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Optimization of Isolate Hybrid Photovoltaic and Wind Energy Instalations in Madeira Islands (Portugal)

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Abstract: This paper deals with the estimation of solar photovoltaic energy and wind energy potential in six defined climatic areas of the madeira archipelago. the areas are climatologically represented by the variables recorded in six meteorological stations (areeiro, funchal, lugar de baixo, ponta do pargo, são jorge, and porto santo) during the period 2002–2005. in order to make the conclusions of the study as general as possible, PV modules are supposed to be in the horizontal plane. an advantage of this arrangement is that the calculated PV production for square meter of module coincides with the pv production per square meter of horizontal land.

Based on this study, this papers is also focused on the optimization of hybrid off-grid PV-wind systems. to facilitate the comparison of the systems, energy productions are given as specific values related to the square meter of horizontal land occupied by the systems. the DC PV electric generation per square meter of module (and horizontal land) in the sites of the stations was obtained in a parent paper. the wind electric generation is obtained from the wind daily data of the stations and considering an instantaneous weibull distribution.

The paper ends advising about the best places for the use of solar photovoltaic in the region and the optimal combination of solar and wind energy installations. the results show that, from the technical point of view, the optimum percentage of pv power in the pv-wind hybrid systems varies from 44% to 91%, with a renewable energy coverage in the range of 91-93 percent of the total, and that, from the economic point of view, the best hybrid solutions are hundred percent PV.

Keywords: solar photovoltaic energy, wind energy, hybrid installations, optimization, archipelago, Madeira

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1. Introduction

The Autonomous Region of Madeira, composed by the main island of Madeira and Porto Santo Island with other minor islands, is dependent on the imports of energy resources, basically fossil fuels, like the majority of the other European Regions. At the same time, local renewable energy resources such as solar energy are underused or not used at all. Electricity generation has been increasingly dependent of the fossil fuel thermal plants, down from the hydro dominance a few decades ago. As the growth of hydropower is very limited, and the economical exploitation of the irregular wind energy is only feasible in a few places, sustainable electricity will have to be generated mainly by solar photovoltaic plants. The use of local renewable energy resources is of vital importance for the desired sustainable development of the world, but it is especially urgent in isolated and populated areas such as the islands of the archipelago of Madeira. The technology is well developed for the exploitation of both resources, and the area has a good PV potential and, given its situation in the Atlantic Ocean, foreseeably good wind potential.

A first step to this desirable future is to evaluate the PV potential in the archipelago, which is the object of this paper. Climatologically, the Madeira Archipelago has very differentiated areas but we are going to study six of them that, all together, can characterize the entire archipelago. The six climatic areas are represented by the variables recorded in six corresponding meteorological stations.

PV system production and performance is obtained from a published typical I-V (intensity-voltage) PV model (1), and using, as input variables, those daily radiation and temperature evolutions on the "characteristic days", and the photo-thermal-electric characteristics of a good performance module in the market, for each month and station. In order to make the conclusions of the study as general as possible, or, in other words, in order to compare each other the PV potential of the areas without the influence of secondary factors such as possible shades, reflection of the ground, etc., we suppose the PV installations formed by only one PV module of one square meter placed horizontal in each site. An advantage of this arrangement is that the calculated PV production for square meter of module coincides with the PV production per square meter of horizontal land. In a first step, the theoretical direct current out of the module is calculated considering it always works at the Maximum Power Point (MPP) without any external losses. In a second step, a more realistic useful direct current out of a PV system is calculated considering losses. Several authors have studied the different types of losses and the actions for their reduction (2, 3). There are papers about losses caused by soil and dust, and variability of the Sun spectrum and incidence angle (4, 5). Losses due to Ohm effect in cables and other electric elements such as protection diodes, and losses due to module mismatches and series-parallel connections (6), and losses caused by shades (7), and non-availability of the system and MPP tracking faults (8), among others. Finally, conversion to alternating current with an inverter is studied, and losses in this process (9) are taking into account to end the PV analysis.

In relation to the wind potential, in a first step, a study of the wind daily data in the six stations is done and it is obtaining wind probabilistic distribution function considering a Weibull function (10) and an efficient small wind generator in the market. The wind generator electric output is divided by the recommended minimum number of land square meters needed by the wind generator in order not to interfere with other similar generators in the field, and the electric wind potential per square meter of horizontal land is obtained.

With the daily Wind and PV electric energy per land square meter obtained, the simulation of hybrid off-grid PV-Wind systems is performed for the sites of the six stations. The conditions imposed are: an electric daily consumption constant and equal to the yearly daily average electric PV-Wind production, and a capacity of the battery equal to a three-day electric consumption. If daily generation surpasses daily consumption with a full battery, energy is lost. If daily generation is less than daily consumption with an empty battery, energy is supplied with a back-up generator.

For hybrid PV/Wind systems it is interesting to analyze their optimization, both from the technical and economical points of view (11, 12). In this paper we obtain the optimum percentages of PV/Wind powers in the hybrid systems as well as the percent of coverage of the demand with both types of renewable energy.

2. Data Base

The six stations used for this study are operated by the Meteorological Institute of Portugal in the Madeira archipelago. Geographical localization of the stations is shown in Table 1 (the fourth column is the altitude in meters above sea level).

Table 1: Madeira archipelago meteo-stations geographic coordinates

Station	*Latitude (North)*	*Longitude (West)*	*Meters above sea level (a.s.l)*
Areeiro	32º 43' 15"	16º 54' 49"	1510
Funchal	32º 38' 46"	16º 53' 27"	58
Lugar de Baixo	32º 40' 47"	17º 05' 28"	48
Ponta do Pargo	32º 48' 44"	16º 53' 27"	312
São Jorge	32º 49' 54"	16º 54' 24"	271
Porto Santo	33º 04' 23"	16º 20' 50"	82

The Standard Test Characteristics STC (1000 W/m^2 irradiance, air mass AM 1.5, and cell temperature 25ºC) of the PV module in the market used, are:

- Short circuit current	Isc	5.85 A
- Open circuit voltage	Voc	47.65 V
- Nominal power	PM	210 W
- Dimensions (length x width)	1559 x 798	mm
- Module useful area	S	1.244 m^2
- Current temperature coefficient		+2.27 mA/ºC
- Voltage temperature coefficient		-0.1368 V/ºC
- NOCT		48.5 ºC

Even though the results will be referred to a square meter of module, the simulation was made considering a PV plant formed by 32 groups connected in parallel, each group formed by 15 modules in series, totaling 480 modules.

Therefore, the electric characteristics of the plant are:

- Short circuit current	Iscplant	187.2 A
- Open circuit voltage	Vocplant.	714.75 V
- Installation, nominal peak power	Pmplant.	100 kW
- Total area of modules		597.12 m^2

As the modules are put horizontally, total area of modules is also the area of land occupied.

Direct current conversion to alternating current is produced by an inverter with a nominal power peak of 105 kW and with efficiency as showed in Table 2.

Table 2: Efficiency of the inverter

Input/Nominal power (%)	*Efficiency (%)*
0 %	0.0 %
10 %	92.0 %
25 %	94.8 %
50 %	95.6 %
100 %	94.8 %

In relation to wind production, the available wind speed data base in those stations is only of daily average wind speed, registered during the four- year period (January 2002- December 2005) at 10 meter above ground allow us to calculate from these data, the monthly and yearly average wind speeds are calculated and shown in Table 3. As the simulation of the operation of the wind system will be made with a wind generator whose rotor axis is supposed to be at 23 m above ground, the average wind speed at that altitude is obtained from the 10 m high data and the well-known altitude-related logarithmic wind speed formula (1), and shown in Table 4.

Table 3: Monthly/yearly average wind speed (10 m high) in meters per second

Station Month	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
January	5.7	2.0	1.9	3.1	3.3	3.5
February	7.6	2.0	2.2	3.3	3.4	4.7
March	6.2	1.8	2.2	3.6	3.2	4.8
April	5.4	1.7	2.1	3.3	3.1	4.5
May	6.1	1.4	2.0	3.1	2.6	4.8
June	4.1	1.1	1.7	2.6	2.3	4.5
July	5.6	1.1	1.8	2.8	2.1	4.9
August	4.4	1.2	1.8	2.7	2.4	4.6
September	5.0	1.4	1.9	2.9	2.2	4.2
October	5.1	1.7	2.2	3.4	2.9	4.4
November	6.5	1.8	1.9	3.6	3.4	4.5
December	7.6	2.0	2.2	3.6	3.6	5.2
Year Average	5.8	1.6	2.0	3.2	2.9	4.6

Table 4: Monthly/yearly average wind speed (23 m high) in meters per second

Station Month	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
January	6.8	2.3	2.3	3.7	3.9	4.1
February	9.0	2.4	2.6	3.9	4.0	5.6
March	7.3	2.1	2.6	4.3	3.8	5.7
April	6.3	2.0	2.5	3.9	3.7	5.4
May	7.2	1.7	2.3	3.6	3.1	5.7
June	4.8	1.3	2.0	3.0	2.8	5.3
July	6.6	1.3	2.2	3.3	2.5	5.8
August	5.2	1.4	2.1	3.2	2.9	5.4
September	5.9	1.6	2.2	3.5	2.6	5.0
October	6.0	2.0	2.6	4.0	3.4	5.2
November	7.7	2.2	2.3	4.2	4.0	5.3
December	9.0	2.3	2.6	4.3	4.2	6.1
Year Average	6.8	1.9	2.4	3.7	3.4	5.4

Since only average daily values of wind speed are available, it is necessary to estimate the instantaneous wind speed distribution along the day. We selected the well-known Weibull statistic function to characterize that distribution. In it, the probability is given by *Eq. 1* that express the probability that the wind speed velocity take the value of “v”:

$$f (v) = k (c)k \bullet vc\text{-}1 \bullet \exp [-(cv)\cdot k] \qquad (Eq.\ 1)$$

Where, k and c are the equation shape and scale parameters, related to the value of the daily average wind speed vm through *Eq. 2*, which uses the Gamma function $\Gamma(x)$

$$vm = c \cdot \Gamma(1 + 1 / k) \qquad (Eq.\ 2)$$

A typical value of k is 2, and c is obtained from the daily average wind speed from *Eq. 2*.

For the simulation we chose a 1000 W nominal power (Pnom) wind turbine at 11.6m/s wind speed, a rotor diameter (Dr) of 2.7m, and useful wind speed range of 3-20m/s. The axis rotor is supposed to be on a 23m high tower. The output power vs wind speed graph is shown in following figure (Fig. 1).

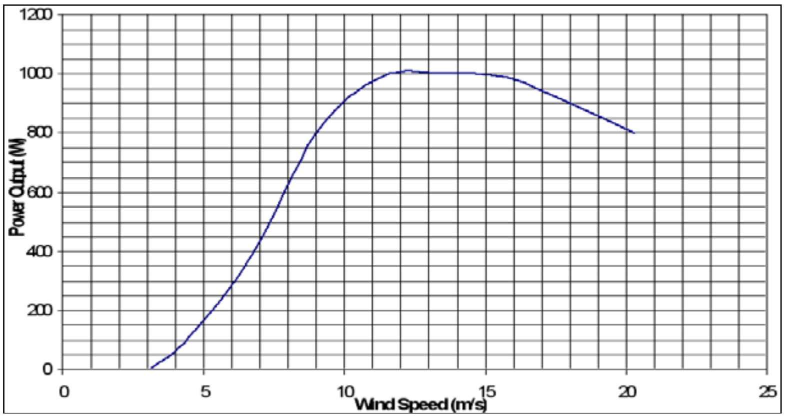

Fig. 1: Output wind turbine power function of wind speed

3. Methodology

In a first step, instantaneous PV productions of the module are calculated at the Maximum Power Point (MPP), applying a widely used typical I-V (current-voltage) model (3) to the module characteristics, and considering as input the evolution of temperature and irradiance in the monthly characteristic days of the stations. No other losses are considered, except those related with radiation and temperature.

By integration of the irradiances, maximum daily average PV energy production is obtained for each month and station. All these values are referred to one square meter of module (equivalent to one square meter of horizontal land) and are shown in Table 5 together with the yearly daily average values.

Table 5: Monthly and yearly daily average PV production (wh/m^2 day) for six stations in Madeira

Station Month	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
January	540	483	477	480	420	468
February	549	576	591	598	519	613
March	761	768	775	754	693	829
April	864	780	843	934	831	1004
May	1098	937	1013	1116	937	1175
June	1219	926	1013	1192	1032	1148
July	1292	924	993	1178	968	1140
August	1055	901	977	1066	998	1058
September	873	827	861	863	823	905
October	646	620	656	661	623	680
November	437	487	501	480	412	531
December	400	425	443	445	348	432
Year Average	813	722	763	815	718	833

In order to obtain a more realistic estimation of the PV potential in the Archipelago, several considerations about typical losses in the PV installations are taken into account. The theoretical maximum energy production above obtained for a single module is affected by different losses due to different causes (dispersion in the manufacturing process of the modules, air mass AM different to nominal value, non-perpendicular incidence of the radiation, dust and soil on the panels, connection of the panels in series and parallel, shadows of the terrain on the panels, aging of the installation, Ohm losses in the cable connections, system availability and MPP tracking, etc.).

All these losses must be evaluated and considered. Table 5 shows the losses here considered in a yearly basis for all the stations and as percent of the output generation. The global efficiency of the systems because of these losses is affected by an 83.80%, obtained by the multiplication of all the efficiencies related to the losses. However, some losses have a seasonal variability. For instance, losses due to shadows and reflection of radiation on the modules are higher in fall and winter because the lower solar altitude in these seasons. By contrast, losses due to dust and soil are lower in these seasons due to higher rains.

This seasonal variability was in some way considered and Table 6 shows the monthly global efficiencies obtained for the systems because of these DC losses.

Table 6: Losses considered in the dc side of the PV systems as percent of the module output

Losses	%
Module manufacture	1.5
Radiation spectrum	1.5
Reflection of radiation	1.0
Dust and soil	3.0
Mismatch in series	2.0
Mismatch in parallel	0.0
Shadows	1.5
Aging	2.5
Wire Ohm resistances	1.5
System availability	1.5
MPP tracking	1.5

Table 6: Monthly total efficiencies (%) because losses in the PV systems

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Ago*	*Sep*	*Oct*	*Nov*	*Dec*
Effic.	83.94	83.76	83.81	83.81	83.86	83.77	83.85	83.77	83.76	83.79	83.67	83.83

Considering all these losses, Table 7 shows the monthly and yearly daily average useful DC PV production (Wh/m2 day) in the six stations of the archipelago. These data can be useful for the design of small isolated off-grid PV systems working in direct current (DC).

Table 7: Useful monthly and yearly daily average DC-PV production (wh/m^2 day) for six stations in Madeira

Station Month	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
January	453	406	401	403	352	393
February	460	482	495	501	434	514
March	638	644	649	632	581	695
April	724	654	707	783	697	841
May	921	786	850	936	786	985
June	1021	776	849	998	865	961
July	1083	775	833	988	812	956
August	884	755	819	893	836	886
September	732	693	721	723	690	758
October	542	519	549	554	522	570
November	365	408	419	401	344	445
December	336	356	372	373	292	362
Year Average	681	605	639	683	602	698

In order to complete the analysis with the evaluation of the capacity and viability of grid-connected system, the conversion of DC energy production into alternating current (AC) energy production is analyzed. Electrical conversion is made by an inverter defined in section 2 with typical values of efficiency (see Table 2). The simulation of the entire systems (PV-DC-AC) is performed considering the mentioned monthly characteristic days of each station. Table 8 shows the average monthly and yearly AC PV productions.

The efficiency of the DC/AC conversion depends, for each defined inverter, on the DC power input, being maximum when it operates close down its nominal power. For this reason the nominal power of the inverter must be chosen in such a way that the inverter operates close to its nominal power for much of the time. In all our cases, the average yearly efficiency of the inverter resulted in values around 95% for all the stations.

Table 8: Useful monthly and yearly daily average DC-PV production (wh/m^2 day) for six stations in Madeira

Station Month	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
January	422	377	373	375	327	366
February	430	451	463	468	405	481
March	599	604	610	594	545	654
April	687	619	670	742	659	798
May	888	757	819	903	757	951
June	994	754	826	971	840	936
July	1045	746	803	953	781	922
August	838	715	776	847	792	841
September	688	650	678	679	647	712
October	507	485	513	518	487	533
November	340	379	389	373	320	414
December	312	331	345	347	271	337
Year Average	647	573	606	649	570	663

The results are conditioned by the performances of the PV module and inverter selected as well as the DC losses considered. For this reason the results cannot be seen as general but as given an orientation of the PV potential, if we look at them in absolute terms. Nevertheless, they increase their generality is they are used in relative terms for comparison purposes. In this way, the results show that the conversion efficiencies of Sun radiation to DC PV are similar for all the stations as are the DC PV to AC PV conversions in the inverters. As a consequence of this, there is hardly no difference in comparing, in each case, the maximum, the useful DC and the useful AC outputs.

At the same time, the relative results let to compare the several zones of the archipelago in order to fix the best places for on-grid PV systems. Table 9 shows the percent of differences in the PV production of the different sites respect to Funchal, as well as a summary of the yearly PV productions: maximum (EM), useful DC (EDC) and useful AC (EAC) and % respect to Funchal station.

Table 9: Maximum, useful DC and AC PV yearly productions (kwh/m^2) and % respect to Funchal station

Station	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
EM	296.75	263.53	278.50	297.48	262.07	304.05
EDC	248.57	220.83	233.24	249.30	219.73	254.77
EAC	236.16	209.15	221.19	236.89	208.05	242.00
%	+13%	0%	+6%	+13%	-1%	+16%

In relation to wind production, the admissible wind turbine range (3-20m/s) is divided in intervals.

For the middle speed of each interval the power output is obtained from Fig. 1, and the daily probability of the interval is obtained from *Eq. 1*. Multiplying each other both factors and by 24 hours, the electric energy output during the daily time the wind speed is in that interval is obtained.

Integration of the energy outputs of all the intervals gives the daily wind-electric energy output for each day of the 2002-2005 period in the six stations.

The monthly and yearly daily average values of wind-electric energy production per rotor square meter of the turbine selected are shown in Table 10.

Considering a separation between wind generators in a field of five times the rotor diameter in the direction of the predominant wind, and three times in the perpendicular direction, we obtain the land area occupied by the wind generator.

Table 10: Monthly and yearly daily average wind-electric energy production per square meter of rotor area (wh/m^2 day) for six stations in Madeira

Station Month	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
January	1235	148	123	478	569	691
February	1650	159	196	571	614	1207
March	1359	110	221	680	561	1252
April	1156	82	174	530	534	1147
May	1320	37	132	461	337	1261
June	810	2	64	266	253	1132
July	1195	9	98	339	163	1296
August	893	7	90	313	301	1149
September	1050	29	120	414	201	1000
October	1028	97	202	615	439	1063
November	1354	99	125	675	615	1109
December	1560	145	230	691	680	1408
Year Average	1216	77	148	503	438	1143

Dividing the energy output of the generator by this area we obtain the electric generation referred to the square meter of land occupied, Table 11.

Table 11: Monthly and yearly daily average wind-electric energy production per square meter of land area (wh/m^2 day) for six stations in Madeira

Station Month	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
January	65	8	6	25	30	36
February	86	8	10	30	32	63
March	71	6	12	36	29	66
April	61	4	9	28	28	60
May	69	2	7	24	18	66
June	42	0,1	3	14	13	59
July	63	0,4	5	18	9	68
August	47	0,4	5	16	16	60
September	55	2	6	22	11	52
October	54	5	11	32	23	56
November	71	5	7	35	32	58
December	82	8	12	36	36	74
Year Average	64	4	8	26	23	60

TECHNICAL OPTIMIZATION OF THE HYBRID OFF-GRID PV-WIND SYSTEMS

The hybrid off-grid systems studied consist of a PV sub-system and a wind generator sub-system, both supplying in parallel DC energy either to a battery and/or to the consumption. PV and Wind electric productions are considered as referred to the square meter of horizontal land occupied, in the case of wind as shown in the previous sections of the paper. The conditions imposed for the simulations are: an electric daily consumption constant and equal to the yearly daily average electric PV-Wind production, and a capacity of the battery equal to a three-day electric consumption. If daily generation surpasses daily consumption with a full battery, energy is lost. If daily generation is less than daily consumption with an empty battery, then it is supposed that a back-up generator supplies the differences but does not recharge the battery.

The analysis is made without considering an inverter. Simulations are performed with varying degrees of percentage of PV and Wind powers in the hybrid systems (from 0 to 100 per cent).

Table 12 shows the yearly daily average production per square meter of land occupied of a hundred per cent PV system and the land area occupied by a hundred per cent wind system for the same production.

Table 12: Yearly daily average production and land occupied by a sole-PV and sole-wind system

Station	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
Production (Wh/m^2day)	813	722	763	815	718	833
PV area (m^2)	1	1	1	1	1	1
Wind area (m^2)	12.77	180.04	98.55	30.98	31.30	13.91

Figure 2 shows the percent of energy consumption covered with both renewable energies in function of the fraction of solar power in the hybrid system.

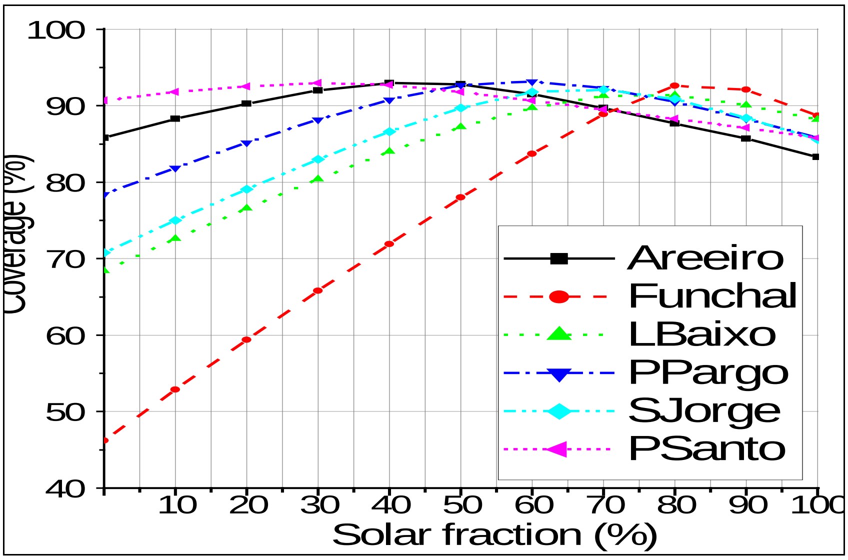

Fig. 2: Yearly consumption coverage of hybrid systems

The optimum percentage of PV power in the PV-Wind hybrid system varies, depending on the station, from 44% to 83%, with renewable energy coverage in the range of 91-93 percent of the total. As an interesting information, Table 13 gives how much over-dimensioned must be the hundred per cent PV systems in order to obtain consumption coverage equal to the optimal hybrid systems.

Table 13: Over dimensioning needed by isolate-PV systems with the same coverage as optimal hybrid systems

Station	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto
% of over dimensioning	42	14	10	27	28	29

ECONOMIC OPTIMIZATION OF THE HYBRID OFF-GRID PV-WIND SYSTEMS

The economic optimization is studied with respect to the costs of the PV modules in comparison with the costs of wind generators, as the other parts of the systems (regulators, batteries, etc.) are supposed to be non-changeable. Inversion costs (including installation) were obtained from average prices from various manufacturers and installers. Maintenance and replacement costs were not considered but through a reduction of the lifetime (amortization time) of the systems and based on the warranty of the components.

The amortization time was supposed to be 20 years for modules and 5 years for the wind generator. Following the technical optimization, all the costs were referred to the square meter of land occupied. Considering the renewable electric energy generated during the amortization years in each station, the cost of the renewable kWh can be obtained for each PV/Wind arrangement and station.

They are shown in Table 14 together with the costs for the technically optimum and the sole-PV over-dimensioned solutions. The conclusion is that the economically optimum is in all cases the hundred per cent PV and that even the over-dimensioned sole-PV solution is more economic than the technically optimum hybrid configuration.

Table 14: Renewable energy costs (€/kWh) for each station in Madeira Archipelago

%Solar	Areeiro	Funchal	LBaixo	PPargo	SJorge	PSanto	%Wind
0	0,34	10,03	3,51	0,90	1,14	0,34	100
10	0,31	7,92	2,99	0,79	0,99	0,31	90
20	0,28	6,29	2,54	0,69	0,85	0,29	80
30	0,26	5,00	2,14	0,60	0,73	0,27	70
40	0,24	3,94	1,77	0,52	0,62	0,25	60
50	0,23	3,06	1,45	0,44	0,53	0,23	50
60	0,21	2,31	1,16	0,38	0,44	0,21	40
70	0,19	1,67	0,89	0,32	0,37	0,20	30
80	0,18	1,12	0,64	0,26	0,30	0,18	20
90	0,17	0,64	0,40	0,20	0,23	0,16	10
100	0,15	0,16	0,15	0,15	0,16	0,14	0
Opt-Hybrid	0.235	0.975	0.791	0.391	0.401	0.271	Opt-Hybrid
Overdim-PV	0.192	0.174	0.162	0.171	0.198	0.170	Overdim-PV

4. Conclusions

In this paper we have evaluated the solar photovoltaic energy potential in six defined climatic areas of the Madeira Archipelago. The areas are climatologically represented by the variables recorded in six meteorological stations. Variables used for the calculation (solar irradiance and temperature) were taken into account through their daily evolution in the monthly characteristic days defined in a parent paper. The results are conditioned by the performances of the PV module and inverter selected as well as the DC losses considered, but in relative terms they can be considered as the general application. With respect to Funchal, and in decreasing order, Porto Santo has a 16% higher PV potential followed by Areeiro and Ponta do Pargo with a 13% and Lugar de Baixo with a 6%. São Jorge has a 1% less of PV potential than Funchal.

Also, we have studied the optimization of hybrid off-grid PV-Wind systems in six climatic areas of the Madeira archipelago (Portugal). The data base consists of the variables recorded in six corresponding meteorological stations during the period 2002–2005. First, we calculate the monthly and yearly daily average values of wind-electric energy production per rotor square meter of a selected wind turbine. Dividing the energy output of the generator by its land area of influence we obtain the electric generation referred to the square meter of land occupied. From these results, and those of PV systems studied in the same stations in a parent paper, we simulate the hybrid off-grid PV/Wind systems. The conditions imposed for the simulations are an electric daily consumption constant and equal to the yearly daily average electric PV-Wind production, and a capacity of the battery equal to a three-day electric consumption. The percent of energy consumption covered with both renewable energies in function of the fraction of solar power in the hybrid system are calculated. From a technical point of view, it is found that the optimum percentage of PV power in the PV-Wind hybrid system varies, depending on the station, from 44% to 83%, with renewable energy coverage in the range of 91-93 percent of the total. From an economic point of view the optimum solutions are in all cases hundred per cent PV systems.

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