitive equilibrium, extended to include not only producers and consumers, but also the government and foreign sectors (see, for instance, Ref. [46]). General equilibrium theory is a concept of theoretical economics. It seeks to explain the behaviour of supply, demand, and prices in a whole economy with several or many interacting markets, by seeking to prove that a set of prices exists that will result in an overall equilibrium. In our approach, we use applied general equilibrium model, following this theory, in contrast to partial equilibrium approach, which only analyses single markets.

This is a static model with its advantages and disadvantages against a dynamic CGE. In this case, we have chosen this short-run version to capture the overall effects of the investment, with a given technology, in order to obtain a better sensitivity of the results, following an impact assessment of a special public policy for the renewable energy. Specifically, economic equilibrium is determined by a price vector, an activity-level vector, and a set of macrovariates so that supply equals demand in all markets, with the sole exception of the labour market, as previously mentioned. 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.

Final demand includes the following sectors: consumption (households), investment (firms), public expenditure (government) and exports. We consider 19 types of goods (which correspond to the 19 sectors) and one representative consumer who demands certain goods. The rest of the consumer's disposable income is saved. The purchase is financed with revenues from the sale of the consumer's initial factor endowments. Taking all this together, Eq. (17) summarizes the situation:

$$\begin{aligned} \mathrm{YD} &= \text{Gross income} - \text{Total direct taxes} \\ \mathrm{YD} &= wL(1-u) + rK + \text{cpi TPS} + \text{TFS} - \tau(rK + \text{cpi TPS} + \text{TFS}) \\ &\quad - \tau[wL(1-u) - \text{ess } wL(1-u)] - \text{ess } wL(1-u) \end{aligned} \tag{17}$$

where w and r represent labour and capital prices, respectively, and cpi is the consumer price index.

With respect to investment and saving, it should be mentioned that a '*saving driven model*' is used, which means that the closure equation of the model is defined by making investment (INV) exogenous. This implies that saving will be defined by the utility function of a consumer who is modelled by a Cobb–Douglas technology in his choice and allowing that deficits – public (PD) and foreign (ROWD) – will be determined in an endogenous way:

$$\sum_{j=1}^{19} \mathrm{INV}_j p_i = p_i S + \mathrm{PD} + \mathrm{ROWD} \tag{18}$$

Finally, we assume the total use of the initial factor endowments, although in the case of labour factor, the model includes unemployment. Additionally, the level of activity of the government and foreign sectors will be fixed, allowing relative prices, sectors' activity levels, public deficit and foreign deficit to work as endogenous variables as mentioned before.

From this, the equilibrium will be an economic state in which the representative consumer will maximize his utility, the firms will maximize their profits after taxes, and the public revenues will be equal to the payments made by 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 prices 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 equal to unity at the initial time. From this initial condition, we introduce an increase of demand associated with the standard solar parks using photovoltaic technology that is needed to reach the PASENER target, 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 [8] with *MINOS* as the solver.

It was also assumed that during the period under consideration, the operating and investment costs would remain constant.[11]

The model allowed us to analyze two types of socio-economic impacts:

(i) Direct impacts caused by the expansion of production in other activity sectors that require intermediate inputs of the manufacturing process from a branch of activity. In this case, the construction, operation, maintenance and dismantling of a solar park requires inputs from other activities and this requirement causes effects on production.[12]
(ii) Induced impacts that occur in the production structure, derived from the production cycle by the relationships between consumption and intermediate demand among activity sectors. To satisfy the input requirements of the solar park, 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 production process.

This paper estimates both direct and induced impacts.

3. Data

This Section discusses the costs and other data related to solar parks used for electricity generation, the general data related to the Andalusian economy, and data related to CO_2 emissions.

3.1. Solar park costs

Photovoltaic technology transforms sunlight into electricity through the photovoltaic effect using modules or panels, usually made of silicon, which produce direct current electricity.

This study considers solar parks that are connected to and export electricity to the national power grid [51]. A solar park connected to the grid needs a photovoltaic array large enough to make profitable the other common facilities as needed, including earthworks and civil works, security and surveillance facilities, water supply and especially electrical infrastructure [24,41].

[11] This is a restrictive assumption which could limit conclusions underestimating or overestimating some benefits of deploying such plants.

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

Table 2
Breakdown of investment costs needed to achieve the PASENER goal.

Item	Investment total cost (thousand euros)	Investment total cost (%)	Total cost portion imported (%)	Total cost portion domestic (%)	Total cost portion domestic (thousand euros)
Photovoltaic modules	688,595	64%	95%	5%	34429.7
Inverters, measuring and monitoring	167,950	16%	75%	25%	41987.5
Basement structures	117,565	11%	30%	70%	82295.5
Transformers and connection to the grid	60,462	5.7%	60%	40%	24184.8
Security, alarms, surveillance	30,231	3%	25%	75%	22673.2
Installation, engineer, filing and processing	3359	0.3%	10%	90%	3023.1
Total	1068,162	100%			208593.8

Source: own elaboration. Figures expressed in 2008 euros.

Table 3
Solar park operation, maintenance and other costs (excluding salaries).

Item	Total cost per annun (thousand euros)	Total cost (%)	Total costs (30 years) (thousand euros)	Total cost portion domestic (%)	Total cost portion domestic (30 years) (thousand euros)
Maintenance and operations (7% of Income)	10228.1	8%	199888.0	80%	159910.4
Insurance (0.2% of Income)	3688.2	3%	72077.7	95%	68473.8
Surveillance (2% of Income)	2922.3	2%	57111.1	95%	54255.5
Land lease (1.7% of Income)	31349.5	25%	612674.9	100%	612674.9
Financial Costs	76585.2	61%	1496710.3	70%	1047697.2
Total	124773.3	100%	2438462.0		1943011.8

Source: own elaboration. Figures expressed in 2008 euros.

There are currently two types of photovoltaic systems, those that are deployed on the ground, usually on rural land, and smaller ones that are mounted on the roofs of existing buildings. We focus on the first type.

Ground-mounted photovoltaic installations have larger dimensions, have electrical ratings in MW and require infrastructure to raise the specific electric power output of the installation (500 V) to the power at the network level, generally a distribution grid, which operates at 15, 20 or 25 kV. Such solar photovoltaic installations have panels connected in series-parallel to produce a DC voltage suitable as input to an inverter (which converts DC to AC[13]) whose output voltage is changed using transformers so that the transformer output can be connected to the electric grid operating at higher AC voltages. In addition to these primary elements, a solar park has structural supports (made of aluminum or galvanized steel) for the panels. In some cases, the facilities that have been installed in recent years have used solar tracking mobile structures, either on a single axis (azimuth) or on two axes (azimuth and orbital), increasing the performance of facilities by up to 30–35% but also with an increase in the investment and operating costs as well as in maintenance. Because of their isolation in rural areas and the lack of accessibility, solar parks have been equipped with safety features, fencing, video surveillance, alarms, etc. and it is usual to monitor them to check their electrical operation at any time, and in case of faults in the facilities, to correct them quickly.

We have chosen for our study a typical installation of 2 MW peak power (approximately 10% above the nominal) on rural land, being a standard pattern in recent years due to a distribution agreement between the principal electrical distribution company and the competent regional Government. Such installations are typically rated at 1.89 MW inverter output with two banks of three transformers each rated at 630 kVA.

The future trends of installation sizes of "on ground" systems will likely increase if the feed-in tariffs system that was in place until 2012 is maintained in the future, and therefore will provide economies of scale. However, we must take into account the growing deployment of installations on roofs with a higher tariff, especially those under 20 kW, reducing impacts of changes in the voltage of the larger installations [28]. While on one hand, some of the elements required for ground installation are not necessary in the roof application, the required auxiliary equipment in the latter make the investment cost difference not significant.

The original data have been provided by AAE [1]. Table 2 shows the details of the total investment costs associated with standard solar parks of 2 MW.[14]

In order to determine the operation and maintenance costs of this type of solar park, an operational life of 30 years with an annual discount rate of 8% is assumed.[15] Total annual operation and maintenance costs and other costs accumulated over the 30 years are shown in Table 3.

The estimation of the financing expenses has been computed considering a 12-year repayment loan with a 5% interest rate.

Following Caldés et al. [9]; we assume that 62% of the expenses related to the annual operation, maintenance and other costs of a solar park are salary costs. Additionally, according to the National Statistics Institute (INE) data, the average salary of a Spanish employee in sector 40 amounts[16] to 73,794.14 €/year.

[13] AC/DC alternating current/direct current.

[14] However, the learning curve of this technology is enabling these costs to be reduced very significantly so that grid parity may be achieved in a short time. It is said that a power generation technology reaches grid parity when the price of energy generated by the system, in this case photovoltaic power, is the same as the reference price of electricity [7]. As the cost of electricity continues to increase, mainly due to the rising price of fossil fuels, whereas the photovoltaic kWh cost decreases due to improved economies of scale and competitiveness, we should also consider the environmental costs and other welfare gains [50]. The grid parity is defined as the crossing point of the two trend lines. Therefore, depending on certain factors such as plant size and type (which will influence the production costs per kWh), and the evolution of energy prices, the grid parity will occur at different points in time [30]. Estimates from the reports by Ref. [34] for the Photovoltaic Association (ASIF) [35] consider that in any case grid parity will occur later this decade, between 2013 and 2018.

[15] We assume the use of the Return-on-Assets (ROA) rate as in Ref. [10].

[16] See Ref. [31] Quarterly Survey of Labour Cost QIV. For sector 40 of CNAE09, every Full Time Employee (FTE) is employed 1800 h/year. Sector 40 refers to production and distribution of electricity, gas, hot water and steam.

Table 4
Assumed percentage distribution of the domestic investment costs to the economic sectors included in the SAMAND08.

Sector No.	Production Sector name	Photovoltaic modules	Inverters, measuring and monitoring	Basement structures	Transformers and connection to the grid	Security, alarms, surveillance	Installation, engineer, filing and processing
5	Production and distribution electricity power	6					
11	Chemical	23	15	10	5	5	
12	Mining, Iron and Steel Industry	33	10	10	7	7	
13	Metallic products	5	5	70	68	71	
14	Manufacturing	16	58		2	2	15
15	Construction	8	10	6	8	10	32
16	Commerce and transport	9	2	4	10	5	6
18	Sales services						40
19	Non-sales services						7
	Total (%)	100	100	100	100	100	100

Source: own elaboration. Figures are distribution percentages.

Table 5
Assumed percentage distribution of the domestic O&M (Operation and Maintenance) and other costs to the economic sectors included in the SAMAND08 (excluding salaries).

Sector No.	Production Sector names	O & M costs	Insurance costs	Surveillance costs	Lease land costs	Financial costs
1	Primary Sector				33	
11	Chemical	5				
14	Manufacturing	5				
15	Construction	15			14	
16	Commerce and transport	15.50				
17	Other services	21	100	100	20	100
19	Non sales services				33	
	Total	62	100	100	100	100

Source: own elaboration. Figures are distribution percentages.

Direct employment created by the PASENER compliance is generated during the lifetime of the solar park. In the case of the type of park considered in the article, direct employment amounts to 390 FTE (Full Time Employees).

The increase in the total direct demand associated with the construction and operation of the solar parks needed to meet the PASENER goal (400 MW by 2013) amounts to 2.15 billion euros (total in column 6 of Table 2 plus total in column 6 of Table 3), assuming a construction period of 12 months, an operating life of 30 years, and an annual discount rate of 8%.

We assume that final capacity required in PASENER is obtained from many parks distributed across the region (87,597 km^2).

3.2. Andalusian economic data

In order to study the effects of the solar parks in the Andalusian economy, the SAM used for the modelling and computation is based on the Andalusian economy data (SAMAND).

When this research was carried out, the most recent SAMAND dated from 2000 and was due to Cardenete et al. [20]; constructed from Andalusian I–O Tables dating from 2000 as the basic source. This Matrix has been adapted for the year 2008, using the CE (cross entropy) method,[17] and the overall available information on the production and GDP for that year. We refer to it as SAMAND08. The cross-entropy approach involves projecting technical coefficients instead of total SAM flows – a traditional method called RAS. Cross-entropy aims directly at estimating technical coefficients. Therefore, with regard to standard RAS, the difference is that CE uses technical coefficient matrices in the minimand instead of total flows.[18]

As for the degree of disaggregation of the sectors, the SAMAND08 is a 32 × 32 matrix, so it contains 32 accounts, where the flows realized in the Andalusian economy for the year 2000 are described.

The production sectors have been reduced to 19 (account numbers 1–19); plus two production factors, labour and capital (20 and 21, respectively), together with consumption (22), the saving/investment account (23), and indirect taxes, employers' social security taxes, net taxes on production, tariffs and VAT (valued added tax), direct taxes, income tax and employees' social security taxes which represent sectors 24–30. Public administration is sector 31, and the last one is the foreign sector (32).

As shown in Tables 4 and 5, total investment and the operating costs of solar parks have been broken down and associated with the different sectors included in the SAMAND08.

3.3. CO_2 emissions data

It is possible to estimate the volume of CO_2 emissions avoided when the photovoltaic technology for electricity generation is used. This is done by assuming that this technology displaces a similar installed capacity of combined cycle technology or thermal technology, these being two technologies with high levels of CO_2 emissions. Both technologies are able to be managed related to generate power. They have flexibility regarding starting and stopping, specially CCP (combined cycle power plants). This allows that variability on solar power generation can be compensated real-time by last one energy sources. Currently, Andalusia have seven CCPs, with an aggregate capacity up to 6044 Mw and Coal power plants up to 2072 Mw.

Taking in account overcapacity of CCPs, producing currently below 50% and it flexibility, could allow reasonably and viability such substitution. Furthermore, Spanish National Energy Commission has been set a mechanism to guarantee supply of CCP;

[17] For more information about the cross entropy method, see Ref. [45].
[18] For more information about the discussion about CE and RAS methodology, see Ref. [18].

Table 6
CO_2 emissions associated with displaced technologies.

A Combined cycle plant (g CO_2 per kWh)	A thermal plant (Fuel + Gas) (g CO_2 per kWh)	A thermal plant (coal) (g CO_2 per kWh)
370	700	950

Source: Red Eléctrica Española [43,52].

setting a remuneration for the investment of first ten years, as well as a remuneration due to availability service [11].

It should be noted that photovoltaic technology is a clean technology with no CO_2 emissions per MWh generated. Solar parks in Andalusia are located in the so-called Zone V of the CTE, with radiation that allows an average energy output of 1500 kWh per kWp (kilowatt peak installed power) for installations without solar tracking. However, the percentage of facilities with dual-axis solar tracking is around 23%, 13% of which is with only single axis tracking and the rest fixed (64%) [34]. Two-axis tracking increases the power by 33% to 1995 kWh per kWp, while single-axis tracking raises the output by 10%–1650 kWh.

However, the remaining technologies in the power generation sector cause emissions. This paper estimates the CO_2 emissions avoided when photovoltaic technologies displace a combined cycle plant, which consists of a thermal plant with fuel + gas or with coal. The CO_2 emissions per kWh generated by these plants are shown in Table 6.

CO_2 emissions avoided has another point of view, taking in account also costs avoided because of that. Thus, we would able to have one o some estimated numbers of the total cost avoided (or induced benefits from reduced emissions). Those costs could be consider from different perspectives. In one hand, it might be use market price of carbon tonne, obtained from the Carbon Trading Scheme, or in other hand using the SCC (Social Cost of Carbon).

The advantage of the first one is that is a market revealed price, from demand-supply forces to negotiate, but the disadvantage is that it history has been characterized by its high price volatility [3].

Otherwise, the SCC is an estimate of the monetized damages associated with an incremental increase in GHG in a given year, thus, estimates the benefit to be achieved in the future, expressed in monetary value, by avoiding the damage caused by each additional metric ton of carbon dioxide put into atmosphere. It had been important project to reach a range of number of this, from USA and UK administration, based of knowing models, for those, economists fit some subset of factors such as human health effects, net agricultural productivity loss, changes in ecosystem and property and put into a Integrated Assessment Models. Some of them are DICE, PAGE o FUND.

The Interagency Working Group -IWG- for Obama Administration, in 2009, recommended a range of SCC values, from €3.4 to €44.2, and €14.2 is the "central number" [29].

The UK administration had a range of € 27.8to € 84.3per tone of CO_2 with a central value of € 56.4 (Stern, 2007) [2].

According to the data of Table 11 related to avoid CO_2 emissions, we can estimated that if we consider IWG, the total economic cost would be between € 698,894 to € 9,085,629 with a central value of € 2,935,357 and considering UK administration € 5,730,935 to € 17,332,585 with a central value of € 11,601,649. Technology considered to assessment the SCC is CCP due to its flexibility above mentioned.

4. Scenario results and discussion

This section analyses the impacts of the solar parks associated with compliance with the PASENER goal.

The CGE model developed allows us to estimate the socio-economic impact derived from the compliance with the MW installed capacity goal described in the PASENER 2007–2013' plan requiring an additional 335.9 MW by 2013 from the installed capacity in 2007. Table 7 disaggregates the production sectors included in the final demand impact used in the CGE.

Compliance with the PASENER goal would generate an increase of 3.12% in the total output of the 19 sectors considered during the lifetime of the park. Table 7 shows the associated effect of the PASENER goal compliance on every sector included in the SAMAND08. The highest impact occurs in the 'Sales services' sector (18) with an increase of 11.3%, while there is an important impact on the 'Other services' sector (17), equal to 8.96%.

These results are compared with those estimated in Ref. [19] for the cases of biomass technology and biomass co-combustion technologies and those contained in Refs. [14,15] for the two types of solar electricity technology considered. By taking into

Table 7
Impacts on production sectors given compliance with the PASENER goal.

Production sector number	Production sector name	Benchmark amount, Thousand €	PASENER scenario, Thousand €	Total variation (%)
1	Primary sector	12.563	12.846	2.3
2	Extracts of primary sources of energy	2.855	2.921	2.3
3	Remaining extractives	2.590	2.629	1.5
4	Coke, Refined Petroleum and Nuclear Fuel	12.271	12.536	2.2
5	Electricity power and Electricity Supply	4.706	4.854	3.1
6	Gas generation and Gas supply	0.506	0.518	2.4
7	Water generation and water supply	1.082	1.114	3.0
8	Food industry	31.299	31.820	1.7
9	Textile and Leather	7.265	7.445	2.5
10	Wood products	4.460	4.555	2.1
11	Chemicals	13.347	13.618	2.0
12	Mining, Iron and Steel industry	13.347	13.618	2.0
13	Metallic products	5.580	5.623	0.8
14	Manufacturing	23.139	23.608	2.0
15	Construction	55.859	56.621	1.4
16	Commerce and transport	63.094	64.491	2.2
17	Other services	28.924	31.514	9.0
18	Sales Services	31.082	34.594	11.3
19	Non- Sales Services	26.174	26.212	0.1
Total		340.529	351.146	3.1

Source: own elaboration. Figures expressed in 2008 Euros.

Table 8
Total impact on production sector by technology.

	PASENER's gap (MW)	Impact (%)
Power generation biomass	91.8	0.77
Co-combustion biomass	122	1.25
Solar electricity technology (parabolic trough power plants)	157.8	4.57
Solar electricity technology (solar tower power plants)	631.2	30.81
Photovoltaic technology	335.9	3.12

Source: Refs. [14,15,19] and own elaboration.

account the gap of MW that PASENER's goal implies for every technology, together with the total impact on production sectors, Table 8 shows that power generation using biomass technology, co-combustion biomass and photovoltaic technology produced the lowest impact.

Data in Table 2 can explain the lower impact of photovoltaic technology because only 5% of photovoltaic modules' cost (which represents 64% of the total investment cost) is domestic expenditure. This differs from technologies such as solar technologies in which the investment costs are almost completely internal and therefore the increase of its capacity produces a greater impact on the economy.

The CGE model developed also shows that the increased demand for goods and services in the Andalusian economy as a result of the increase in the installed capacity of photovoltaic technology generates an additional 215,148 one-year jobs.

This result can be compared with those included in Ref. [19] and related to biomass technology for electricity generation and biomass co-combustion technology. The figures in Table 9 show that there exists a non-significant difference in the number of one-year jobs created per MW of new installed capacity.

Table 10 shows the impact on the other macroeconomic variables considered. The construction and operation to meet PASENER's goal compliance would generate a positive effect on all the variables considered, with no exception.

During the lifetime of the solar parks, the disposable income of the Andalusian economy would increase by 3.99% and the GDP by 10.83%. The effect on the tax revenues would be positive and equal to 10.07%.

Installation of an additional 335.9 MW (335,900 kW) due to PASENER, taking into account existing photovoltaic solar technology, yields 555,343,470 kWh produced in total.

In accordance with Red Eléctrica Española and AAE [43], we can estimate the CO_2 emissions avoided with PASENER compliance if combined cycle power plants are replaced by photovoltaic technologies; this amounts to around 205,475 tonnes. If it is assumed that the photovoltaic plant leads to the replacement of a coal power plant, the CO_2 emissions avoided are shown in Table 11.

Table 9
One-year jobs created per MW of new installed capacity.

Power generation biomass	571
Co-combustion biomass	625
Photovoltaic technology	640

Source: Ref. [19] and own elaboration.

Table 10
Impacts on macroeconomic variables based on compliance with the PASENER goal.

Macroeconomic variable	Variation (%)
Disposable income	3.99
Tax revenues	10.07
GDP	10.83

Source: own elaboration.

Table 11
CO_2 emissions avoided if the nominated dirty technologies are displaced by solar photovoltaic plants.

Combined cycle plant (CO_2 tonnes)	Thermal plant (Fuel + Gas) (CO_2 tonnes)	Thermal plant (coal) (CO_2 tonnes)
205,475	388,738	527,573

Source: Red Eléctrica Española [43] and own elaboration.

5. Conclusions

The public promotion of photovoltaic technology for electricity generation can be justified in terms of social outcomes. Together with this reason, the public promotion of photovoltaic technology also could be justified with its environmental benefits mainly due to the abatement of GHG emissions (205,475, 388,738 or 527,573 tonnes of CO_2 depending on the polluting technology displaced).

The photovoltaic technology deployment also contributes to the security of energy supply, by avoiding/reducing oil/gas/coal imports, which represent an important target for the EU energy policy.

We reproduce the data contained in the SAM as a *benchmark equilibrium* in which all prices (endogenous and exogenous) are equal to unity at the initial time. After provoking an *exogenous shock* in the model we evaluate the changes by comparing benchmark equilibrium with the simulation equilibrium.

At the first step, all macroeconomic variables considered would increase in terms of employment generated (215,148 one-year jobs) and of the activity level of the 19 economic sectors included in the SAMAND08. The favourable impact on the 'Sales services' sector (11.30%) and 'Other services' sector (8.96%) is noteworthy.

In the second step, this paper estimates the socio-economic impacts considering the PASENER installed capacity goal for photovoltaic technology for electricity generation, which would lead to a total of 400 MW installed capacity by 2013.

It can be concluded that the socio-economic effects derived from the accomplishment of the PASENER installed capacity goal are remarkable in terms of the increase of the activity level of the economic sectors considered, the increase in direct and induced full time employment generated, the higher disposable income, tax revenues and GDP. Results support the program evaluated due to its economic impacts.

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