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Research Article

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Preliminary Study for Energy Self-Sufficiency in a Portuguese Region-Évora

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Abstract

Energy self-sufficiency is a concern on the rise over the last few years, as energy transition away from fossil fuels is pressing and (energy) security issues gain importance. To help in creating a first overlook at regional energy self-sufficiency, a preliminary study is here reported, for the Portuguese region of Évora. The study quantifies the energy generated by a large photovoltaic array (composed by static and dynamic parts), plus a solar concentration backup system, managing energy storage through the latter and a Pb-Acid range of stationary batteries. Solar energy production technologies are prioritized because this region is one of the most radiated municipalities in Portugal (and across Europe), being low on other renewable energy sources (ex: wind, hydraulic and geothermal). Preliminary results show that a peak photovoltaic system power capacity of 397 MW (dynamic and static systems combined), served by an 230 MW input power Pb-Acid battery system and backed up by a parabolic panel solar concentration system with 144 MW of electrical power output capacity, can cover energy demand at about 99.9% of the time. Surplus energy generated by the solar concentration backup system can still be offered or traded with neighboring regions, to the benefit of all stakeholders.

Keywords: Energy self sufficiency; Renewable energy; Power systems; Portuguese region evora.

Introduction

Energy self sufficiency has of late been discussed and analyzed, both at the political and technological/industrial level. Whereas at the political level some mixing of concepts and imprecise language have often led to vague public debate and contributed to popular opinion confusion [1], at the technological level there seems to exist more palpable results, although in general over small to medium-size scales [2] [3-8]. In some occasions energy self-sufficiency analysis has been skewed by the assumption that only certain energy sources are available, preventing others from being considered and explored, thus rendering the result artificially unfavorable [9]. Others, like in the European Alps, crave for energy independence (which in practice amounts to self-sufficiency) and some already implemented examples show that energy self-sufficient regions is not “just a pipe dream, but a worthwhile alternative” [10]. At the more global level, several national initiatives are actively searching for energy transition paths away from fossil fuels, which at least in part is linked to self-sufficiency and energy security [11-13]. Finally, and at the multi-regional and worldwide scales, the case for renewable energies-especially solar, wind and hydraulic sources-has clearly been demonstrated, not only at the technical level, but also in economic (monetary) terms, not to mention possible synergetic benefits from inter-regional or inter-national energy cooperation schemes [14-16].

Regional energy self-sufficiency has been analyzed in some detail from an institutional and historical point of view, for a German municipality [17]. Although not technical in nature, this sort of analysis is fundamental to address the reasons and reasoning present day local decision-makers tend to engage. In this particular case-which can mirror some of the challenges the Portuguese municipality of Évora might face if willing to step up to renewable energy self-sufficiency (RESS)-the focus was on energy conservation, but it depicts nonetheless a real case of progression of public policies in this direction. It was found that the energy conservation issue (along with investing and reinforcement of renewable energy supply in the region) was brought about by some citizens concerned about the environment. In spite of these early warnings, nothing relevant was done until energy prices rose, regulations were enforced at the national level, subsidies (for energy conservation) came about and RESS activities were perceived as adding value to the municipality envisioned character.

As for the Évora municipality, a survey on the possible renewable energy sources was done, in order to identify the one or several sources it might aspire to explore to reach RESS. Geothermal resources for electricity generation purposes are insignificant in the region, mainly because underground water in the area does not reach high enough temperatures. In Portugal, thermal waters’ temperature never surpass 80ºC, i.e., they are usually between 20 and 40ºC [18]. In addition, the Évora region has a low energy generation potential, even within this temperature range found in the continental Portuguese territory; this is supported by the fact that, from all thermal water springs in the national territory, only one is located within the Évora municipality area, and only supplying an operational temperature between 15 and 20ºC [19]. Geothermal resources for electricity generation are usually associated with higher water/saturated vapor temperatures, namely above around 100ºC for binary cycle electricity production systems, and above 140ºC for conventional electricity production [20].

Also wind resources are scarce in the region, for electricity generation purposes, as shown in Esteves [21]. This is especially due to the region’s low altitude and modest average wind velocities.

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Finally, low water availability (Évora is the Portuguese region receiving less rainwater, amounting to 550 mm/year [22] and relatively flat topography limits the hydraulic energy generation potential.

Solar power is the most abundant energy resource in the Évora region, being one of the most radiated municipalities in Portugal [23]. In fact, the yearly sum of global solar irradiation in Évora is around 2000 kWh/m^2, which is amongst the highest in Europe [24,25].

Energy Needs Assessment

All energy source needs are accounted for in the present study. These needs are divided in five main energy sources: electricity, natural gas, butane gas, propane and liquid fuels. Here electricity is listed as an energy source although it actually is only a transmission means (electricity production sources used in Portugal are mainly hydraulic, wind, natural gas, petroleum and biomass); however, electricity is here cited as an energy source in order to quantify regional energy needs, since it is accounted for in this way in the available statistical data. These five main energy sources have several end uses, of which the most important are transportation (liquid fuels), industry (electricity and gases) and buildings (electricity and natural gas).

Electricity consumption is accounted for in official statistics, by region (statistically defined regions and municipalities) [26]. Natural gas consumption is also statistically registered, in [27], as well as butane gas, propane and liquid fuels [28]. Converted to the same units (kWh), this energy consumption is listed in Table 1

Table 1 shows that the main regional energy source consumption is liquid fuels, with 51% of all energy needs, followed by electricity, which accounts for 38%. The Évora region is responsible for approximately 0.53% of the Portuguese total energy consumption, which corresponds to a *per capita* consumption 5% under the national average.

Energy Generation and Storage

Present solar energy generation technologies today are mainly photovoltaic and solar concentration. Photovoltaic panels have been deployed commercially before solar concentration technology, and are clearly a step further in optimization and industrialization. However, both technologies represent still very little of the world's energy generation capacity, with less than 2% overall, with none of the OECD countries having more than 4% of their installed capacity [29]. Their further penetration in the energy generation market has been hindered essentially by cost related issues [29]. However, these are due to social phenomena and are not particularly connected to technical aspects or physical potential to produce good quality electrical energy from solar radiation.

To guarantee the region's RESS using these two technologies, three types of installation were considered: static and dynamic photovoltaic systems, and solar concentration. Natural fluctuations of both energy supply and demand in the region must be taken into account, and so a battery energy storage will be necessary, as discussed below (3.4).

Static photovoltaic systems

Static photovoltaic systems are typically installed where it is not possible (or not convenient) to place dynamic systems, as for instance over building roofs. The latter, normally underutilized in their energy generation potential, but with general good solar exposure positions, due to their height relative to the ground, are prime candidates as support for static photovoltaic systems. This has been, in fact, translated into the Portuguese Law, as micro and mini renewable electricity generation systems. This gives private and public owners the possibility to sell energy to the main electricity network at a premium [30,31].

To swiftly estimate the energy produced by rooftop static photovoltaic panels, over existing buildings in the region, a single type of panel was considered, with the general characteristics presented in Table 2.

[1] - Solterm [32] simulation, location Évora, unobstructed shading conditions with an optimum tilt of 34º. For other locations, optimum tilt may be estimated using Solterm or optimum tilt spatio-temporal models such as in Ertekin [33].

Total energy generation will depend on the global roof area with proper conditions to support static photovoltaic panels, namely south orientation and absence of significant shading. This roof area firstly depends on the total number of existing buildings in Évora. From the statistics [34], this number was 18 279, in 2001. In the next few years, onto 2009, an extra 1651 buildings were added [35]. Ignoring buildings built from 2010 up until now, around 20 000 exist in the region (19 930). From all these buildings, a part has pitched roofs, with several orientations, and another part has flat roofs. Based on INE [34], a total pitched roof percentage of 94% was estimated, with 6% being flat terraces (Table 3).

For pitched roofs, a random distribution of orientations was considered, as if the total area of pitched roof is uniformly distributed by the eight octants. Conservatively, and for electricity production purposes, only the south oriented octants were considered, which means between southeast and southwest. Further limitations are imposed by external shadings-other buildings, trees, terrain topography, among other obstacles - which were considered to cut down installation area down to 40% (this number is drawn from personal professional experience, and refers to total south oriented pitched roof surface). This area cut down was considered both to flat and pitched roofs. All these considerations together result in a total of adequate installable south quadrant oriented roof surface of 210 500 m^2.

With this useful roof surface area for static photovoltaic panels, supplying an average of 182 kWh/m^2.year, a total of 38 316 MWh/year can be produced. This equates to having a system with about 152 500 photovoltaic panels (considering the unitary panel surface designated in Table 2), which amounts to a peak electrical power of 26.7 MW. The overall static photovoltaic system, generally outlined in this way,

Energy sources	kWh	%
Electricity	261 836 388	38.3
Natural gas	40 030	0.01
Butane gas	38 906 070	5.7
Propane gas	34 084 605	5.4
Liquid fuels (petroleum based)	345 990 063	50.6
Total	683 857 157	100

Table 1: Energy consumption distribution in Évora, year 2013.

Panel type	crystalline
Panel area, m^2	1.38
Rated power, Wp	175
Annual energy output, Wh/Wp [1]	1 435
Annual energy output per m^2 of panel area, kWh/m^2.year	182

[1] - Solterm [32] simulation, location Évora, unobstructed shading conditions with an optimum tilt of 34º. For other locations, optimum tilt may be estimated using Solterm or optimum tilt spatio-temporal models such as in Ertekin et al. [33].

Table 2: Rated power, area and energy output of chosen photovoltaic panel.

Number of floors	Number of buildings	%	Average useful area, m^2	Average roof area, m^2	Number of pitched roofs	Number of flat roofs	Average pitched roof surface, m^2	Average flat roof surface, m^2
1	10 555	58	1 022 225	1 022 225	10 247	111	1 011 270	10 955
2	6 512	36	1 261 341	630 671	4 995	728	550 445	80 225
3	824	4.5	239 407	79 802	588	74	70 882	8 920
4	300	1.6	116 217	29 054	193	84	20 244	8 811
5	55	0.3	26 633	5 327	29	20	3 152	2 174
6	19	0.1	11 041	1 840	19	0	1 840	0
7 or more	14	0.08	9 491	1 356	8	6	775	581
Total	18 279	100	2 686 354	1 770 274	16 079	1 023	1 658 608	111 666

Table 3: Determination of average number and surface area of pitched and flat roof surfaces in Évora (data 2001-2009).

Necessary area of dynamic photovoltaic panels to cover energy needs, m^2 [1]	3 130 409
Terrain occupancy, relative to the non urban area with no permanent cultivations, % [2]	0.50
Terrain occupancy, relative to the total Évora municipality area, %	0.48
Total yearly supplied energy from dynamic photovoltaic panels, MWh/year	740 758
Yearly daylight hours in Évora, h	4 560
Average operational dynamic photovoltaic system power, MW [3]	162
Peak dynamic photovoltaic system power, MW	397
Number of necessary dynamic photovoltaic system panels [4]	2 268 413

[1] - Remaining global energy needs after discounting for the static photovoltaic panels system production.
[2] - Allowing for enough space to place panel rows, without risk of self shading (considered as twice the terrain area per m^2 of installed photovoltaic panel).
[3] - Total supplied energy divided by total daylight hours.
[4] - Considering the rated power of the chosen photovoltaic module (Table 2).

Table 4: Basic parameters relative to the dynamic photovoltaic energy system implementation.

can potentially generate as much as 6% of the total energy demand (as presented in Table 1).

Of course that exploiting the full potential of south quadrant oriented roof surfaces in the region can arguably result in loss of architectonic characteristics, especially within the historical city centre. However, and given the rapid urbanization rate of the last few decades (since 1950-60)-56% of all buildings in the Évora municipality area have been built after 1970-plenty of opportunities for installing static photovoltaic panels remain in the region, even ruling out the older historical city centre buildings. As a quick example, installing only on buildings with less than 40 years old would still cover as much as 3.3% of all regional energy needs.

Dynamic photovoltaic systems

Dynamic photovoltaic systems are those which are supplied with tracking devices which maintain the panels perpendicular to the sun rays for as many hours as possible. These systems provide, everything else remaining constant, as much as 30% more energy than an equivalent static system [36]. The energy amount this system is intended to cover refers to the total identified in Table 1, from which is subtracted the energy potentially supplied by the static photovoltaic panel system. Furthermore, a performance rate of 85% is considered [37], which allows for losses not expected in calculation models, for instance time-dependent power degradation phenomena in the panels over the years. Table 4, is presented, as a result of these considerations, given the municipality total surface area (1307 km^2) [38] and the non urban with no permanent cultivations area (1241 km^2) [39,40].

The area that needs to be occupied with the global dynamic photovoltaic system (not necessarily at only one determined spot), relative to the total municipality area-or more relevant still, with the non urban with no permanent cultivation area-is less than 1%. This order of magnitude figure on footprint area occupied fits well with some estimates, such as in Jacobson and Delucchi [15], which points to a global footprint area of renewable systems to power the world of 1.16% (spaced area of hydraulic, solar and wind power systems only). Other estimates, such as Ertekin and Evrendilek [41], point to a value of 30% for land occupation percentage. However, in this last case, the estimation includes biomass combustion as a renewable source, which can arguably be responsible for the majority of this high land occupation percentage (since hydraulic, solar and wind power systems require so little land occupation).

Solar concentration energy systems

There are several solar concentration energy technologies, as parabolic panels, towers, concentration photovoltaic panels and Stirling dishes. Although tower solutions have already been launched commercially, it is the parabolic panel trough technology which is the most mature and proven in the field [42], with more installations being made in the last three decades (comparing to the other cited technologies). Stirling dishes and concentration photovoltaic panels are not yet mature enough to be massively deployed.

Solar concentration parabolic panels can reach dozens of MW in a single facility (the biggest one until now with 80 MW), with average efficiencies around 14%. The system is thermally driven, capable of heating up the transmission fluid (water or oil) over 400 °C, with a theoretical limit over 500 °C [42].

In the present case, its capacity was determined as a function of the estimated hourly energy demand, as detailed in chapter 4. Specifically, it derives from the hourly energy demand peak during night time periods. From this peak capacity, a basic set of facility parameters were quantified, based on an existent operating parabolic panel solar concentration central (San José del Valle; Table 5).

Yearly supplied energy, GWh	360
Parabolic panel area, m^2	1 020 000
Terrain occupancy area, ha	396
Thermal nominal power, MWt	524
Thermal storage capacity, MWht	2 020
Energy storage time, at full output power, h	7
Electrical generation capacity, MWe	100
Electricity generation efficiency, %	38
Annual capacity factor, %	41
Horizontal plane radiation intensity in San José del Valle, kWh/m^2	2 057

Table 5: Basic characterization parameters of the San José del Valle solar concentration facility (Torresol).

Design electricity generation capacity, MWe	144
Parabolic panel necessary area, m^2	1 604 700
Energy storage time, at full output power, h	7
Terrain occupancy area, ha	620
Terrain occupancy, relative to the total Évora municipality area, %	0.47
Thermal nominal power, MWt	755
Yearly supplied energy, GWh	519
Average operational solar concentration system power, MW [1]	114

[1] - Total supplied energy divided by total daylight hours.

Table 6: Basic characterization parameters of the potential solar concentration facility in Évora.

A further adaptation to these parameters was considered, as the average solar radiation on the horizontal plane is not exactly the same, between regions (in Évora the horizontal plane radiation intensity is 1884 kWh/m^2, converted from a 162 kcal/cm^2 Figure [8]. As for the energy storage time (at full power), the same 7 h period was considered, as in the San José del Valle installation (Table 6).

Energy storage systems

Given the need to store energy, due to typical large oscillations in production from the main photovoltaic generation system (no generation at night and cloudy periods), which also entails overproduction during sunlight hours (more details in 4), an adequate technology must be selected. The most relevant present day energy storage technologies were listed, aiming at solving the problem at hand - large energy storage needs, on a daily cycle, from intermittent sources - based on Connolly [43], from which Table 7 was put together. From this general energy storage technology review, it seems clear that Pb-Acid battery technology is the most adequate, for the envisioned purpose. It surpasses other alternatives since it can, simultaneously, be scalable, have an adequate charge/discharge time (given the application), have a relatively high efficiency and be recyclable. Moreover, Pb-Acid batteries constitute a proven, mature technology. It however carries some disadvantages such as a relatively low durability (as compared, for instance, with hydraulic pumping) and the need to recover and manage the led flux.

As shown in chapter 4, the battery energy storage system input capacity must be at least 230 MW, since this equals the maximum difference between the daylight period photovoltaic generation and the energy demand power, on a yearly basis. The same system must be able to supply an output energy power of 144 MW, which corresponds to the peak night time energy demand. Total battery weight was calculated considering a power density of 130 W/kg, which comes from a common commercial Pb-Acid stationary battery. Table 8 compiles the basic design parameters of the proposed battery storage system.

Matching Energy Supply and Demand

An electricity generation system can be considered effective if, at least, is able to match demand, at any given instant. In order to investigate this using a generation system exclusively based on solar energy with storage, a simplified hourly analysis was conducted, on a two day per month basis (reference year - 2014).

According to REN data [44] (national electricity network), total nationwide hourly energy demand data was listed, for the selected days (1 and 15 of each month). From this data, an equivalent energy demand was calculated for Évora, assuming all energy needs are electrical. This assumption may seem far fetching, but from Table 1 it can be seen that it only takes electrifying the transportation system (for which mature technology already exists for most wheeled vehicles, including heavy duty ones [45,46] and using electricity-based heating equipment to replace current butane and propane gas using equipment (in households and industry). The equivalent energy demand for Évora

Energy storage system type	Capacity range, MW	Charge/discharge periods	Durability, years	Efficiency, %	Costs, US$/ kWh	Material/chemical management issues	Notes	Appropriate, given the purpose at hand, in Évora?
Pb-Acid	0.001 a 50	1m - 8h	5-10	80	175 - 250	Led recovery and treatment	Discharge can occur in several hours. Limited durability. Low cost.	Yes
Na-S	0.001 a 10	0 - 8h	5	80	245	Hazardous substance handling	Still experimental.	No
Hydraulic pumping	100-4000	4-12h	30	80	0-20	Beyond the initial construction, there are no particular materials management issues	Needs considerable height difference.	No
Flying wheels	< 1.65	< 1h	20	90	200-300	None	Very short response time.	No
Compressed air	100-300	6-20h	30	65	3-10	None	Needs an underground reservoir, therefore very particular geological conditions.	No
Flux batteries	0-3	< 10h	unknown	80	unknown	Hazardous substance handling	Still experimental.	No
Magnetic (supercondutors)	10	<1m	30	95	72 000	Magnetic fields handling	Very short response time. Too expensive.	No

Table 7: Possibility search for an adequate large scale energy storage system.

Input power capacity, MW	230
Output power capacity, MW	144
Maximum design storage energy, MWh	963
Type of battery	Pb-Acid
Total necessary battery weight, kg	1 769 937
Number of stationary Pb-acid batteries	29 015
Number of stationary battery 30 MW groups	8

Table 8: Basic design parameters for the Pb-Acid battery energy storage system.

was considered (for this study calculation purposes only) to mimic the nationwide energy demand pattern, from the REN data, but scaled down considering total average energy power demand for the region (78 MW) and for the nation (5282 MW). This average energy power demand is simply calculated by dividing total energy consumption (all energy sources) by the annual amount of hours (8760 h). The hourly pattern of electricity demand, even only for two days per month, is too lengthy to include here. However, Figure 1 shows its daily evolution for a selected day, in Évora (an equivalent demand curve), charted with a possible photovoltaic electricity generation curve for that day (Figure 1).

For estimating the hourly generation capacity of the photovoltaic system, typical incident radiation days were scheduled, based on Castro [36]. From those typical days - clean and cloudy sky - average mixed clean and cloudy sky days were considered, as well as a mix between the latter and clean sky typical days. Incident radiation values were converted onto percentages of the day's radiation peak, applying those percentages - day types were associated with Winter, Summer and Spring/Autumn seasons (adapted in order to agree with any month's daylight hours) - to global photovoltaic annual operational average power, which for the static and dynamic photovoltaic systems combined amounts to around 171 MW. This typical day definition for photovoltaic energy production is presented in Table 9

Hourly electricity production can be estimated, from the global photovoltaic system, as exemplified in Figure 1. From total daily energy generation and needs (especially night time needs), a design power requirement can be estimated for the solar concentration system (which acts as a backup for the photovoltaic system), which in this case has been determined as 144 MW (electric). As referred above, the battery storage system must be able to store all excess energy produced by the photovoltaic system, relative to energy needs, at any daylight hour. This way, the battery system input power capacity is determined by the maximum difference between (the photovoltaic) energy production and need, during daylight hours of all listed days. This is depicted in Table 10, from which the input power capacity of 230 MW (electric) was determined.

The energy generated by the solar concentration system and the stored energy in the battery system must then be managed, in order to satisfy night time energy needs. This has been done, on an hourly basis, as shown in Table 11. Considering that the battery system stored energy, produced through the photovoltaic system, is prioritized over the consumption of the energy stored by the solar concentration system, a global energy correspondence of 99.9% is reached (difference between 100% and the relation between potential energy shortages (calculated from Table 11) and total annual demand). This and some other results are presented in Table 12.

The fact that the total photovoltaic energy generated and stored is almost as high as total demand does not eliminate the need for a backup system (in this case the solar concentration system). During summer months (April through August) this energy is even higher than demand, as stored energy is generally enough to cover night time needs, but in the rest of the year night time energy consumption exhausts storage and demands a backup source. The existence of this backup system, with its own storage capacity, implies an annual energy production surplus of about 21% over total demand, already considering disconnection from April through August. This comes due to the fact that only at few moments all the energy generated and stored by the solar concentration system is actually used up by night time needs. This means that this extra stored energy must be directed to other uses, or it will be wasted. Actually, and in order to take advantage of the full energy producing capacity of the solar concentration system, avoiding its shut down in summer months and waste of a part of its generated energy, the region can (and should, as too much stored energy can damage the system and dissipation systems can be large and expensive) supply it to neighbor regions, through sharing agreements or more traditional trade.

Conclusion

A preliminary study for energy self-sufficiency in the Portuguese municipality of Évora has been performed. The present study, broad in nature, aims at matching of global regional energy demand and potential generation, exclusively through solar energy capture systems (static and dynamic photovoltaic panels and parabolic trough panels) and making use of a large size energy storage capacity (Pb-Acid battery range). As a result, all necessary energy to assure modern day life standards in the region, including buildings, industry, public lighting and transportation (independently of the energy sources presently used for those same purposes), can in principle be supplied from solar radiation, namely through:

- making an optimized use of existent building roofs - pitched or terraced - to install static photovoltaic systems, this way covering around 6% of all energy needs;
- installing around 2.3 million photovoltaic panels on two axis sun tracking systems, in large energy producing fields, occupying 0.5% of all non urban, non permanently cultivated areas, while generating over

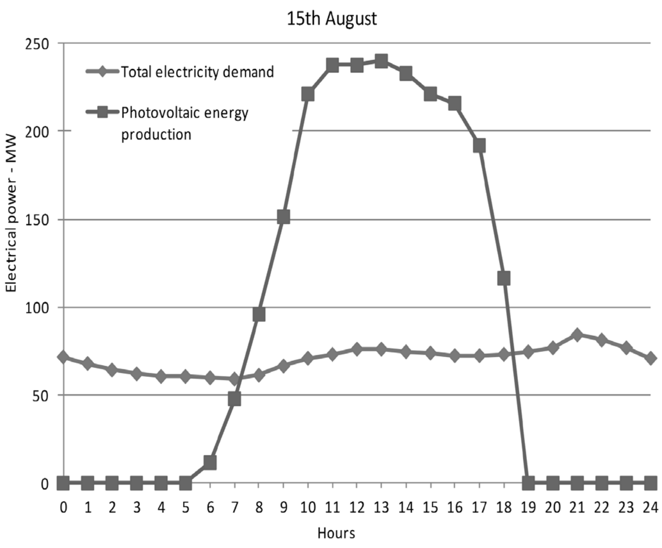

Figure 1: Photovoltaic energy production and total electricity demand (proportional) in Évora, at 15 of August.

Hour	Incident radiation, typical clean sky day, W/m²	Incident radiation, typical cloudy sky day, W/m²	Incident radiation, average base day, W/m²	Incident radiation, average base/ clean sky day, W/ m²	% of peak, average base day	% of peak, clean sky day	% of peak, average base/clean sky day	Adapted average base day, January, November and December, %	Adapted average base day, February and October, %	Adapted average base day, March and September, %	Adapted average base/clean sky day, April, %	Adapted average base/ clean sky day, May, %	Adapted clean sky day, June and July, %	Adapted clean sky day, August, %
0														
1														
2														
3														
4														
5											0	0	0	0.00
6										0	4.66	4.66	4.85	4.85
7								0	0	4.00	10.00	10.00	20.00	20.00
8	50	20	35	43	4.00	4.85	4.66	4.00	4.00	71.43	30.00	30.00	40.00	40.00
9	650	600	625	638	71.43	63.11	69.86	71.43	71.43	100.00	69.86	69.86	63.11	63.11
10	950	800	875	913	100.00	92.23	100.00	100.00	100.00	100.00	100.00	100.00	92.23	92.23
11	1 020	150	585	803	66.86	99.03	87.95	66.86	66.86	66.86	87.95	87.95	99.03	99.03
12	1 020	100	560	790	64.00	99.03	86.58	64.00	64.00	64.00	86.58	86.58	99.03	99.03
13	1 030	100	565	798	64.57	100.00	87.40	64.57	64.57	64.57	87.40	87.40	100.00	100.00
14	1 000	150	575	788	65.71	97.09	86.30	65.71	65.71	65.71	86.30	86.30	97.09	97.09
15	950	100	525	738	60.00	92.23	80.82	60.00	60.00	60.00	80.82	80.82	92.23	92.23
16	800	70	435	618	49.71	77.67	67.67	29.71	40.00	49.71	67.67	67.67	90.00	90.00
17	500	20	260	380	29.71	48.54	41.64	0	0.00	29.71	50.00	50.00	80.00	80.00
18										0	41.64	41.64	70.00	48.54
19											0	20.82	48.54	0.00
20												0	0	
21														
22														
23														
24														
						Daily average, %		58.5	59.6	61.5	61.8	61.8	72.9	71.2

Table 9: Incident radiation in typical days (clean and cloudy skies) and percentage of the daily peak.

Date			Hours of the day												
Year	Month	Day	7	8	9	10	11	12	13	14	15	16	17	18	19
2 014	1	1	-	-	153	230	125	111	113	119	103	14	-	-	-
2 014	1	15	-	-	106	187	87	79	85	84	67	-	-	-	-
2 014	2	1	-	-	123	199	102	92	93	98	84	28	-	-	-
2 014	2	15	-	-	125	202	104	93	96	103	87	31	-	-	-
2 014	3	1	-	126	197	191	96	86	87	92	76	49	-	-	-
2 014	3	15	-	131	203	200	108	97	100	105	91	64	10	-	-
2 014	4	1	-	-	94	176	141	137	141	135	119	83	36	15	-
2 014	4	15	-	-	108	188	153	149	155	148	133	96	50	29	-
2 014	5	1	-	24	127	206	171	166	168	168	153	118	70	46	-
2 014	5	15	-	2	105	188	152	148	152	146	130	94	47	27	-
2 014	6	1	-	38	86	150	163	160	163	159	148	144	121	97	46
2 014	6	15	-	31	80	145	158	155	158	152	142	137	116	91	38
2 014	7	1	-	14	61	127	140	140	144	135	123	117	96	75	26
2 014	7	15	-	12	56	122	135	134	139	130	116	110	88	68	19
2 014	8	1	-	18	64	131	145	145	150	140	128	123	102	30	-
2 014	8	15	-	35	85	150	164	161	164	158	147	143	119	43	-
2 014	9	1	-	124	193	189	93	83	86	87	68	39	-	-	-
2 014	9	15	-	119	190	186	92	84	89	88	72	44	-	-	-
2 014	10	1	-	-	117	196	99	91	95	94	77	19	-	-	-

2 014	10	15	-	-	114	193	96	87	92	92	76	18	-	-	-
2 014	11	1	-	-	138	218	119	109	111	118	101	15	-	-	-
2 014	11	15	-	-	133	212	113	101	104	108	93	6	-	-	-
2 014	12	1	-	-	113	195	97	90	96	98	81	-	-	-	-
2 014	12	15	-	-	108	189	89	81	86	89	72	-	-	-	-

Table 10: Difference between photovoltaic energy production and need, during daylight hours (MW).

Date			Hours of the day																								A [1], MWh	B [2], MWh	C [3], MWh
Year	Month	Day	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23			
2 014	1	1	74.6	73.2	68.7	64.3	60.6	59.1	57.6	57.6	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	42.8	75.4	83.5	87.2	88.7	87.2	85.0	80.6	758.4	57.4	523
2 014	1	15	85.0	78.3	73.2	72.4	70.2	70.2	72.4	82.0	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	42.8	104.9	112.3	115.3	114.5	110.1	104.9	96.1	758.4	38.2	-11.4
2 014	2	1	87.9	81.3	74.6	72.4	70.9	70.2	70.2	70.9	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	57.6	86.5	95.3	104.9	106.4	100.5	96.8	90.2	773.2	78.1	174.6
2 014	2	15	85.7	77.6	73.2	70.2	68.0	67.3	68.0	68.0	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	57.6	85.0	92.4	103.5	104.9	99.0	94.6	90.2	773.2	112.1	195.3
2 014	3	1	85.0	77.6	73.2	70.2	61.3	61.3	61.3	5.8	102.9	144.1	144.1	96.3	92.2	93.1	94.7	86.5	71.6	42.8	90.9	102.7	103.5	96.8	92.4	87.2	974.2	62.8	790.2
2 014	3	15	76.1	70.9	66.5	65.0	63.6	63.6	63.6	5.8	102.9	144.1	144.1	96.3	92.2	93.1	94.7	86.5	71.6	42.8	73.9	85.7	90.2	85.7	81.3	76.9	974.2	94.6	974.2
2 014	4	1	81.3	75.4	70.9	69.5	68.0	68.0	6.7	14.4	43.2	100.7	144.1	126.7	124.8	125.9	124.4	116.5	97.5	72.1	60.0	102.7	108.6	108.6	100.5	92.4	1 157	19.5	1 157
2 014	4	15	73.2	70.2	66.5	65.0	63.6	63.6	6.7	14.4	43.2	100.7	144.1	126.7	124.8	125.9	124.4	116.5	97.5	72.1	60.0	87.2	89.4	93.1	88.7	83.5	1 157	270.0	1 157
2 014	5	1	73.9	68.7	65.0	62.8	61.3	61.3	6.7	14.4	43.2	100.7	144.1	126.7	124.8	125.9	124.4	116.5	97.5	72.1	60.0	30.0	76.1	83.5	79.1	74.6	1 187	622.5	1 187
2 014	5	15	73.9	69.5	66.5	65.8	65.0	65.0	6.7	14.4	43.2	100.7	144.1	126.7	124.8	125.9	124.4	116.5	97.5	72.1	60.0	30.0	99.0	94.6	87.2	74.6	1 187	298.1	1 187
2 014	6	1	67.3	63.6	60.6	59.1	57.6	56.2	7.0	28.8	57.6	90.9	132.9	142.7	142.7	144.1	139.9	132.9	129.7	115.3	100.9	70.0	70.9	76.1	77.6	73.2	1 436	764.4	1 436
2 014	6	15	75.4	70.2	66.5	64.3	62.8	62.8	7.0	28.8	57.6	90.9	132.9	142.7	142.7	144.1	139.9	132.9	129.7	115.3	100.9	70.0	77.6	81.3	76.9	81.3	1 436	624.7	1 436
2 014	7	1	76.1	72.4	69.5	67.3	66.5	66.5	7.0	28.8	57.6	90.9	132.9	142.7	142.7	144.1	139.9	132.9	129.7	115.3	100.9	70.0	88.7	89.4	88.7	83.5	1 436	354.3	1 436
2 014	7	15	79.8	75.4	71.7	70.2	69.5	69.5	7.0	28.8	57.6	90.9	132.9	142.7	142.7	144.1	139.9	132.9	129.7	115.3	100.9	70.0	94.6	94.6	94.6	87.2	1 436	240.4	1 436
2 014	8	1	76.9	72.4	68.0	66.5	65.8	66.5	7.0	28.8	57.6	90.9	132.9	142.7	142.7	144.1	139.9	132.9	129.7	115.3	70.0	86.5	86.5	89.4	86.5	81.3	1 335	253.8	1 335
2 014	8	15	71.7	68.0	64.3	62.1	60.6	60.6	7.0	28.8	57.6	90.9	132.9	142.7	142.7	144.1	139.9	132.9	129.7	115.3	70.0	74.6	76.9	84.2	81.3	76.9	1 335	530.2	1 335
2 014	9	1	72.4	68.0	65.8	62.8	62.8	63.6	65.8	5.8	102.9	144.1	144.1	96.3	92.2	93.1	94.7	86.5	71.6	42.8	94.6	92.4	96.1	99.0	92.4	87.2	974.2	62.1	782.0
2 014	9	15	69.5	65.8	62.8	62.1	62.1	62.1	65.0	5.8	102.9	144.1	144.1	96.3	92.2	93.1	94.7	86.5	71.6	42.8	90.9	92.4	99.8	96.1	89.4	82.0	974.2	83.5	785.0
2 014	10	1	73.2	69.5	66.5	65.0	64.3	64.3	66.5	65.0	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	57.6	94.6	92.4	92.4	101.2	96.8	88.7	82.0	773.2	72.2	238.9
2 014	10	15	71.7	66.5	65.8	65.0	63.6	64.3	65.8	73.2	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	57.6	94.6	93.1	99.8	102.0	97.6	90.9	82.8	773.2	35.2	237.5
2 014	11	1	70.9	66.5	63.6	62.1	62.1	62.1	60.6	59.9	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	42.8	70.9	82.8	85.0	83.5	79.8	75.4	70.2	758.4	67.0	513.8
2 014	11	15	74.6	70.2	64.3	62.8	62.1	62.8	62.8	62.1	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	42.8	81.3	91.6	94.6	93.1	86.5	83.5	79.1	758.4	60.3	381.5
2 014	12	1	73.2	68.0	64.3	62.8	62.1	62.8	66.5	74.6	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	42.8	94.6	104.9	107.2	107.2	100.5	95.3	87.9	758.4	79.6	136.2
2 014	12	15	82.0	74.6	70.2	67.3	66.5	66.5	70.2	79.8	5.8	102.9	144.1	96.3	92.2	93.1	94.7	86.5	42.8	104.9	114.5	115.3	115.3	110.9	107.2	97.6	758.4	58.1	-23.5

Solar concentration system storage	░	Battery system power supply	▒	Solar concentration system output	█	System can be disconnected	▓	Low remaining energy	Very Low remaining energy

[1] - Solar concentration system energy storage.
[2] - Remaining energy in batteries after night time consumption.
[3] - Remaining energy in solar concentration system after night time consumption.

Table 11: Solar concentration and battery systems energy management.

Solar concentration system energy supply, compared to total demand, %	10.8
Solar concentration system energy supply, compared to night time demand, %	21.0
Photovoltaic system energy generation with storage, compared to total demand, %	98
Energy used from the solar concentration system, compared to its maximum potential (during usage months), %	51
Number of months in which the solar concentration system can be disconnected [1]	5
Global energy correspondence - generation / demand, annual, %	99.9
Annual energy production surplus [2], compared to demand, %	20.6

[1] - from April through August.
[2] - considering solar concentration system disconnection in the period referred in (1).

Table 12: Global energy production system results.

100% of (regional) global energy demand (not guaranteeing, though, complete hourly energy balance between production and demand);

- building and operating a solar concentration system - solar trough parabolic mirrors - with a total capacity of 144 MW(electric), potentially able to cover about 76% of global energy needs (but as backup for the photovoltaic system with storage, covers only 11%).

An annual 99.9% match between energy demand and supply is possible (even though a complete year daily analysis is needed to refine this number), even if generation only occurs during daylight hours. This is valid as long as a Pb-Acid large scale energy storage system is in place, backed up by the solar concentration system storage capacity. The system, as configured above, will generate surplus energy (around 21% over total demand), which can - and should -

be supplied to neighbor regions, to the benefit of all stakeholders. However, in order to materialize such a system, large infrastructures must be built, namely the static and dynamic photovoltaic fields, the solar trough concentration system, the Pb-Acid battery range and all the interconnection of these system parts (for which some of the existent infrastructure might be used). Besides this, the whole regional transportation fleet must be electrified. This may seem far reaching, but all these infrastructural needs make use of existent technology, proven and available commercially.

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