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A simulation of the economic impact of renewable energy development in Morocco

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ABSTRACT

In this paper we identify the renewable energy source (RES) demand scenarios for Morocco, the needs of RES installed capacity according to those scenarios and the detailed investment plans needed to achieve such installed capacity supply. Then, using a dynamic variant input output model, we simulate the macroeconomic impact of the foreign investment inflows needed to make available these Moroccan RES generation capacity plans in the medium and long term. The use of concentrated solar plants, photovoltaic generation and wind power farms are considered and compared in the simulation.

1. Introduction

There is no doubt about the importance of the Mediterranean countries as optimum producers of clean solar energy in terms of density of normal irradiation (DNI). The installation and operation of renewable energy source (RES) plants can produce meaningful economic implications in terms of induced production and employment creation. The Mediterranean Solar Plan (MSP) of the European Union is now a reality and crucial political decisions about its implementation in the coming years need to be soundly sustained with robust simulation models of the different environmental, economic, and social effects of this project.

As highlighted by the European Commission (2010): 'The MSP is not restricted to any particular technology. Even though it has a specific focus on solar CSP (Concentrated Solar Power), solar PV (Photovoltaic) and windbased power generation, it integrates an important component that considers energy efficiency and will also consider smaller-scale decentralised systems based on other RES technologies.' Similarly, Kost et al. (2011) saw advantages in the combined development of solar and wind energy plants. These authors suggest this mix as a first step to reducing investment costs and electricity production prices.

The Moroccan authorities launched a National Renewable Energy and Efficiency Plan in 2008 in order to promote energy efficiency and to meet a 40% target of green energy production by 2020. Through this, Morocco has shown its interest in participation in the MSP, which would enable the country to exploit its important solar and wind potential, increase energy supply, reduce energy dependency and diversify its energy mix. Morocco is probably the best-positioned country within the Southern Mediterranean region to implement the MSP. Morocco already has a relatively significant solar and wind energy installed capacity, and given its proximity to Spain (14 km) it has the only relevant and functioning electricity interconnection with the EU in the region. The MSP will help Morocco to supply its internal electricity market and eventually export the surplus to the EU, thus benefiting from the new green energy trade scheme provided by Directive 2009/28 article 9.

The main objective of this paper is to identify future RES implementation scenarios in Morocco and simulate their economic effects over the next 30 years in terms of GDP, added value by economic sector, and employment in the country.

We start from a consensus scenario of future electric demand of (different international agencies and alternative research projects) and we concentrate on the supply side, analysing several alternatives of future RES electric production mix in Morocco, and comparing the economic effects of these alternatives.

The econometrical methodology applied in this paper is based in a dynamic input–output (IO) model, with a detailed exposition of the analytical strategy to conduct the evaluation of different scenarios of the next 30 years.

In a 30-year span of time, major changes in the economic structure of a developing country can be expected. It is forecast that the Moroccan economy will experience deep change in its internal and external economic linkages in terms of the production structure. In order to capture this evolution dynamics in the simulation system, we start with the classic I–O model framework in its traditional implementation (see Ciorba et al., 2004 and Caldés et al., 2009) but, in order to avoid the constraints of the static point of view of this focus in a long-term simulation, we incorporate some technical variants. The main variant in our model is use of a dynamic evolution in the technical coefficients of I–O and in the labour productivity coefficients, developing a changing structure of these crucial factors during the simulation forecasting time.

The paper begins with a brief exposition of the dynamic I–O model and the analytical strategy used. After this exposition, the data and hypotheses of our research are introduced. Then, the main results of the scenario simulations are shown and, finally, we conclude.

2. Analytical schema and dynamic input–output model

In order to determine the level of investment needed for simulations based on different technological alternatives, we start with some basic inputs that are used to outline the RES investment needs in the country, and the 'Business Plan' (investment needs) for each of the alternative scenarios considered.

a) The expected electricity demand for the entire forecast horizon and the production mix are exogenous inputs in our simulation model and in line with those provided by the Moroccan authorities.

b) In order to determine the required investment to meet this demand with a given set of investment resources a *capacity factor* is empirically calculated.

c) In order to evaluate both the investment and operation and maintenance costs (O&M) for each of the different technologies, the most up-to-date information in the industry market is considered.

d) In order to adjust those costs for our medium-long-term simulation scenarios, a well known learning curve was applied to estimate the cost evolution and the global installed capacity of each technology growth, according to a specific hypothesis of different progress ratios for each technology.

Depending on the investment needs, the share of resources that should be provided by the different sectors of the domestic economy and the share that should be covered by imported production are determined. In the context of the medium- and long-term simulation of economic impacts, the imported percentage of investment resources becomes a key factor in defining the different simulation scenarios up to 2040.

Finally, considering the increase in demand for every sector, we compute the direct production needed to achieve the simulation scenarios, following an I–O model according to the methodology of Leontief (1966) and the previous works of Arce and Mahía (2010) and Arce et al. (2011).

Taking into consideration some previous literature about RES economic impacts (see Laitner and McKinney, 2008 and Wei et al., 2010 for an extensive survey) two main methodological approaches exist. On the one hand there are *analytic models*, using the sensibility analysis of aggregated data without interaction between sectors. On the other hand there are the *I–O based models* which include the interlinked economic structure considering the multiplicative effects between sectors.

In the United States, the National Renewable Energy Laboratory (NREL) has developed the JEDI Model Project, based on I–O methodology. In its origin, it was focused on the Wind Powering America initiative but, currently, it has been extended to the other electricity production alternatives (CSP, photovoltaic, biofuels, marine and hydrokinetic power, coal and natural gas power). This methodology has been extensively used in a large number of technical projects (see Algoso and Rusch, 2004, Stoddard et al., 2006 and Vote Solar Initiative, 2009 among others).

In Europe, the European Commission has sponsored several projects using this methodology (see Viebahn et al., 2008; or Project REACCESS, 2009). Madlener and Koller (2007) analysed the impact of bioenergy in Austria. Lehr et al. (2008) estimated the economic impact of renewable energy use in Germany up to 2030, and Caldés et al. (2009) investigated the socio-economic impact of increasing the installed solar thermal energy power capacity in Spain. Allan et al. (2008) examined the economic and environmental impact that the installation of 3 GW of marine energy capacity would have on Scotland.

For the Middle East and North African area (MENA countries) the number of such studies is small. Ciorba et al. (2004) measured the impact of photovoltaic investment in Morocco in terms of induced production and job creation, using the static I–O methodology. More recently (World Bank, 2011), an application of the JEDI model was used to estimate the impact on GDP, foreign trade and job creation of the development of a local manufacturing industry for CSP components in the MENA region by 2020.

In contrast with the methodology frequently applied in the past, in this research we use a dynamic I–O model (DIO) (see Arce and Mahía, 2010 for a detailed analysis of such models). With this DIO variant, we try to address the fundamental simulation drawback that comes from the static nature of I–O, especially when medium- and long-term simulations are undertaken. The limitation of a classic I–O framework for long-term simulations arises from the fixed nature of the intersectoral relations (or technical coefficients) describing the economy interlinks at a given moment. It seems obvious that, in the future, every country's economic structure will change, especially in those developing countries chasing development standards. In this context, we use the French input–output table as a benchmark for convergence between now to 2050. This convergence path means that, by the year 2050, the Moroccan I–O tables will achieve a relative sectoral distribution similar to that in France today.

This gradual convergence of Moroccan I–O levels to those that currently exist in France does not imply that French and Moroccan economies will be the same in 2050, but only that the degree of interdependency between sectors will be similar in Morocco in 2050 to the situation in France today.

In order to achieve this marginal convergence, the technical coefficients of the current Moroccan I–O table have been progressively and slowly adapted, but at the end of the adjustment period (in 2050) the internal structure of the Moroccan economy does not coincide with the French one; the coincidence between the respective I–O tables is limited to the degree of interdependency of each sector.

Although reference can be made to previous I–O benchmarking experiences (see, for example, Antille et al., 2000), using I–O tables from other countries as a point of reference is infrequent. The reason is that most of I–O simulation exercises are not long-term future-based approaches and, thus, existing I–O tables for the country being considered (more or less up to date) can be adapted and used. Nevertheless, the need for a benchmark reference for our future scenario (year 2040) is essential in our long-term study. The accuracy and implications of the selection of French benchmark are difficult to foresee but, in the end, we simply say that the French economy serves as a future reference for the level of interdependency between sectors in the year 2050.

The main changes seen in the Moroccan I–O marginal convergence to 2050 can be summarised as an increase in the level of interdependency of almost every sector during the simulation period. These changes sound reasonable and quite in line with the natural path of tertiarisation and modernisation of a catching-up process.

To implement the dynamisation assumption, we use the technique of bi-proportional distributing RAS (Allen and Gossling, 1975 and Dijkman and Burgess, 1994) to determine the actual values of the French marginal values of the matrix of intermediate consumption from the I–O tables. We suppose a progressive convergent evolution of the current Moroccan technical coefficients in three stages during the next three decades. We use a similar strategy regarding the ratios of value added versus production.

From the Leontief inverse matrix, we then get the total effect (direct plus indirect) due to the direct increase in demand, stemming from the construction, operation and management of the different plants for various RES energy production scenarios.

Once again, in a dynamic context and with a time horizon of 30 years, it is necessary to make a plausible estimation of the future evolution of productivity in the Moroccan economy. We use a trend regression for the ratio of number of employees over the estimated production for each sector of activity using the historical data available on value added and employment in the country.

When this first stage of the simulation (commonly known as *production effect*) has been accomplished we can compute the induced demand effect. Technically, we compute the new disposable income for consumption (derived from the new jobs created in the previous stage) and distribute it as new demand for each sector, using the vector of typical consumption in Morocco from the I–O final demand matrix structure. Once again, the Leontief demand model is used to estimate the valued added and new employment with the same dynamic features already mentioned. Fig. 1, Fig. 2, Fig. 3 and Fig. 4.

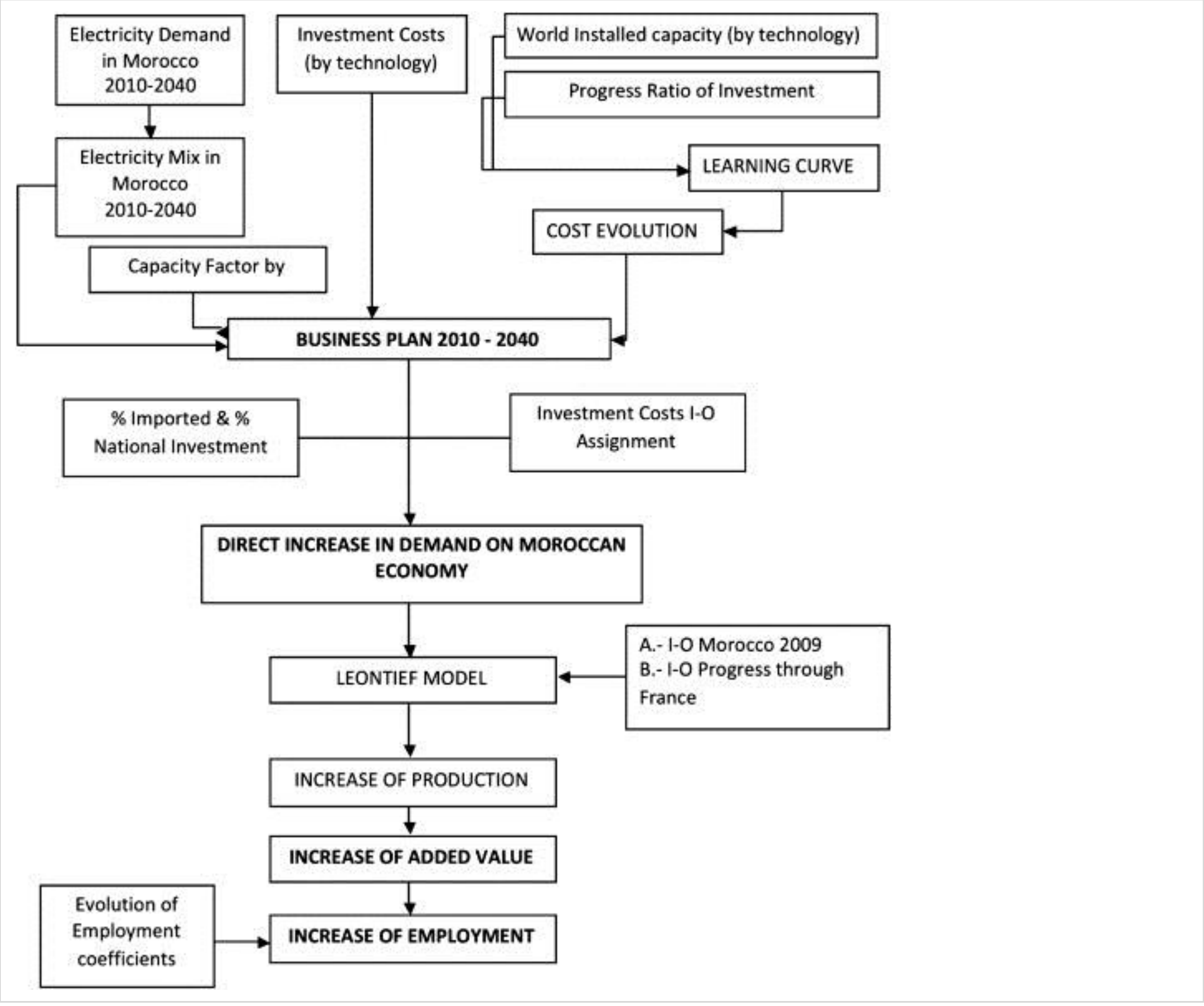


Fig. 1.
Simulation design.

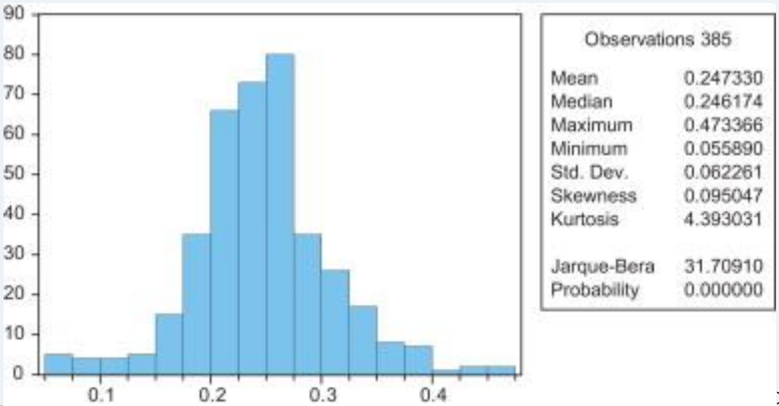
-  >

Fig. 2.
Observed CF: Wind power, Spain (2002–2010).

Source: Own elaboration.

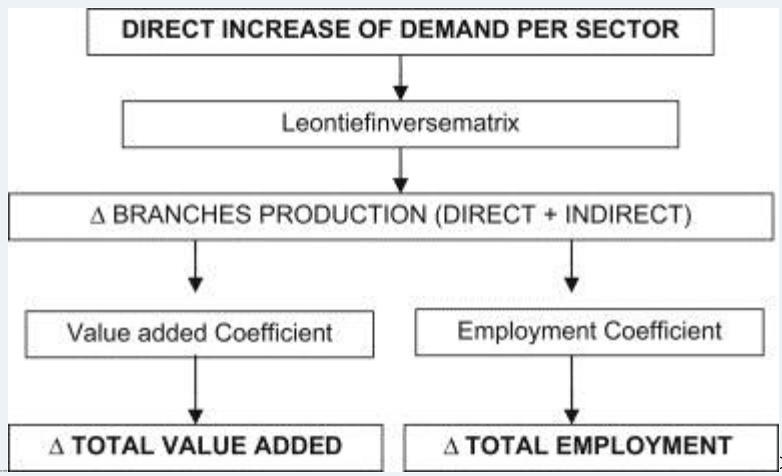
-  >

Fig. 3.
Production effect schema using Leontief algorithm and dynamized coefficients.

Source: Arce and Mahía (2010).

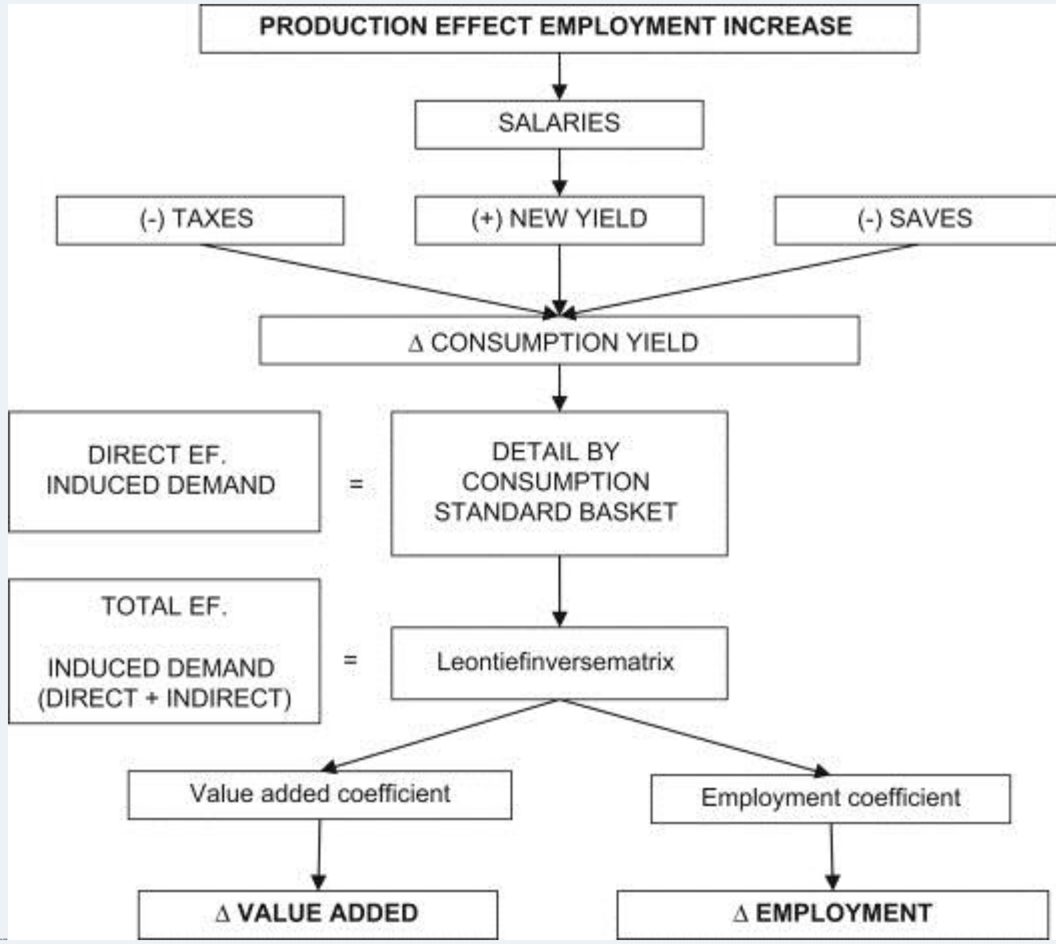


Fig. 4.
Induced demand schema using Leontief algorithm and dynamized coefficients.

Source: Arce and Mahía (2010).

3. Data and hypothesis

3.1. Electricity demand of Morocco 2010–2040

To determine the electricity demand in Morocco over the next 30 years, we use the official estimates of the Moroccan Ministry of Energy, Mines, Water and the Environment, providing data up to 2030. In order to extend these forecasts to 2040, we have also used the data provided by the Project REACCESS (2009). This project formulated a forecast for electricity demand based on a dynamic model using parameters obtained from regressions between electricity demand and per capita income in the MENA region. The results of both the Moroccan ministry and REACCESS are similar for the common forecast period.

3.2. Learning curve and cost evolution by technology

Mathematically, the cost of each component (C) at time t is related to the cost at time zero, the ratio of the global installed capacity (P) and a technological progress rate (PR) as follows:

$$C_t = C_0 \left(\frac{P_t}{P_0}\right)^{\log(\text{PR})/\log(2)}$$

This kind of learning curves assumes that, for a given progress rate, the cost is reduced by (100−PR)% every time the global installed capacity doubles. For example, with a progress ratio of 90%, the cost of each component is reduced by 10% with every doubling of the installed capacity.

Both for CSP and wind power, installed capacity forecasts were taken from the Viebahn et al. (2008). In the case of the future evolution of PV installed capacity, we used data from the IEA, 2010. In order to determine the PR rates, we took the values in Neij (2008) and Viebahn et al. (2008) shown in Table 1.

Table 1
Technological progress rates.
Source: Neij (2008) and Viebahn et al. (2008).

	Technological progress rate(%)
CSP	
Parab. through	
Solar field	90
Power block	98
Storage	92
Tower plant	
Solar field	90
Power block	98
Tower	98
Storage	92
Photovoltaic[a]	
Balance of system (BOS)	80
PV Modules	80
Batteries/storage	80
Wind power	
Cables and network connection	99
Power block	90
Tower	99

[a] The PV progress rate cannot be maintained over a very long period due to the current maturity of this technology. We have assumed that this PR will increase up to 95% by the end of 2040, using a linear progression from 2010 to 2040.

3.3. Capacity factors

The capacity factor (CF) of each RES technology is a crucial aspect in order to plan the investment amount needed to produce a given energy supply. Taking into account the installed capacity of a plant, we can calculate the total potential energy that could be produced per year, assuming that it works 24 h a day and 365 days a year (8760 h a year). Obviously, the plant is not constantly working and so production is going to be lower. We can get the real CF with a simple calculation.

$$\text{capacity factor} = \frac{\text{MW produced per year}}{\text{MW Installed} * 24 * 365}$$

In the following paragraphs, we will discuss this ratio for each RES technology in our study.

3.3.1. Concentrated solar plant CF

The values of CF for CSPs move in a wide range when considering several aspects: current observable data in other countries, type of technology, land characteristics, DNI, seasonal variations, geomorphology, cloud conditions, technological progress, tracking devices, shading, location, etc. (see REACCESS, 2009). The storage capacity does not imply more CF but displaces the output delivery.

For the case of CSP, different technologies are available. In 2012, over a total world installed capacity of 11 GW, the distribution by technology will be (IEA, 2010): Parabolic through (44%), CPV (8%), Stirling Dish (14%), Tower plant (5%), Fresnel concentrator (12%), and other (17%).

For currently available data of working CSP projects around the world, the estimated CFs are in the range 25–29% (using data for Barstow/USA, Almeria/Spain, Ibersol-Puertallano/Spain). In the technical proposals of current projects, the engineers use a figure of 2550 h per year (29%), see SOCOIN (2010).

The seminal research of NREL (2003) about this issue established a CF of 42% in 2010 for Tower plants. The NREL estimates that CFs in 2020 could reach 56.2% with parabolic-through collectors and up to 72.9% with Tower plants.[3]

SOCOIN, Engineering Consulting of Gas Natural Company (Spain), estimates a CF of 53.9% for hybrid projects of CSP (parabolic through) and Gas, using thermal oil as storage fluid. Other projects in Priolo/Italy and Liddell/Australia that use molten salts and Fresnel concentrators obtain an even higher CF (around 70%).

In order to decide the best value for CF CSP plants in Morocco we can examine the basic technical parameters of the five projects announced up to 2020, see Table 2.

Table 2
Moroccan CSP projects basic parameters.
Source: MASEN, 2011.

Location	Capacity installed (MW)	Mix sources (MW)	Land surface (ha)	Annual production GW h/y
Ain Beni Mathar	400	20 CSP[a] 380 Gas	2000	835
Ouarzazate	500	25 CSP[b] 475 Gas	2500	1150
Foum al Ouad	500	25 CSP[b] 475 Gas	2500	1150
Boujdour	100	5 CSP[b] 95 Gas	500	230
Sebkhat Tah	500	25 CSP[b] 475 Gas	2500	1040

[a] Real.
[b] Estimated.

As shown in Table 2, these projects are designed with combined cycle gas (CCG) and parabolic-through technologies, with a heavy weighting of gas over solar. Considering these technical specification of Moroccan CSP projects, we then assume a CF of 55% as a simulation hypothesis. This value may look high, but it is in line with other studies: JEDI uses a 41.7% for California installations and DLR (2009), considering the extraordinary characteristics of Morocco in terms of DNI, solar multiples, geomorphology and land possibilities, support a median CF value of 55%.

3.3.2. Windmill farm and photovoltaic field CFs

The wide spectrum of different plants with various installed capacities for both technologies already operating in Spain (as a Mediterranean reference quite close to Morocco) permits us to obtain more accurate reference data about real CFs.

The official data published for Morocco are scarce and they show high volatility, so data for Spain have been used as a benchmark. In the absence of reliable Moroccan data, the geographical proximity between Spain and Morocco lends support to our assumption.

However, in the case of wind power, the fairly unpredictable behaviour of wind produces wide differences in the total observed CF over the years. The data for 2002–2010 for Spain shows a robust mean of 24.7%, with a standard deviation of six points (dropping some outlier observations for recently installed wind power farms). This 25% average CF may decrease in the future on the assumption that the current windmills are already positioned in the best available locations. On the other hand, technical improvements may raise the power and efficiency of windmills. Under these considerations, a 25% CF could be considered a conservative hypothesis. In any case, this figure is within the ranges used in other studies, such as REACCESS (2009) (15–50%), EWEA (2009) (20–35%) and Schwabe et al. (2011) (35%).

In the case of the photovoltaic, we did not find out any reliable specific information for Morocco, and we took the CF values from REE (2010) that computed a CF of 19.8% (as an average for 2010 in Spanish fields) slightly lower than the figures of Hynes (2009) who assumes a reasonable range of 20–25% CF.

3.4. Investment and operating and maintenance (O&M) costs

For the determination of investment and O&M costs we compared a variety of sources: the available information in Caldés et al. (2009) (especially regarding CSP), Viebahn et al. (2008), the Call for Proposal issued by Abengoa to build the Moroccan CSP Central in Ain Beni Mathar, data from several volumes of the industry specialized magazine CSP Today, some specific interviews with Spanish experts in the field of renewable energy technologies (from Abengoa Solar, Iberdrola and Union Fenosa) and the JEDI Model data (see Section 2 of this paper) frequently used in RES-related literature. For the specific case of photovoltaic technology, the wide range of costs in the market, due to the very different qualities of mirrors employed, forced us to take the simple average cost of each component.

In Table 3, Table 4 and Table 5, we show the final data used in the simulation for each technology and decade, considering the cost reduction curve for each component according to the progress ratios and the evolution of the global capacity installed as detailed above.

Table 3
Parabolic through investment and O&M costs per 1 MW installed (000 h).

Source: Own elaboration based on different sources.

	2010 2040	2020	2025	2030	
Solar field	2,469.7	1,262.0	1,121.6	995.6	900.6
Solar field	2,103.3	1,074.7	955	847.9	766.9
HTF field	288.7	147.5	131.1	116.4	105.3
Spare parts and other expenses	77.7	39.7	35.3	31.3	28.3
Power block	1,113.8	979.3	957.4	935.7	917.9
Natural gas boiler	3,051.0	2,682.4	2,622.5	2,563.2	2,514.4
Vacuum generator	4,767.0	4,191.1	4,097.4	4,004.9	3,928.6
BOP	13,173.0	11,581.7	11,322.7	11,066.9	10,856.1
Generation plant	30,811.0	27,089.0	26,483.3	25,885.0	25,391.8
Spare parts and other expenses (50%)	3,888.0	3,418.3	3,341.9	3,266.4	3,204.2
Terrain	24.2	24.2	24.2	24.2	24.2
Storage	663.7	390.2	355.4	323.4	298.7
Storage system	19,837.0	11,660.4	10,621.3	9,665.3	8,927.6
Salts	13,350.0	7,847.2	7,148.0	6,504.6	6,008.1
Construction	531.7	531.7	531.7	531.7	531.7
Engineering	256.8	159.1	91.2	48.4	24.1
Contingencies	256.8	159.1	91.2	48.4	24.1
Total	5,316.7	3,505.5	3,172.6	2,907.4	2,721.3
Operating and maintenance annual cost					
Fixed operational costs	25.8	25.8	25.8	25.8	25.8
Maintenance	55.2	55.2	55.2	55.2	55.2
Financing (r 7%)	108.6	108.6	108.6	108.6	108.6
Natural gas	31.3	31.3	31.3	31.3	31.3
Electricity	25.0	25.0	25.0	25.0	25.0
Total	246.0	246.0	246.0	246.0	246.0

Table 4
Wind power investment and O&M costs per 1 MW installed (000h).
Source: Own elaboration based on different sources.

	2010	2020	2025	2030	2040
Electric installationþnet connection	85.3	83.6	83.1	82.7	82.2
Tower (steel)	103.4	101.3	100.7	100.2	99.6
Turbine	583.8	469.6	444.0	418.4	392.0
Land (terrain)	54.3	36.2	24.1	16.1	10.7
Storage	0.0	0.0	0.0	0.0	0.0
Construction	38.6	31.9	30.4	28.9	27.4
Engineering	14.5	12.0	9.4	7.1	5.0
Transports	14.5	12.0	9.4	7.1	5.0
Total	894.5	746.6	701.3	660.5	621.9
Operating and maintenance annual cost					
Fixed operation	5.1	5.1	5.1	5.1	5.1
Maintenance	4.2	4.2	4.2	4.2	4.2
Financing (r 7%)	19.3	19.3	19.3	19.3	19.3
Natural gas	0.0	0.0	0.0	0.0	0.0
Electricity	0.6	0.6	0.6	0.6	0.6
Total	29.2	29.2	29.2	29.2	29.2

Table 5
Photovoltaic investment and O&M costs per 1 MW installed (000 h).
Source: Own elaboration based on different sources.

	2010	2020	2025	2030	2040
PV Module	1880.18	986.80	712.52	608.06	470.22
Solar cell	849.12	445.65	321.78	274.61	212.36
Other components	129.89	68.17	49.22	42.01	32.48
Electrical connections	7.46	3.91	2.83	2.41	1.86
BOS	805.79	422.92	305.37	260.60	201.52
Inverter	175.30	92.01	66.43	56.69	43.84
Batteries	402.90	211.46	152.68	130.30	100.76
Rest	45.70	23.99	17.32	14.78	11.43
Land	0.43	0.43	0.43	0.43	0.43
Construction and engineering	975.17	975.17	975.17	975.17	975.17
Total	3661.57	2385.31	1993.48	1844.24	1647.34
Operating and maintenance annual cost					
Financing (r 7%)	17.09	11.13	9.30	8.61	7.69
Rest	12.50	8.15	6.81	6.30	5.63
Total	29.59	19.28	16.11	14.90	13.31

3.5. Direct demand assignment and dynamic I–O framework

The construction, installation and O&M domestic demands are satisfied by different economic sectors. The theoretical allocation of these supply–demand interrelations have been taken, as a proximate reference, from the Spanish economy according to the I–O tables of 2009 (see Appendix Table A1, Table A2 and Table A3). However, it should be remembered that a percentage of these supplies are supposed to be imported and, thus, this imported share will be one of the key input parameters used for the definition of the different simulation scenarios (see Section 4).

These supply shares assigned to each sector equal the direct increase in demand in the simulation model. Starting from this demand increase, we then estimate the total effects of increased production in Morocco using the Leontief inverse matrix, conveniently *dynamized* (as explained above). Once the increase in total production is estimated, the impact in value added and employment is deduced using the *value added over production* and the *employment over value added* coefficients.

Finally, the *induced demand effect* is obtained using the Leontief model to connect the employment of the previous section with the final demand in the I–O system (see next illustration).

This induced demand effect comes from the new disposable income derived from the new jobs created in the previous stage. This new wage income (properly reduced by a fixed proportion of savings and taxes) is distributed as new consumption among the different branches using a basket of typical consumption in Morocco generating an induced demand effect both direct and indirect.

It should be clarified that, with this methodological approach, we are not taking into account the potential loss of employment and economic activity in other sectors, eventually needed to be matched by the new labour demand of emerging RES activities.

4. Simulation scenarios and main results

To observe the different effects on the Moroccan economy over the next 30 years, seven scenarios of simulation are discussed.

As seen in Table 6, each of these different scenarios results from a combination of two basic hypotheses:

a)

That a progressive reduction of import dependency of RES investment will take place over the years. Two alternatives are simulated: (i) maintaining the current dependency on investment imported goods (scenarios I or III) or (ii) considering a progressive reduction of investment imports dependency of up to one-half of the existing level (scenarios II or IV).

b)

That an additional RES capacity will be installed with the aim of exporting the energy surplus to third countries in the future (and identifying which technology will be used for that). The alternative exporting hypothesis comprises the export of 20% of electricity production, using the same electricity mix as in the baseline scenario[4] (scenarios III or IV) or, alternatively, with additional installed capacity in just a single technology in order to generate the production surplus to be exported (scenarios V to VII, depending on the technology chosen to produce that export-oriented surplus).

Table 6

			Progressive reduction of import dependency of components	
			No	Yes
Additional capacity for exporting	No		Scenario I (Baseline)	Scenario II
	20% of increase according to the technology mix		Scenario III	Scenario IV
	20% of increase with a single technology	Csp plants	Scenario V	–
		PV plants	Scenario VI	–
		Wind farms	Scenario VII	–

Definition of the scenarios of simulation.

The results obtained for the different scenarios can be compared to the baseline results for scenario I (no energy exports and no import dependency reduction). The comparison between I and II or III and IV allows us to determine the effect of the import dependency reduction. The comparison between scenario III and any of V, VI or VII permits the evaluation of the differential impact of using each one of the alternative RES technologies.

In the baseline scenario I, the *value-added* global average annual effect on the Moroccan economy resulting from the installation of renewable energy starts at about 0.18% of GDP in 2010 and reaches 1.21% in 2040. The corresponding impact on employment would be about 36,000 new jobs in 2010 and around 269,000 at the end of the forecasting period.

It seems logical to consider that the optimum outcome for Moroccan authorities would be described in scenario IV, where a surplus of 20% is exported with the actual investment effort (and once domestic demand has been satisfied) and, at the same time, the economy progressively reduces dependence on imported investment goods needed to construct the energy plants. Scenarios II and III are intermediate situations that permit us to isolate the impact of import dependency reduction (scenario II) or the exporting benefits (scenario III). For scenario III, the effect of exports is relatively small: at the end of the period, the value-added impact is about 1.45% on GDP (compared with 1.21% in the baseline) and the number of jobs created would be around 323,000 (slightly less than 146,000 above scenario II).

On the other hand, reducing the import dependency (scenario II) increases the value-added impact to 1.83% at the end of the period (an additional impact of around 0.6% compared with the baseline) and increases by up to 468,255 the creation of employment (around 200,000 more than in the baseline).

For the optimum scenario (scenario IV) the combined impact of RES, reducing dependence on imports and exporting a 20% surplus is equal to 1.99% (in terms of value added) and 499,000 employees.

The remaining scenarios (V–VII) permit us to make a ceteris paribus comparison on the differential economic impact due to the selection of each one of the three RES technology alternatives.

The results of scenarios V and VI indicate that the use of photovoltaic technology or CSP have similar consequences in terms of economic effect on the Moroccan economy, only slightly higher in the case of CSP: the impact on GDP would be about 0.03% higher with CSP than in the photovoltaic case and the number of jobs created are very similar at the end of the forecast horizon. In contrast, the wind farm scenario VII makes a clear difference: the impact would represent 1.92% of GDP in 2040 compared to 1.28% average of the two alternative sources and, regarding employment, the use of this alternative would lead to about 421,355 jobs in the economy.

This relatively greater impact arises due to two different reasons. The first is the lower CF of windmill technology, which basically means that more installed capacity is required to safely provide a given amount of energy and, thus, more employment and investment is needed. The second reason is the lower import dependency of Morocco for the production of windmill technology (around 50%) compared with the high dependency on foreign investment for the other technologies. Table 7, Table 8 and Table 9

Table 7

			Progressive reduction of import dependency of components	
			No	**Yes**
Additional capacity for exporting	**No**		+1.21% GDP +269,252 Empl.	+1.83% GDP +468,255 Empl.
	20% of increase according to the technology mix		+1.45% GDP +323,102 Empl.	+1.99% GDP +499,009 Empl.
	20% of increase with a single technology	**Csp plants**	+1.30% GDP +292,891 Mill. Empl.	–
		PV plants	+1.27% GDP +286,153 Empl.	–
		Wind farms	+1.92% GDP +421,355 Empl.	–

Comparative summary of basic results for the different scenarios of simulation (impact on value added in % of GDP and employment at the end of the forecasting period).

Table 8
New employment by scenario (Full-time equivalent workers).

Scenario	2010	2020	2030	2040
I	35,989	67,609	165,096	269,252
II	35,989	89,775	256,620	468,255
III	35,989	81,130	198,115	323,102
IV	35,989	95,474	276,574	499,009
V (CSP)	35,989	81,418	180,798	292,891
VI (PV)	35,989	78,304	164,385	286,153
VII (WIND)	35,989	96,671	241,948	421,355

Table 9 Detailed figures of added value impact by acenario (000 €).

Scenario	2010	2020	2030	2040
I	137,936	295,070	852,075	1600,004
II	137,936	359,063	1180,546	2423,818
III	137,936	354,084	1022,490	1920,005
IV	137,936	396,586	1303,734	2636,582
V (CSP)	137,936	334,664	911,930	1723,633
VI (PV)	137,936	327,647	857,599	1689,690
VII (WIND)	137,936	443,991	1316,510	2547,973

The current legal and regulatory framework in Morocco is helpful to the achievement of the proposed scenarios. The Renewable Energy Act allows, for the first time, clean energy exports to third countries, as EU member states aim to achieve certain shares of renewable power by 2020. Morocco should take advantage of its proximity to the EU to become a European energy trade partner. This would encourage the development of the renewable energy sector in Morocco with major impacts on economic growth and job creation in the country.

In this scenario, the economic effects of the development of the renewable energy sector would intensify if Morocco managed to reduce the high import dependency of components related to the renewable energy sector. The ongoing liberalization of the electricity sector facilitates the entry of foreign investors in the country. This opportunity should be seized by local businesses to implement agreements that can reduce costs and improve technology.

5. Final remarks

The purpose of this paper is to present a meaningful comparison of the economic impact of various investment options of renewable energy production in Morocco. Some important issues, such us the legal, regulatory or institutional constraints or the financial viability of the projects, are beyond the scope of the paper.

The overall figures for the economic impact on GDP range from 1.21% to 1.99% at the end of the forecasting period covered (2040), with a full-time equivalent employment effect of between 269,252 and 499,000 jobs.

In the light of our results, we conclude that the alternative that produces most benefits in terms of impact on GDP and employment growth would be the installation of windmills, whatever framework of exports and imports is observed.

The positive environmental impact of the installation of these RES technologies is obvious and this work makes it clear that there are also significant socio-economic outcomes.

The Moroccan RES investment project is still in its infancy, but the benefits in the near future seem clear. The geographical characteristics of Morocco, which favour the production of green energy, and the significant effects derived of the installation of this kind of power plant (in terms of added value and job creation) allow us to expect a big development of this industry in Morocco supposing that the necessary conditions continue to improve (regulatory stability, finance commitments, EU-Morocco agreements about exports, etc.). In that sense, the results of our investigation provide a useful quantitative framework that should help to foster the implementation of RES plans.

The simulation hypotheses used in this exercise may be more or less questionable and, thus, the final figures may be also doubtful to some extent, but this paper provides a transparent and complete analytical framework that could be easily reproduced by other authors using alternative assumptions.

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Appendix

Table A1
Percentage assignment of investment goods demands (columns) to different supply sector (rows): parabolic through plants.

	Solar field	Power block	Terrain	Storage	Construction	Engineering	Contingencies
Agriculture, forestry & fishing Fishing	3.3		13.4	28.6			
& pisciculture							
Mining & quarrying							
Food, beverages &							
tobacco Textiles, apparel							
& leather							
Metallic, metalurgical & electric industry	60.8	72.4		41.4			
Other manufacturing	19.2						
Petroleum & coal		25.4	10.6	22	100		
products Electricity, gas &	8.6						
water Construction			22.1				
Wholesale & retail trade							
Restaurants & hotels	8.1	2.2		8			
Transport & storage							
Communication							
Finance & insurance			22.1				
Real estate & business services							
Producers of government services							
Education, health & social services			31.8			100	100
Non financial services							
Statistical discrepancy							
Total sectors	100	100	100	100	100	100	100

Table A2.

Percentage assignment of investment goods demands (columns) to different supply sector (rows): Wind power.

	Electric installation+net connection	**Tower (steel)**	**Turbine**	**Land (terrain)**	**Storage**	**Construction**	**Engineering**	**Transports**
Agriculture, forestry & fishing				13.4				
Fishing & pisciculture								
Mining & quarrying								
Food, beverages & tobacco								
Textiles, apparel & leather								
Industrial chemicals, drugs & medicines								
Metallic, metalurgical & electric industry	21.4	98	96					
Other manufacturing								
Petroleum & coal products				10.6				
Electricity, gas & water	78.6							
Construction		2		22.1		100		
Wholesale & retail trade								
Restaurants & hotels								
Transport & storage								100
Communication								
Finance & insurance								
Real estate & business services				22.1				
Producers of government services								

	Electric installation+net connection	Tower (steel)	Turbine	Land (terrain)	Storage	Construction	Engineering	Transports
Education, health & social services								
Non financial services			4	31.8			100	
Statistical discrepancy								
Total sectors	100	100	100	100	100	100	100	

Table A3.
Percentage assignment of investment goods demands (columns) to different supply sector (rows): photovoltaic.

	Solar cell	Other components	Electrical connections	Bos	Inverter	Batteries	Rest	Land	Construction and engineering
Agriculture, forestry & fishing								13.4	
Fishing & pisciculture									
Mining & quarrying									
Food, beverages & tobacco									
Textiles, apparel & leather									
Industrial chemicals, drugs & medicines	68.19					50	33		
Metallic, metalurgical & electric industry		100	100		100	50	67		
Other manufacturing	23.15								
Petroleum & coal products								10.6	
Electricity, gas & water	8.66								
Construction								22.1	100
Wholesale & retail trade									
Restaurants & hotels									
Transport & storage									
Communication									
Finance & insurance									

	Solar cell	Other components	Electrical connections	Bos	Inverter	Batteries	Rest	Land	Construction and engineering
Real estate & business services								22.1	
Producers of government services									
Education, health & social services									
Non-financial services								31.8	
Statistical discrepancy									
Total sectors	100	100	100	100	100	100	100	100	100

Table A4

Baseline electricity mix of morocco — installed capacity by source (MW, Scenario 1).

	CSP (parab. through)	Wind power	Photovoltaic	Total
2010	20	284	13	317
2012	20	1192	20	1232
2015	225	1595	50	1870
2020	416	2000	80	2496
2030	1299	3390	128	4816
2040	2893	5777	205	8875

Table A5
Projected installed capacity (MW) by decade and scenario.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2010	317	317	317	317	317	317	317
2012	1232	1232	1,479	1,479	1,406	1,735	1.662
2015	1870	1870	2,244	2,244	2,136	2,436	2.323
2020	2496	2496	2,995	2,995	2,868	3,384	3.226
2030	4816	4816	5,780	5,780	5,623	6,268	5.926
2040	8875	8875	10,651	10,651	10,450	11,839	11.171

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