UTILITY-SCALE PV POWER AND ENERGY SUPPLY OUTLOOK FOR SOUTH AFRICA IN 2015

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Abstract

In South Africa, the projects for the first two rounds of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) have reached financial closure and construction has commenced on all of the twenty-seven PV sites. The question now is: what can be expected from these PV facilities in 2015 should all of them be fully operational by the end of 2014? The paper summarises an analysis of the power and energy supply outlook on a 2015 annual time series simulation of all approved utility-scale PV facilities. The total amount of delivered energy, if the solar resource profile in 2015 will be similar to that of 2010, will be 1,906 GWh. This amounts to just below 1% of the total (net) electricity generated by Eskom – the national utility – in 2012. The cumulative maximum power will almost reach 900 MW. Thus, all of the PV projects will represent up to a maximum of 2% of the Eskom's net rated capacity. Of importance to policy- and decision-makers, is that the supplied power and energy performances are well within the spinning reserve of the national grid. As a consequence, the intermittencies of these facilities are of lesser importance. The findings of the paper are of particular significance for grid-planners and -managers in terms of stabilising the grid, policy-makers that need to consider an extension of the renewable development scheme, and decision-makers pertaining to the investment attractiveness of utility-scale PV projects.

Keywords: PV, load behaviour, forecast, REIPPPP, supplied power, supplied energy.

1. Introduction

Electricity supply in South Africa is characterised by outdated structures that cannot meet contemporary requirements. The distribution is centralised and mostly unidirectional, while the generation is mostly based on the use of coal. Currently there is a substantial backlog of electricity supply, because electricity demand increased beyond the generation capacity of the national utility - Eskom [1]. During the last decade, the government has subsequently implemented a variety of mid- and long-term programmes to rapidly acquire new capacities and to ensure onward sustainable development. A meaningful part thereof is the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), a subsidy mechanism for large-scale and grid-connected renewable energy systems such as PV to promote an increase of installed capacities by independent power producers [2].

The context of the paper is to address the existing backlog in satisfying the demand with reliable forecasting of the utility-scale PV contribution that is to be made within the next decade. Although previously released forecasts take capacities into account [3], they do not take into consideration the temporal and technology distributions of energy systems.

1.2. Policy regime

The South African government has pursued a policy over the last decade that provides a legal framework to regulate a cumulative implementation of large-scale (>5MW_{el}), grid-connected renewable energy sources.

The government has realised that the private sector should be given the opportunity to take part in the process of ensuring energy security. It thus announced its plans to procure renewable energy from the private sector, in order to relieve the current energy limitations that it is experiencing. The road map is divided into a:

- long-term guideline in the form the Integrated Resource Plan from 2010 to 2030 (IRP 2010) [3]; and
- short-term mechanism in the form of the REIPPPP [2].

1.2.1. Integrated Resource Plan 2010 – 2030 (IRP 2010)

The leading stakeholders are the national Department of Energy (DoE), the National Energy Regulator of South Africa (NERSA), the national utility Eskom, and all involved project developers, or independent power producers (IPPs).

The IRP 2010 stipulates additional capacities of 42.6GW. The renewable capacity share will be 17.8GW until 2030 and is split into the technologies summarised in Tabel 1.

Table 1. IRP 2010 – renewable energy power share

Technology	Share of power in GW
Solar PV	8.4
Wind power	8.4
Concentrating Solar Power	1.0

The final IRP suggests a possible replacement of nuclear generation by means of renewable capacities (9.6GW) if the nuclear programme cannot be rolled out.

1.2.2. Renewable Energy Independent Power Producer Procurement Programme (REIPPPP)

The procurement documents of the REIPPPP, which were proclaimed by the DoE, were released on 3 August 2011, with an adjacent bidder's conference held in September 2011. At the time the government admitted that the original 10,000 GWh target, to be generated from renewable sources [4], could not be met by 2013, but by 2015. Therefore, the target was expanded. Instead of determining a certain amount of energy, a capacity of 3,725 MW was announced [2]; including 100MW for small-scale projects. Since the government expected that it was going to surpass the intended 10,000 GWh, the allocation was capped to keep up demand during the bidding process. The total capacity for large-scale renewable projects of 3,625 MW was then determined in calling for tenders in subsequent bidding rounds.

Table 2 depicts the major large-scale technologies involved, excluding biomass, biogas, landfill gas, and small hydro power, the allocated total capacities, and the allocations for the first two bidding window. Solar PV offers the second highest share with an approved capacity of 1,043 MW.

Table 2. REIPPPP – qualifying technologies

Qualifying technologies	REIPPPP capacities	Preferred bidder: Round 1	Preferred bidder: Round 2	Allocation still available
Solar PV	**1 450**	**631**	**417**	**402**
Onshore wind	1 850	634	562	654
CSP	200	150	50	0
Total	**3 625**	**1 415**	**1 043**	**1 167**

1.3. REIPPPP PV projects

Within bidding rounds one (R1) and two (R2), altogether 47 renewable energy projects reached financial closure by May 2013, with 27 of them solar PV plants with a specific power range between 5 and 75MW. The PV facilities are spatially distributed all over the country as is illustrated in Figure 1. Some of the PV plants (in yellow) are close to each other and cannot be shown separately. Table 3 provides an overview of all the solar PV facilities that were assigned in R1 and R2.

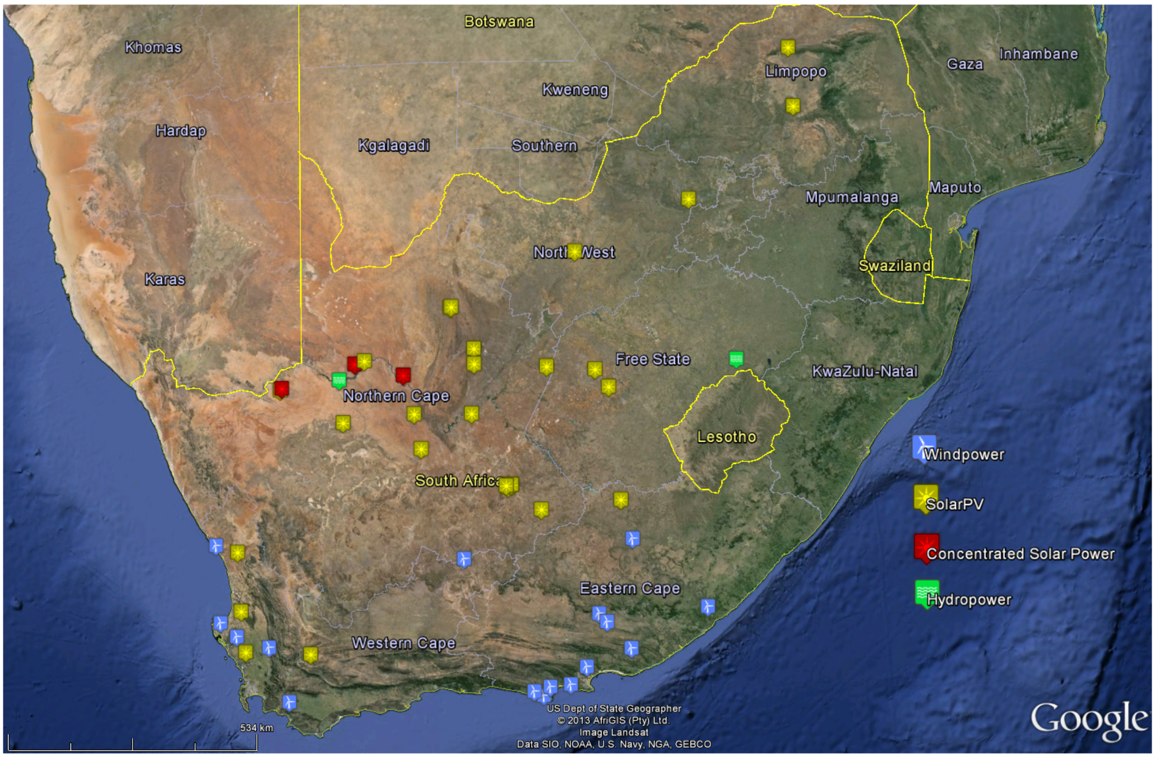

Figure 1. Location of REIPPPP projects countrywide

(Source: Centre for Renewable and Sustainable Energy Studies, Stellenbosch University)

Table 3. Solar PV facilities approved for R1 and R2 of the REIPPPP

Solar PV facilities – project designation		**Rated capacity [MW]**
SlimSun Swartland Solar Park	**R1**	5.0
RustMo1 Solar Farm		6.7
Mulilo Renewable Energy Solar PV De Aar		9.7
Konkoonsies Solar		9.7
Aries Solar		9.7
Greefspan PV Power Plant		10.0
Herbert PV Power Plant		19.9
Mulilo Renewable Energy Solar PV Prieska		19.9
Soutpan Solar Park		28.0
Witkop Solar Park		30.0
Touwsrivier Project (**CPV**)		36.0
De Aar Solar PV		48.3
SA Mainstream Renewable Power Droogfontein		48.3
Letsatsi Power Company		64.0
Lesedi Power Company		64.0
Kalkbult Solar PV		72.5
Kathu Solar Energy Facility		75.0
Solar Capital De Aar (Pty) Ltd		75.0

Solar PV facilities – project designation		Rated capacity [MW]
Solar Capital De Aar 3	R2	75.0
Sishen Solar Facility		74.0
Aurora Solar Park		9.0
Vredendal Solar Park		8.8
Linde (Scatec Solar Linde)		36.8
Dreunberg Solar PV		69.6
Jasper Power Company		75.0
Boshoff Solar Park		60.0
Upington Solar PV		8.9

1.4. Objectives of the paper

The major objective of the paper is to address the need for a countrywide prospective PV contribution forecast for 2015; should all the projects in Tabel 3 be commissioned by the end of 2014. Such a simulation of the annual power profile shows the strengths and weaknesses to the overall supply system and provides an insight into the annual performance of utility-scale PV in terms of energy contribution. A systems cumulative maximum power is determined by adding up the capacities of energy production of all the 27 facilities on an hourly basis, which provides further information about the peaking properties, including seasonal variations.

2. Research approach

The model consists of an hourly-based time series simulation. The quasi-static nature of the model was obtained by using basic physical correlations and external time series simulated data records for the specific sites of the 27 projects. The model was composed of different approaches for each modelled technology, depending on the availability of existing simulations. If an already developed model or method was utilised, it was necessarily validated. Such validation contains analogies to other simulation approaches, a comparison to the expectations of the project developers, and a plausibility check by project members. For simulation concerns, certain boundary conditions and assumptions had to be met. Each assumption was clearly specified and technically justified to ensure transparency and clarity. Furthermore, every uncertainty and possibility of error has been stated. Giglmayr provides the details [5].

The default input parameters for simulation issues were provided by GeoModel Solar Ltd and its solar GIS database. The simulated time series records were averaged on hourly based values (8 760), taking annual data records from 2010 into account; from 1 January to 31 December 2010. The solar GIS data specification document [6] provides detailed information about the data acquisition, as well as the related method and its occurrence.

The following data records were used:

- **GHI** and **DNI** [W/m²]: The solar radiation primary parameters, such as GHI and DNI, are derived by advanced and scientifically validated models that use satellite data and outputs from atmospheric models. The solar database input parameters are based on, inter alia, the cloud index, the water vapour database, the atmospheric optical depth, the elevation, and the horizontal profile, among other. According to solar GIS, the quality assessment in South Africa shows a low bias within a range of ± 2.5% and an hourly root mean square error (RMSE) between 16 and 22% [6].
- **Ambient temperature** [°C]: The spatial resolution of simulated air temperature is 1km, at an elevation of 2 meters above surface.

2.1. Associated tools

Beside the development of a particular model, several tools were used for simulation and verification purposes. The following tools reflect the connection between the raw weather data and the corresponding power loads and were deemed reliable:

- The basic PV model of Gauché [7], which is a time series simulation for solar PV issues.
- The System Advisor Model (SAM), of the National Renewable Energy Laboratory [8], for CSP and solar PV applications.

2.2. Modelling framework

The simulation calculates the hourly position of the sun – in terms of an equation of time, altitude, azimuth, etc. – including several derived, generally valid coefficients [9], and taking mutual module shading into account. The model can be adapted for different solar PV applications, such as for tracking types; for example, fixed tilt, periodic adjustment, azimuth tracking, full tracking, and so forth.

For solar PV purposes, the model processes the following input parameter:

- Net aperture size [m²]
- Pitch of modules [m]
- Site's coordinates – longitude, latitude [deg]
- GHI, DNI, diffuse horizontal irradiance [W/m²]
- Ambient temperature [°C]
- Ground-level wind speeds [m/s]
- Aperture tilt angle [°]
- Cell efficiency [%]
- Inverter efficiency [%]
    - Temperature efficiency [% per °C above 25°C]
    - Irradiance efficiency [% per W/m² below 1000W/m²]
    - Temperature rise coefficient [°C per W/m²]

The model computes, among others, the following values:

- Maximum actual power output [Wmax]
- Time series load behaviour [Wh]
- Annual amount of energy [Wh]
- Maximum cell temperature [°C]

The results were validated by means of single projects that are conducted on a random basis by means of the System Advisor Model (SAM) of the US National Renewable Energy Laboratory (NREL) in efforts to confirm the model's reliability.

2.3. Assumptions

The solar PV simulation required the following assumptions in terms of a consistent approach [5]:

- Most of the 27 solar PV systems would be mounted in a fixed position on a rack facing north.
- A location-dependent optimum tilt (between 24 and 32° north) for a maximum annual energy yield has been developed by GeoModel, and has been adopted [10].
- A conversion factor from a peak power to a certain aperture plain was implemented, since the model requires a PV size, and the developers published only the peak power of each plant. Five appropriate modules of different manufactures from 240 to 250W_p were chosen, and a mean specific peak capacity of 167W_p/m² was determined.
- The module efficiency was generalised to 15.1%, corresponding to an average value for the five chosen modules described above.

- The panels do not cast shadows on each other.
- The following coefficients were derived by Gauché [7] and received from Stine and Geyer [11].
    - Temperature efficiency: −0.5% per °C
    - Irradiance efficiency: 0.0125% per W/m²
    - Temperature rise coefficient: 0.03°C per W/m²
- For the concentrated PV (Touwsrivier) project, a simplified and reproducible methodology was developed. The concentration lenses focused only on the DNI, which was multiplied by the efficiency and the net module size, as the following formula describes:

$$P_{el,CPV} = DNI * \eta_{CPV} * A_{net,plant}$$

The efficiency was derived by means of a concentrator triple-junction solar cell, type 3C40, made by Azur Space Solar Power Ltd. Based on the lack of temperature rise coefficients that could have designated the cell temperatures, the cell efficiency was reduced by means of a mean alternation between 25 and 80°C, and yielded 35.3%.

3. Research outcomes

The annual cumulative output rating was determined for 25 solar PV plants with a fixed tilt, one plant with a one-axis tracker system, and one CPV plant that fully tracks the sun. The total amount of delivered energy would be 1,906 GWh. The cumulative maximum power would almost be 900 MW, which is 14.2% less than the registered capacity – from the bids – of 1,043 MW_p. The gap of 143 MW is based on the fact that the peak power corresponds to the Standard Test Conditions (STC), which does not represent an appropriate irradiance and cell temperature course per day.

Thus, cumulatively, all of the PV projects will represent up to a maximum of 2% of the net maximum capacity of all of Eskom's power stations – as per the 2012 annual report.

The cumulative, delivered solar PV energy visibly runs synchronically with the solar irradiance, influenced by local weather conditions. Solar PV without energy storage basically contributes to the higher demand during daytime, but a base-load firm capacity contribution cannot be ensured. During winter, the total output decreases, based on the limited irradiance, resulting in a further lack of contribution to evening peak loads. Figure 2 depicts two days of an exemplary cumulative generation during January.

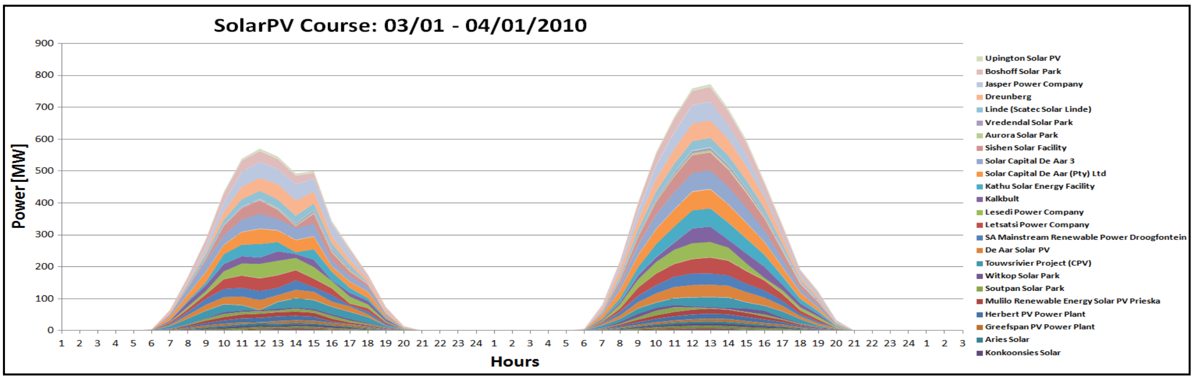

Figure 2. Exemplary cumulative solar PV generation in January

(Source: Giglmayr [5])

The bandwidth of the capacity factor (CF) for the fixed tilt plants ranged between 18 and 22%, which implied consistent specific results. The one-axis tracker CF achieved almost 25% and the CPV CF was 28.5%. Eleven determined IPP expectations (annual energy generation and/or CF) and a SAM simulation output confirmed the results that were obtained. The verification was done for a project called ‘Kalkbult Solar PV’, with a registered capacity of 72.5 MW_P. Even though SAM offered a higher quantity of input parameters, including various default values, the boundary conditions were set equally. The difference in annual distributed energy was immaterial, and the time series is similar as illustrated in Figure 3.

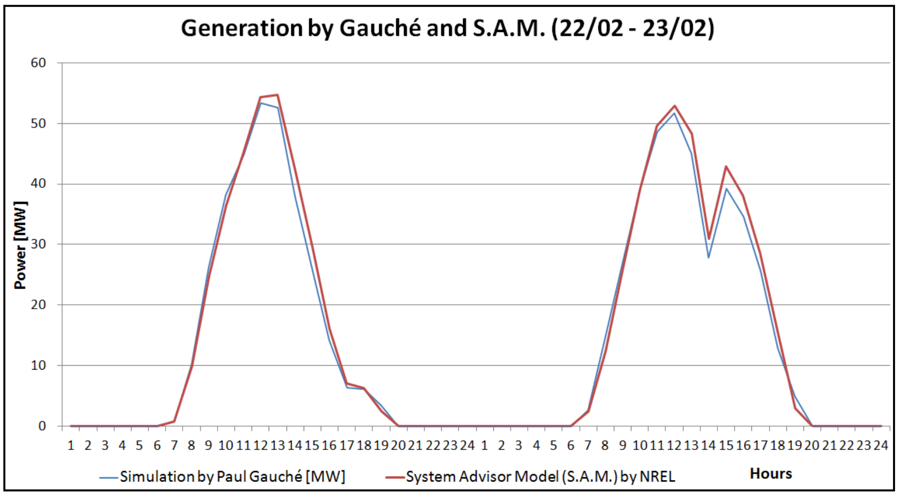

Figure 3. Solar PV model verification [5,6]

(Source: Giglmayr [5])

The seasonal characteristics show that spring delivered the highest amount of energy, which was around 24% more than the autumnal contribution, and, interestingly, around 10% more than the summer contribution (see Table 4). However, the maximum power output could be less in spring, than in autumn, whilst spring could deliver more power at a given time than in summer – due to the high temperatures. The mean delivered energy per day was 5.9GWh during spring and 4.7GWh during autumn.

Table 4. Seasonal characteristics of solar PV generation

	Spring	**Summer**	**Autumn**	**Winter**
Maximum power [MW]	900	852	830	856
Minimum power [MW]	265	291	270	257
Delivered energy [GWh]	533	485	429	459

(Source: Giglmayr [5])

4. Conclusions

The paper provides some insight as to what the solar PV sector will realistically contribute to the national electricity grid, based on utility-scale facilities. Of importance to policy- and decision-makers, is that the supplied power and energy performances from the first twenty-seven projects are well within the recommended reserve margin of the national grid; between 10 and 15 %. Thus the intermittencies of these facilities are of lesser importance, especially with improved solar resource prediction accuracies; now more than 24 hours in advance, thereby providing the grid operators with ample time to respond. Indeed, indications are that the grid could accommodate at least double this amount of PV power generation;

depending on the other renewable energy technologies that are deployed.

Greater accuracies of plant performance predictions also mean less risk to investors. How well the utility-scale facilities perform will only be known after a year of operations, but the growth in this market, globally, already shows a high investor confidence. South Africa is then in an excellent position to capitalise on further investment interests in this sector.

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