IMPACT OF PV SMALL SCALE EMBEDDED GENERATION ON SOUTH AFRICA'S SYSTEM DEMAND PROFILE

Lewis S. Waswa[1], **Bernard Bekker**[2]

[1] Stellenbosch University, Department of Electrical and Electronic Engineering, Private Bag X1 MATIELAND 7602, Stellenbosch, South Africa; Phone: +27610378146; E-mail: 22451102@sun.ac.za

[2] Stellenbosch University; E-mail: bbekker@sun.ac.za

Abstract

The falling cost of photovoltaic (PV) systems has significantly increased the penetration of such systems on the South African electricity network, both in the form of large scale solar farms operated by independent power producers (IPPs) and as small-scale embedded generation (SSEG) systems on residential, commercial and industrial roofs across the country. Several international case studies have shown the effect of significant penetration of PV on the demand profile of the electricity system, popularly known as the "duck curve". The characteristics of this curve is that the evening and morning peak demands stay relatively unchanged, while the midday demand is decreased.

This paper provides a literature review of the current PV SSEG installed capacity in South Africa. It further investigates the resultant changes due to PV SSEG on South Africa's demand profile towards identifying this "duck curve". Lastly, using a German case study the paper attempts to show how increasing PV SSEG on South Africa's grid will impact the future demand profile of the system.

Keywords: SSEG; Demand; Profile; Duck curve; Capacity; MWp

1. Introduction

The International Energy Agency (IEA)'s predictions point to a continued drop in the capital costs of solar PV and other variable renewable energy (VRE) technologies [1]. According to the IEA, in 2017, new costs of solar PV have dropped by 70% benchmarked with 2010 estimates. This is expected to significantly increase the number of installations globally. Fraunhofer [2] further predicts that grid parity for solar generated power will occur around 2025 to hit an approximate 4-6 euro cents/kWh in Europe.

With increasing embedded generation penetration into the grid, the demand profile is being altered and is increasingly becoming unpredictable [3]. Demand profile changes can be analysed on temporal (e.g. daily or seasonal) and spatial (e.g. generator, distributor or end user) scales. These changes in the demand profile poses challenges to the grid operators [4]. Prior planning needs to be done through forecasting and network planning to sustain increasing amounts of SSEG considering its eventual effect on the system. [5].

VREs introduce two aspects into the demand profiles: variability and intermittency. Variability in solar arises from expected temporal variation of the sun's intensity throughout the day. Intermittency on the other hand refers to the unforeseen events that can alter the generation of solar PV during the day. An example is cloud cover.

The table below shows the potential impacts that different temporal variations may have on a power system.

Table 1: Potential temporal impacts of demand changes [6]

Temporal Demand Profile Change	**Potential impact on the Power System**
Seconds	Power quality
Minutes	Regulation Reserves
Minutes to hours	Load following, RTMs, DAM, Unit Commitment,
Hours to days	Unit Commitment

Temporal demand profile changes affect the system operations in different ways, as shown in the figure below, which captures the variations that may take place in a day.

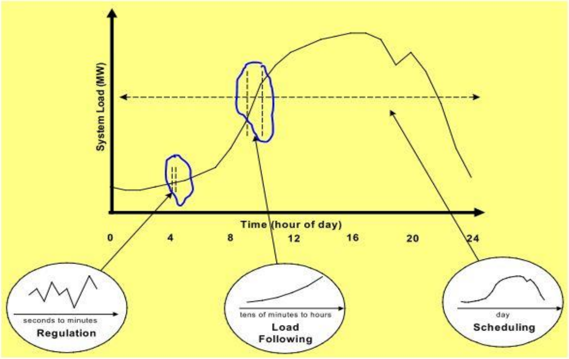


Figure 1: Temporal Demand Profile changes[4]

Key in this paper is the investigation of the variability effect on the demand profile.

The duck curve has been used in several case studies to explain the variability challenge of solar integration. The duck curve is an illustration of the variation of the demand with time in a solar PV integrated grid. It illustrates how generation variability of increasing PV installations change the demand profile as seen by a utility [7]. This effect was first illustrated by the California Independent System Operator [8]. With increasing solar PV penetration on the grid, the midday demand is reduced as most of the consumers self-consume or export resulting in a midday demand slump.

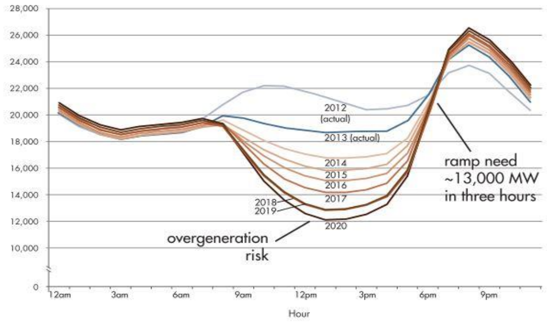


Figure 2: The Duck curve[8]

This paper is divided into three sections. Section one investigates the current installed PV SSEG capacity in South Africa by reviewing the data and literature available. Section two investigates the impact of the estimated amount of PV SSEG on South Africa's demand profile by focussing on variability. Section three discuss South Africa's SSEGs within the context of the Germany demand profile.

2. Current SSEG Installed Capacity in South Africa

Several studies have been carried out in the areas of capacity estimation, policy and future SSEG as well as large scale embedded generation outlook in South Africa. A selection of these are listed below towards providing an estimate of the current PV SSEG installed capacity in South Africa.

Reinecke et al. [9] carries out a capacity estimation of rooftop PV at Riversdale municipality and its impacts on the municipality's financial operations. The WWF Report [10], carries out a similar study on the effects of increased uptake of rooftop solar PV on the financial operations of Drakenstein municipality. The first study concluded that up to 9850kWp of PV SSEG could be installed in Riversdale based only on non-shaded rooftop availability, reducing to 1395kWp if the voltage regulation constraints defined in NRS097-2-3 is considered. With regards to Drakenstein the study estimated 24244 kWp of PV SSEG can be installed without violating the standards.

A study published in 2016 by Green Cape [12] reviewed the SSEG policy development in the Western Cape: 15 municipalities allowed PV installations while 3 did not. Out of the 15, 12 had a grid feed-in policy while 4 also have PV rules, regulations and a tariff in place.

SALGA produced a report [11] which looks into the numbers of municipalities that have SSEG policy frameworks instituted. As of October 2017, 34 municipalities (21% of SA's municipalities) allowed SSEG installations to connect to their networks, 21 (13%) having an official application system in place and 18 (11%) having a NERSA approved SSEG tariff. Out of the 34 which allow SSEG, the Western Cape has the most with 18 municipalities.

Korsten [13] investigates the financial impact that increasing SSEG installations would have on Stellenbosch Municipality. She estimated her installed capacity based on the NRS-097-2-3 standards and estimated that up to 6765kWp of SSEG can be installed in Stellenbosch.

A recent 2018 study by the Western Cape Department of Agriculture [14] mapped out the number of solar panels currently installed in Stellenbosch municipality based on an aerial survey. The fly over results established that the municipality includes around 4248 rooftop solar panels (these preliminary numbers still need to be verified independently). 2162 panels were identified to be on residential roofs, another 845 panels in industrial areas, while the remainder supplies off-grid power to individual dwellings in an informal settlement area. If an average per panel rating of 250Wp is assumed, the total residential and industrial installed capacity can be estimated to be around 752kWp.

Figure 3: Stellenbosch flyover area, with the yellow dots indicating potential PV installations. Note the dense area of dots in the top left quadrant, which represents off-grid installations in an informal settlement [14]**.**

PQRS [15] compiles and keeps updated a database of South African SSEG (i.e. non-IPP) PV installations, which estimates the installed SSEG capacity at 278MWp at the end of 2016.

Table 2: PQRS Estimate SSEG Installed Capacity Data [15]

Year	Verified Installations (kWp)	Estimated growth per year (kWp)
2010	465	1 107
2011	877	2 090
2012	1 339	3 090
2013	9 561	22 784
2014	11 209	26 713
2015	43 570	103 831
2016	50 355	120 000
2017		136 000 [16]
Total		**415 615**

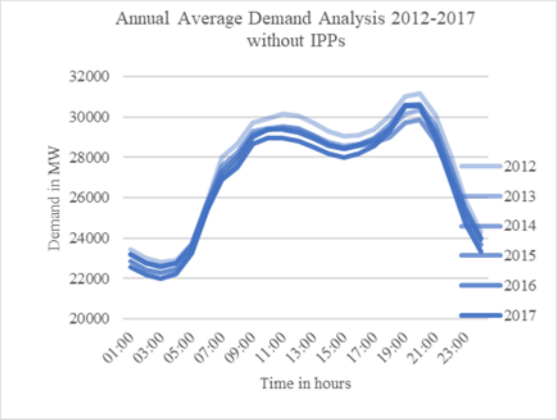
PQRS estimates the data through auditing of installed works and comparing the same with the PV sales in a year to work out a factor which is later used to estimate the amount of installed PV. The factor used for 2016 was 2.38.

PQRS also investigated how much roof space is potentially available on shopping malls (a popular location to install PV in South Africa) for future PV systems [22]. Using the numbers of installations currently available compared to the gross leasable area, PQRS determined the available installation capacity for malls in south Africa. To predict the future, this is coupled with the growth of malls in SA to give the predictions of up to 2020. On a conservative scale the rooftop capacity is set to grow from 597MWp in 2017 to 661MWp in 2020. On a continuous growth estimation, the growth is set to change from 662MWp to 804MWp.

Given that the data is provided by the installers, this information may include inaccuracies due to several reasons. Among them is the risk that installers might be tempted to exaggerate their installation numbers, especially with the smaller residential installations. Omission of data may also arise where illegal connections are concerned. PQRS's database however does appear to be the most comprehensive source of South African SSEG data at present.

3. Investigating the impact of increasing SSEGs on SA's demand profile

Analysis was carried on publicly available Eskom system demand data [18] to review the impact of increasing SSEG grid penetration on the South African demand profile. This data was analysed both including and excluding IPP generation, with the analysis including the annual averaged demand profile from 2012 (the year that IPPs were commissioned) up to 2017. The figures below show the resulting average annual demand profiles.



. **Figure 4: Averaged annual South African demand profiles – excluding IPPs**

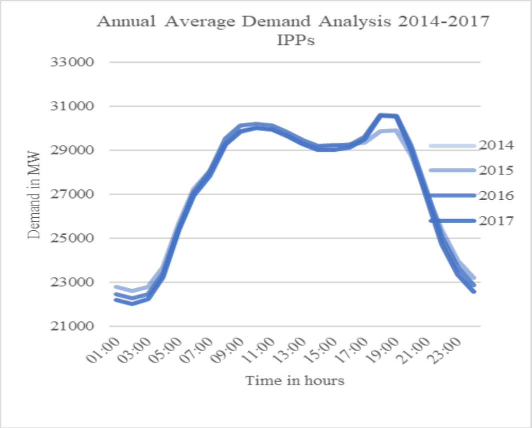


Figure 5: Average annual South African demand profiles - including IPPs

When comparing the above two figures the impact of increasing IPP generation is visible through the steeper evening ramps especially on 2017. This paper’s focus is however on SSEGs impact. The impact of SSEGs as an increasingly “duck curve” shaped profile as the years progress is not apparent in figure 4, which shows the demand profile excluding IPPs.

Based on the assumptions that SSEGs would generate most in summer months, and that demand would be lowest in summer, the total demand profile (excluding IPPs) for summer was analysed next with the aim of identifying clear impacts during daylight hours which could be attributed to SSEG installations. February was chosen as a representative summer month.

As can be seen in the figure 6 below, there appears to be a slight decrease in the midday demand relative to the evening peaks as the years progress from 2012, with the stongest impact visible in 2017.

To investigate this possible changing ratio between the evening peak and midday demand due to SSEG further, data was compiled as shown in Table 3 below. The results again do not show the linear decrease in the ratio as the years progress which would have strengthened the hypothesis of an increasing “duck curve” demand profile shape over time.

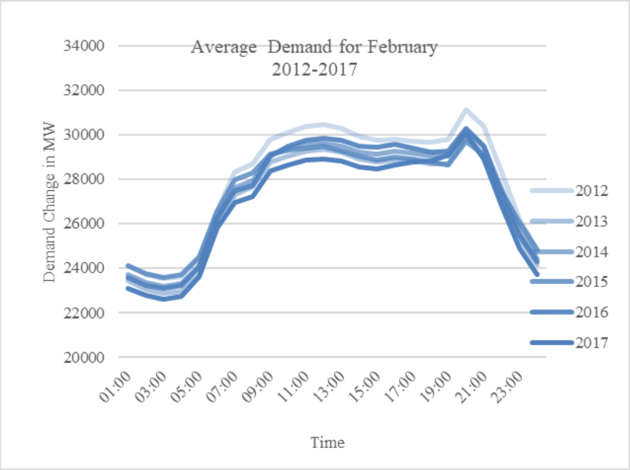


Figure 6: Average monthly South African demand profiles for February – excluding IPPs

Table 3: Ratios of Midday demand over Evening Peak demand for February

	2012	2013	2014	2015	2016	2017
Midday MW	30441	29338	29632	29487	29843	28911
Evening peak MW	31103	29909	30203	29681	30287	30055
Ratio	97.9%	98.1%	98.1%	99.3%	98.5%	96.2%

Based on the assumptions that demand would be lowest in summer, and specifically summer weekends (and SSEG’s impact therefore the most visible), a further analysis was done looking specifically at Saturday and Sunday demand profiles during the month of February for the various years. Figures 7 and 9 below shows the averaged demand profiles for these days from 2012-2017, while figures 8 and 10 analyses how the averaged demand profile changed between 2012 (as the base year) and subsequent years on an hour versus hour comparison. To make trends more apparent, the value of each demand change set (i.e. 2012-2013, 2012-2014 etc) at 18h00 was zeroed and the rest of the values in the set adjusted by the same amount. 18h00 was chosen as the reference time as the PV SSEG outputs would have diminished to low levels compared to midday.

From Figures 8 and 10 there appears to be a general yearly increase in the difference between the 2012 data and later years’ daytime demand, which might represent the impact of SSEGs amongst other factors.

It is however evident from the above discussion that the “duck curve” effect of SSEGs on midday demand and the demand profile cannot be clearly established at the current level of SSEG penetration in South Africa. This may be attributed to various problems:

- Spatial data limitations: The analysis was done on South African total system demand data, which by its nature is highly aggregated. This means that it is difficult to isolate the impact of SSEG from other impacts like increasing energy efficiency and economic impacts. Analysis of demand profiles closer to the loads and installed SSEGs should provide better insight (e.g. on municipal or substation level).
- Methodology: The methodology used in the analysis was designed to do a preliminary, high level scan of the system demand data to identify if any obvious "duck curve" impacts are apparent. The methodology aggregated the data even further into averaged annual and monthly demand profiles, without taking into account the actual solar irradiation data for South Africa.

  Now that it has been established that no clear correlation between SSEG and changes to the South African system demand profile is evident using this methodology, the next step will be to start analysing various demand profile data sets using time-series and statistical analysis techniques towards recognising specific patterns. The ultimate goal of the study which was introduced in this paper would be to establish a methodology capable of estimating to a reasonable accuracy the amount of SSEGs embedded in a specific load, by analysing how the load has changed over time.

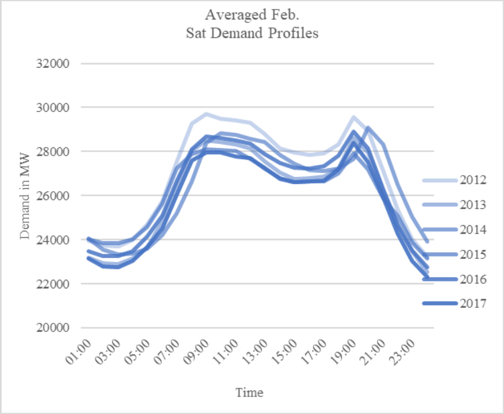


Figure 7: Average Demand profile for Saturday

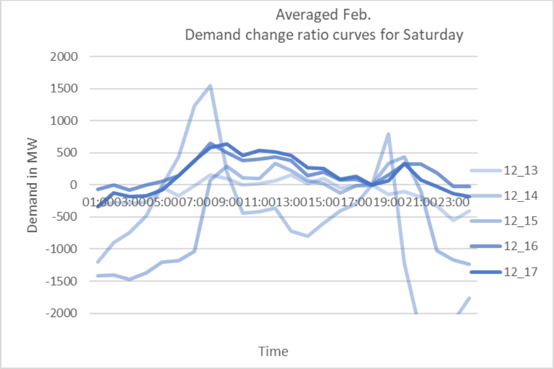


Figure 8: Average demand changes for Saturday

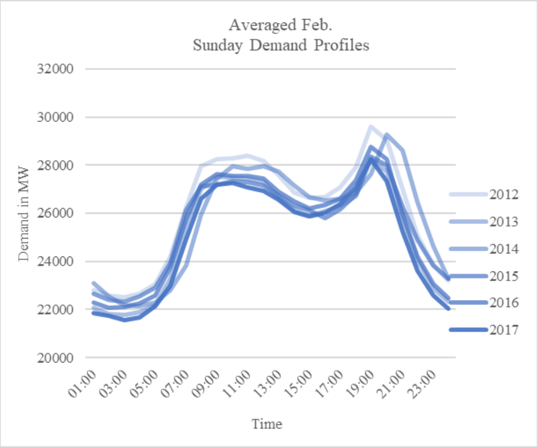


Figure 9: Average demand profile for Sunday

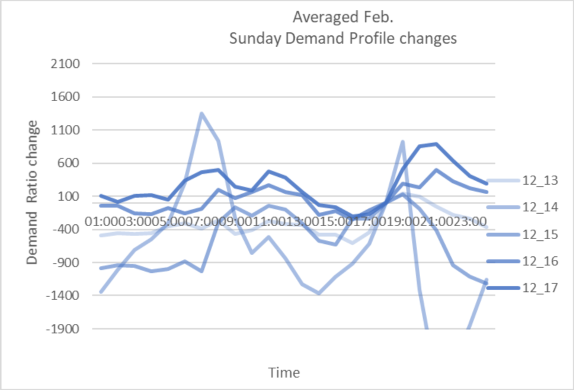


Figure 10: Demand changes for Sunday

4. Germany - a case study

It is interesting to compare South Africa, which is in its relative infancy in terms of SSEG, to a country like Germany.

Research by MIT Energy initiative group has indicated that 85% of solar energy capacity in Germany is produced by installation that are less than 1MW. The study further indicates that 98% of installed solar power, accounting for about 40GW, is connected to low and medium voltage networks

[19].

Germany demand data from 2012 to 2017 was obtained from ENTSO-E data portal [20] and analysis done to determine the demand profile changes between 2012 and 2017. From the analysis made, 26th of May 2017 recorded the highest solar generation in 2017. According to the data obtained, 27.281GW of power on the Germany power grid was contributed by Solar PV on that day at 1pm.

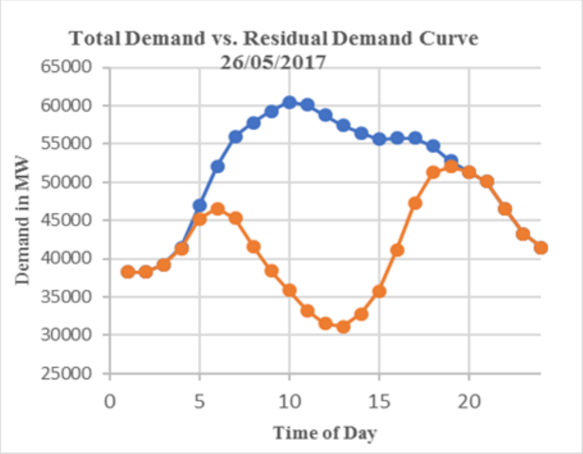


Figure 11: German Total and Net Demand Profile at peak solar generation

A study by German Development cooperation [21] shows that 74% of the German solar installations are rooftop mounted. A further 70% of these installations are less than 10kWp. The report concludes that the German solar industry is driven by the residential sector.

Using the above statistics, up to 20.188GW of the power at 1pm of the 26^{th} of May 2017 could have been a result of rooftop mounted PV, and as much as 14.132GW could have been a result of small scale PV generations of less than 10kWp.

In comparison, PQRS estimates that the total SSEG installations in South Africa was around 419MWp at the end of 2017, as discussed earlier in this paper. It is important to note that Germany has strongly incentivised the adoption of PV, which South Africa has not done yet (except for accelerated depreciation tax incentives like Section 12b of the South African Income Tax Act, which is not applicable to most residential households). The lack of incentives is clearly illustrated in the figure below, which clearly shows that the commercial market segment is currently the main adopters of PV in South Africa.

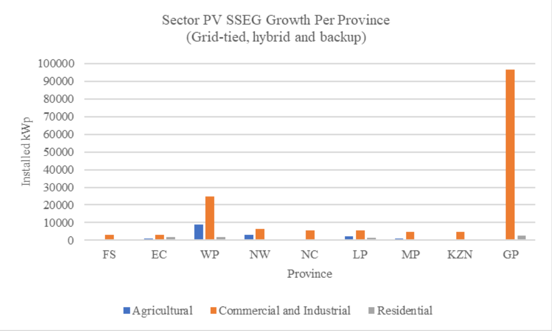


Figure 12: PV verified installations per sector per province as of 2016 [17]

5. Conclusion

From the available literature the contribution of PV SSEG is slightly below 1% of the total South Africa generation capacity.

At these low current levels of penetration, the variability impact of PV SSEG on the South African demand profile cannot be adequately determined using simple methodologies based on averaged demand profile data. More complex analysis involving time-series and statistical analysis techniques will be required.

For a country with high insolation levels such as South Africa, it is likely that the majority of future SSEGs will be PV based, which will alter the net demand curve towards a "duck curve" as witnessed from international case studies, with the associated challenges that come with it.

6. References

[1] IEA, "World Energy Outlook 2017," *Int. Energy Agency*, 2017.

[2] Fraunhofer ISE, "Current and Future Cost of Photovoltaics. Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems," *Agora Energiewende*, no. February, p. 82, 2015.

[3] a P. S. Panel and P. Affairs, "Integrating Renewable Electricity on the Grid A Report by the APS Panel on Public Affairs," *Leadership*, pp. 1–38, 2010.

[4] A. Mills *et al.*, "E RNEST O RLANDO L AWRENCE Understanding Variability and Uncertainty of Photovoltaics for Integration with the Electric Power System," 1000.

[5] H. O. R. Howlader, M. M. Sediqi, A. M. Ibrahimi, and T. Senjyu, “Optimal Thermal Unit Commitment for Solving Duck Curve Problem by Introducing CSP, PSH and Demand Response,” *IEEE Access*, vol. 3536, no. c, pp. 1–1, 2018.

[6] F. Sionshansi, *Future of Utilities Utilities of the future*, First edit. Academic Press, 2016.

[7] C. Wang *et al.*, “Distributed Energy and Microgrids (DEM),” *Appl. Energy*, vol. 210, pp. 685–689, 2018.

[8] C. ISO, “What the duck curve tells us about managing a green grid,” *Calif. ISO, Shap. a Renewed Futur.*, vol. Fact Sheet, pp. 1–4, 2012.

[9] O. Reinecke, C. Leonard, K. Kritzinger, D. B. Bekker, P. J. L. van Niekerk, and J. Thilo, “Unlocking the Rooftop PV Market in South Africa,” *Cent. Renew. Sustain. Energy Stud.*, vol. 27, no. March, 2013.

[10] WWF International, “2015 TECHNICAL REPORT ZA Potential for integration of distributed solar photovoltaic systems in Drakenstein municipality Energy EXECUTIVE SUMMARY,” 2015.

[11] SALGA, GIZ, AMEU, and GreenCape, “STATUS OF SMALL SCALE EMBEDDED GENERATION (SSEG) IN SOUTH AFRICAN MUNICIPALITIES November 2016,” no. November, p. 2, 2016.

[12] Green Cape, “Market Intelligence Report: Energy Services,” *J. Chem. Inf. Model.*, vol. 53, no. 9, pp. 1689–1699, 2016.

[13] N. Korsten, “An investigation into the financial impact of residential Rooftop PV on Stellenbosch Municipality,” no. March, 2016.

[14] Elsenburg, “The Mapping of Agricultural Commodities and Infrastructure in the Western Cape.” Western Cape Department of Agriculture, Cape town, 2018.

[15] PQRS, “Demistifying the total installed PV capacity for South Africa,” 2016. [Online]. Available: http://pqrs.co.za/data/demystifying-the-total-installed-pv-capacity-for-south-africa-nov-2016/.

[16] PQRS, “February 2017 – Solar PV Investment and Equipment Report,” 2017.

[17] C. Ballack, “PQRS shared Data,” 2017.

[18] Keith Bowen, “Eskom Electricity Demand Data,” *Eskom Demand Data, 2012-2017*, 2017.

[19] I. Pérez Arriaga and C. Knittel et al, *Utility of the Future. An MIT Energy Initiative response*. 2016.

[20] ENTSOE, “European Nations Transparency Power statistics.” .

[21] I. D. Cooperation, “The German solar rooftop experience – Applicability in the Indian context Indo-German Development Cooperation,” 2016.

[22] PQRS, “Shopping center rooftop and PV sales”, April 2017. [Online]. Available: http://pqrs.co.za/data/apr-2017-shopping-centers-rooftop-and-pv-sales/