INTEGRATION OF SOLAR ENERGY INTO THE GRID: TECHNICAL OR SOCIAL CHALLENGE? BUILDING A COLLECTIVE VISION

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Abstract

Rooftop photovoltaic (PV) has many benefits and has potential to assist in the transition to a distributed and an environmentally kinder energy future. However, this role is often misunderstood and there is non-alignment of interests between South African municipalities and rooftop PV owners on regulations pertaining to rooftop PV, including the need to register the systems and how the electricity generated is financially compensated.

In this paper this dilemma is unpacked by investigating the electricity consumption data of a typical South African household and analysing the financial implications of rooftop PV installations of different sizes against the existing electricity tariffs of Tshwane, City of Cape Town and eThekwini.

From this analysis, it is clear that the strong financial incentive to flaunt the law by not registering their rooftop PV systems could play at least a part role in the decision of the 75% of South African households who do just this.

Even though it may seem that the end goals of South African municipalities on the one hand and rooftop PV owners on the other do not align, the two parties actually do agree on the bigger picture, but disagree on the detail. A constructive dialogue is necessary to work towards a common understanding of both the opportunities and limitations presented by rooftop PV.

Keywords: Rooftop photovoltaic, household electricity consumption, electricity tariffs, SSEG policy

1. Introduction

The benefits of rooftop PV as a renewable energy technology are widely acknowledged. Households and farms that are too remote to be connected to a utility's electricity network can have access to solar powered electricity, a cleaner and a cheaper option than diesel generators. Solar home systems are also providing electricity to communities in countries with low electrification rates.

In countries with good grid coverage, decentralised rooftop PV introduces local electricity to the distribution system where it could be consumed closer to the source, with resulting lower electricity losses and potentially useful electricity in a constrained system. Research suggests that increased uptake of rooftop PV and the visibility of the technology in neighbourhoods also increase awareness of the availability of alternative and cleaner energy options than the traditional fossil fuel based electricity. Moreover, increased adoption of rooftop PV also creates local jobs [1].

In fact, PV in general and rooftop PV specifically, has become the poster child for the clean energy transition. The technology evokes a vision of a modern, innovative, decentralised, locally owned, clean, green and democratic energy system as an alternative to the current centrally controlled, fossil fuel based system. It is perceived as an inherently good, sustainable, green and cheaper energy source than fossil-fuel generated electricity that travels over long distances before it reaches the consumer [2]. Indeed, rooftop PV is commonly accepted as an option for transitioning to a just low carbon transition in that it has the potential (if not the key solution) to create a more democratic, and socially just energy system [2]. Given its potential to improve the sustainability of the electricity system and to reduce carbon emissions, rooftop PV programmes and policies are designed and implemented worldwide by policy makers to stimulate rooftop PV adoption.

The problem, however, is that its '*virtue*' is often uncontested. The economic and social costs of rooftop PV are sometimes overshadowed by the idea that it is per se sustainable. It is also fuelled by information that projects a story that is too optimistic, particularly with regards to the financial benefits that accrue to both households and municipalities. This could lead to the roll-out of well-intentioned policies to promote rooftop PV, but which have unforeseen and at times negative consequences.

This paper provides an analysis of this dilemma, referencing the results of a 2018 survey [3] and using the consumption of one specific household as a case study refracted through different sized rooftop PV installed, and using different tariff regimes. Following that, the key lessons from the case study is contextualised within a wider theoretical framework.

2. Background

2.1. Rooftop PV policy regime in South Africa

Regulations for of rooftop PV are important to ensure the safety of the electricity network. In South Africa, the Department of Energy and the National Energy Regulator (NERSA) are developing rules and regulation for rooftop PV. One requirement proposed is that municipalities should keep a list of rooftop PV, whether these are connected to their grid or not. In the interim, while these rules and regulations are being finalised, several municipalities have developed their own regulations and bylaws pertaining to rooftop PV. These regulations usually only apply for systems up to 1 MW, as larger systems need a generation licence or exemption letter from NERSA. Most municipalities require an electricity customer who is planning to install rooftop PV to go through an application and authorisation process, have their systems signed off by a suitably qualified engineer, pay for- and have an advanced metering system installed, and migrate to the applicable approved small scale embedded generation (SSEG) electricity tariff.

However, as was shown in [4], only 25% of households who have rooftop PV installed comply with these rules and regulations: the vast majority opt for the undocumented option of not informing their electricity provider of their installation. When an electricity customer has a mechanical meter installed, these often run backwards when the electricity generated from rooftop PV exceeds the electricity consumption, effectively putting this customer on a '*net metering*' tariff unbeknownst to the municipality [5].

2.2. Electricity tariffs in South Africa

While some residential electricity customers in South Africa are charged monthly set charges, the bulk of their electricity bill is made up of active energy charges (in kWh). It is also quite common in South Africa for municipalities to charge residential customers at an inclining block tariff (BiT), with low electricity users paying less than higher users. Indigent customers are also often provided with free basic electricity (FBE), and are charged at even lower rates for their electricity usage.

The residential electricity tariffs for the City of Cape Town (CCT), Tshwane and eThekwini are provided in Table 1, with the SSEG electricity tariffs for the same municipalities provided in Table 2.

Table 1: Residential electricity tariffs for the City of Cape Town, Tshwane and eThekwini from [6], [7], [8]

	CCT domestic	CCT Home User	Tshwane Jun-Aug	Tshwane Sep-May	eThekwini residential
Service charge (R/month)		R163.32	R230.00	R230.00	
0-350 kWh (R/kWh)	R2.29	R2.02	R2.10	R1.75	R1.97
350-600kWh (R/kWh)	R2.29	R2.02	R2.10	R1.75	R1.97
300-625 kWh (R/kWh)	R2.79	R2.78	R2.10	R1.75	R1.97
625+ kWh (R/kWh)	R2.79	R2.78	R2.53	R2.27	R1.97

Table 2: Residential SSEG electricity tariffs for the City of Cape Town, Tshwane and eThekwini from [6], [7], [8]

	CCT SSEG 1 (reg by 1/7/2019)	CCT SSEG 2 (new regs)	Tshwane Jun-Aug	Tshwane Sep-May	eThekwini net billing (not apvd yet)
Service charge (R/day)	R14.21				
Service charge (R/month)		R248.32	R230.00	R230.00	R81.75
0-350 kWh (R/kWh)	R1.57	R2.02	R2.10	R1.75	R1.97
350-600kWh (R/kWh)	R1.57	R2.02	R2.10	R1.75	R1.97
300-625 kWh (R/kWh)	R2.78	R2.78	R2.10	R1.75	R1.97
625+ kWh (R/kWh)	R2.78	R2.78	R2.53	R2.27	R1.97
SSEG purchases (R/kWh)	R0.85	R0.79	R0.10	R0.10	R0.84

2.3. South African household electricity consumption

The electricity consumption curve of South African households, with its pronounced morning and evening peak, is well documented, see Figure 1. It goes without saying that this consumption pattern does not coincide with sunlight hours.

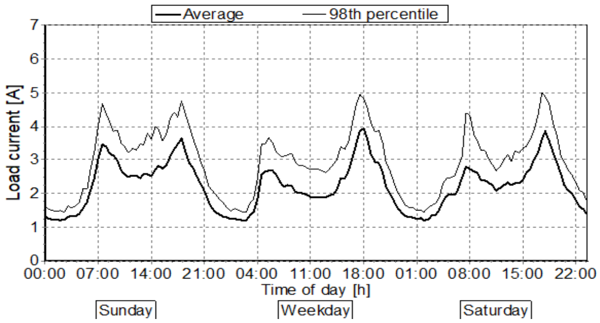

Figure 1: Five minute averaged load data at the house connection level from [9]

This non-coincidence of household consumption with rooftop PV generation in general leads to a high portion of generated electricity being fed back into the electricity grid from households with rooftop PV. This is also evident from the aggregate power flow data of 198 City of Cape Town registered rooftop PV households in Figure 2. The data below the y-intercept is the electricity fed back into the grid.

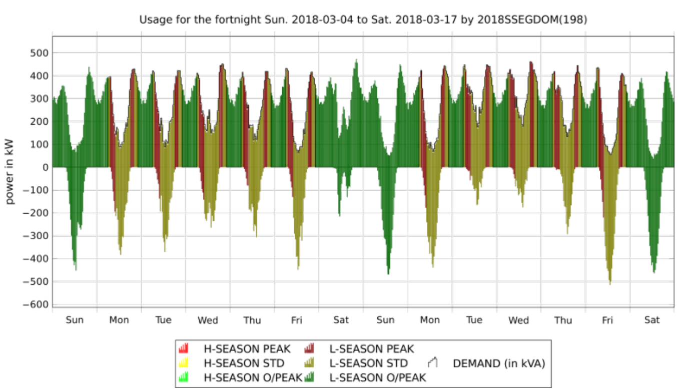

Figure 2: Aggregate power flow profile of 198 City of Cape Town registered rooftop PV households [9]

This non-coincidence might not pose a technical problem if the electricity can be absorbed with the electricity demand of neighbours or other nearby electricity loads. However, the electricity distribution system at local level is designed for aggregate demand and may not be able to evacuate the sum of the electricity generated when rooftop PV is installed in clusters in neighbourhoods, as highlighted in [10]. This challenge is exacerbated by the contagious effect of rooftop PV installations on surrounding properties as reported in [4].

3. South African household case study

3.1. Electricity consumption

In order to understand household electricity consumption and rooftop PV generation better, an analysis is done using one-minute consumption data for 2015 of a specific household located in Pretoria [11] and the solar measurement data for Pretoria from [12]. The analysis is done for 1 kW_p, 2 kW_p, 3 kW_p and a 4 kW_p installations. This analysis is deepened further in Section 3.2**.** using existing electricity tariffs for Tshwane, Cape Town and eThekwini to demonstrate the potential impact on household electricity costs.

The annual electricity consumption of the household used in this case study is 9 950 kWh. This consumption is close to the load parameters for the customer class '*urban residential II*' of 788 kWh per month, or 9 456 kWh per year from [13]. The annual electricity generation from a rooftop PV installation in Pretoria is estimated at 1 738 kWh/ kW_p. When the annual figures are considered, it is expected that 100% of the electricity generated will be self-consumed. A 1kW_p system would generate 17% of the household's electricity, while a 4 kW_p system would generate 70% of the annual electricity consumption. The figures are 35% and 52% for a 2 kW_p and a 3 kW_p system respectively.

When the monthly data is considered, the picture looks different. The household in the case study consumed 9 950 kWh for the year, which is an average of 829 kWh per month. However, the actual electricity consumption ranges from a high of 1 129 kWh for June, with the lowest monthly consumption for February, with 631 kWh. If this household had a 4 kW_p system installed, it would have generated an estimated 112% of the consumed electricity in December, but only 34% of the consumed electricity in June. See Figure 3.

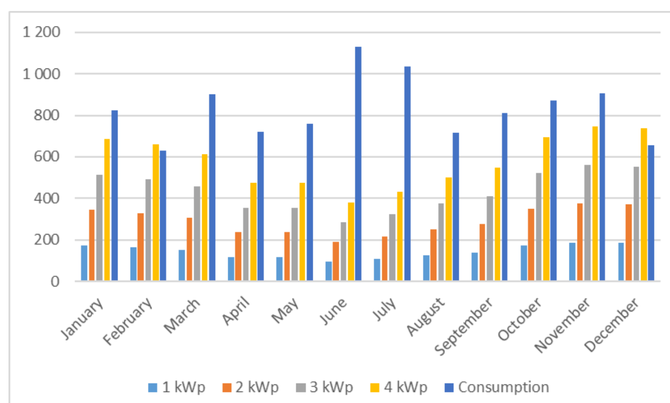

Figure 3: Monthly electricity consumption and rooftop PV generation data from [11], [12]

For typical winter and summer days, the hourly electricity consumption as well as the estimated electricity generation data for four systems ranging from 1 kW_p to 4 kW_p for a typical week and weekend day in summer are provided in Figure 4 and Figure 5. The corresponding data for a typical week and weekend day in winter are provided in Figure 6 and Figure 7. As is clear from these figures, the daily electricity demand curve is typical for a

South African household, with prominent morning and evening peaks on weekdays.

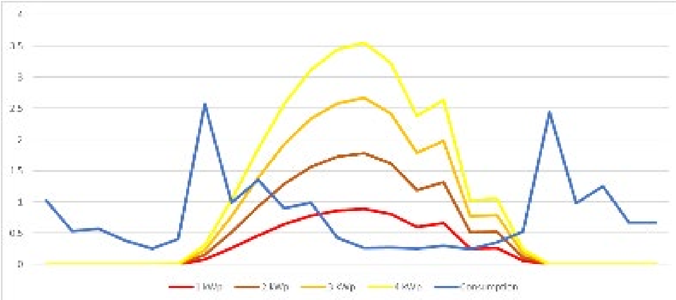

Figure 4: Hourly consumption and rooftop PV generation data for Tuesday, 10 February 2015

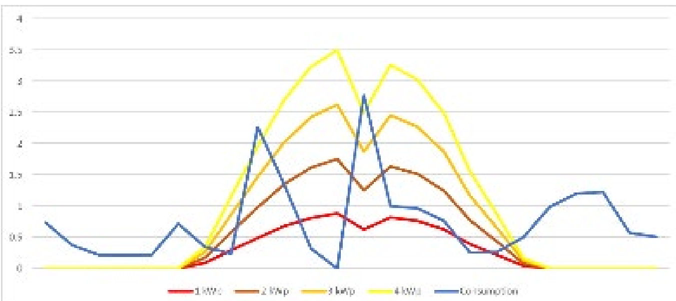

Figure 5: Hourly consumption and rooftop PV generation data for Sunday, 15 February

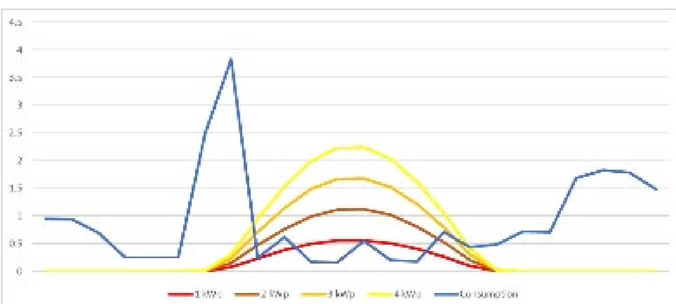

Figure 6: Hourly consumption and rooftop PV generation data for Tuesday, 9 June 2015

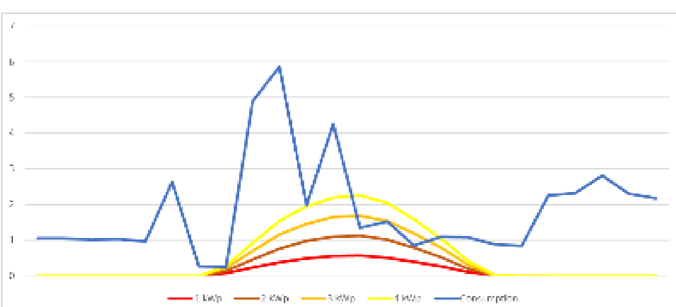

Figure 7: Hourly consumption and rooftop PV generation data for Sunday, 14 June 2015

When the hourly electricity consumption data for the entire year is compared to the hourly electricity generation of the four rooftop PV systems, the electricity self-consumption of the household in the case study would have been 86% for a 1 kW_p system, 71% for a 2 kW_p system, 59% for a 3 kW_p system and 50% for a 4 kW_p system. The remainder of the electricity generated could be fed back into the grid, stored in a battery or curtailed.

Although household electricity consumption in South Africa is typically measured at monthly intervals, the electricity consumption of households with rooftop PV on SSEG tariffs are typically measured continuously and reported on in 15 minute intervals. Whereas hourly data provides a good estimate of the coincidence of electricity generation and consumption and thus of the estimated electricity self-consumption, detail is lost with the aggregation.

The one minute data for the same days depicted in Figures 4 to 7, is shown in Figures 8 to 11. In these figures, both the consumption lines and the rooftop PV generation lines are less smooth than in the previous figures and the intermittency of the household demand becomes clear.

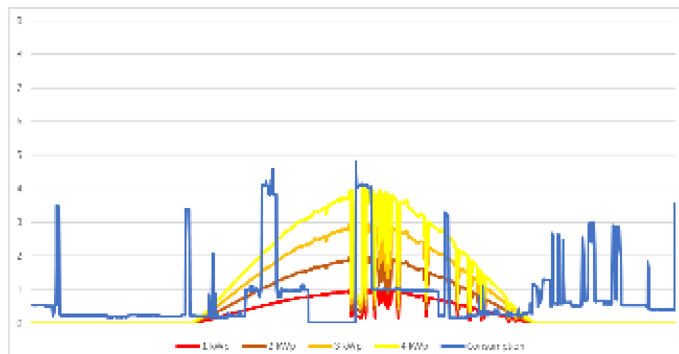

Figure 8: One minute consumption and rooftop PV generation data for Tuesday, 10 February 2015

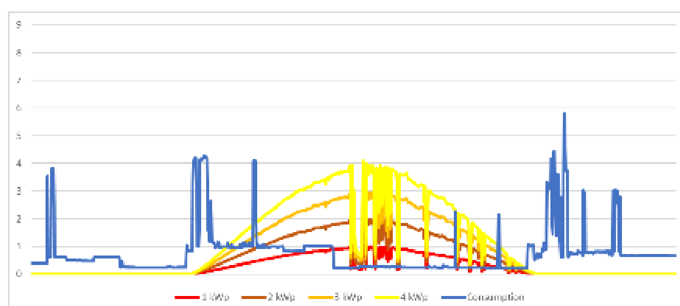

Figure 9: One minute consumption and rooftop PV generation data for Sunday, 15 February

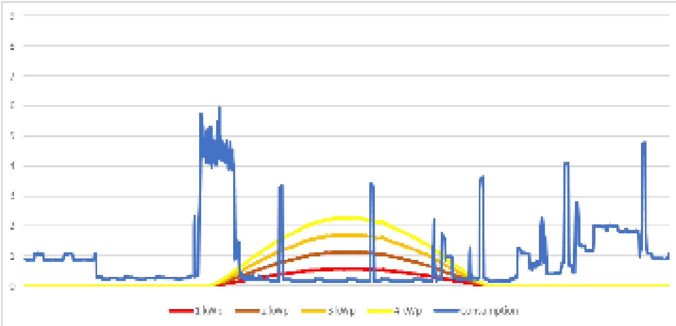

Figure 10: One minute consumption and rooftop PV generation data for Tuesday, 9 June 2015

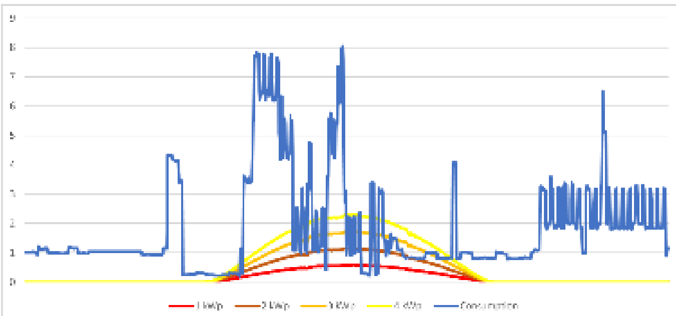

Figure 11: One minute consumption and rooftop PV generation data for Sunday, 14 June 2015

When the one minute electricity consumption data for the entire year is compared to the one minute electricity generation of the four rooftop PV systems, the electricity self-consumption of the household in the case study would have been 79% for a 1 kW_p system, 63% for a 2 kW_p system, 51% for a 3 kW_p system and 44% for a 4 kW_p system. The remainder of the electricity generated could then be fed back into the grid, stored in a battery or curtailed. The results are summarised in Table 3.

Table 3: Rooftop PV self-consumption estimates with different time-frames for different sized installations

	$1kW_p$	$2kW_p$	$3kW_p$	$4kW_p$
Annual data	100%	100%	100%	100%
Daily data	100%	99%	95%	90%
Hourly data	86%	71%	59%	50%
One-minute data	79%	63%	51%	44%

From this analysis it is clear that not only does the electricity consumption of the typical South African household (morning and evening peak) not coincide with the sunny hours of the day, but the intra-hour intermittency of the consumption further exacerbates this non-coincidence, resulting in a lower than expected rate of self-consumption of rooftop PV generated electricity.

3.2. Financial implications

By using the one minute consumption data for 2015 from a household in Pretoria [11], the one minute solar measurement data for Pretoria from the SAURAN website [12] and the Tshwane [7], City of Cape Town [6] and eThekwini [8] tariff structures, this section provides an analysis of the financial implications of these tariffs for the case study.

The calculated annual electricity bill for the case study customer is provided in Table 3 for the different tariff regimes and different sized rooftop PV installations.

As mentioned in above, a rooftop PV system would generate 17%, 35%, 52% and 70% of the annual electricity consumption of 9 950 kWh for this case study with 1 kW_p, 2 kW_p, 3 kW_p and 4 kW_p systems respectively.

Table 4 shows that without a rooftop PV system, this customer will have an annual electricity bill of between R19 616 and R24 147 for the three considered municipalities. From this table, and as expected, it is obviously financially more beneficial for the household in this case study to have an unregistered rooftop PV system and let the electricity meter '*run backwards*', in effect creating their own net-metering tariff, than to register with the municipality and change to the SSEG tariff. This is especially pronounced for the finances of the 4 kW_p system that feeds the most electricity back into the grid. However, even for the 3 kW_p system, that will provide only 52% of the household's annual electricity consumption, registering the rooftop PV system in comparison to letting your meter '*run backwards*' means paying 41% more in eThekwini, 38% more in Tshwane and between 29% and 48% more in Cape Town, depending on the applicable tariffs.

Table 4: Annual electricity bill for the case study customer for different tariff structures and rooftop installations ranging from 1 to 4 kW_p

	No PV	1 kW_p	2 kW_p	3 kW_p	4 kW_p
CCT with PV domestic tariff	R24 147	R19 437	R15 062	R10 923	R6 784
CCT with PV home user	R24 147	R19 508	R15 062	R11 788	R8 125
CCT SSEG 1 tariff		R20 163	R17 389	R15 206	R13 302
CCT SSEG 2 tariff		R21 187	R18 350	R16 141	R14 228
Tshwane residential tariff	R22 340	R18 493	R15 070	R11 830	R8 589
Tshwane SSEG tariff		R19 243	R17 404	R16 276	R15 411
eThekwini residential tariff	R19 616	R16 190	R12 764	R9 338	R6 127
eThekwini SSEG tariff		R17 583	R15 212	R13 173	R11 275

The financial modelling in this section is based on the sole use of credit meters and assumes that these meters are able to "run backwards" and that the household is thus compensated accordingly. Modern prepayment meters can, however, be programmed to either trip out or treat the reverse power feedback as consumption. The trend with South African municipalities is to move all household customers to prepayment meters. This would cut out the "net metering" potential.

Even though this case study is for only one specific household, and considering the provisos above, valuable lessons can be drawn from it. As already mentioned, both the annual electricity consumption of this household, as well as the daily demand curve correlates well with the typical South African household who could consider investing in rooftop PV.

4. Discussion

The rapid increase of rooftop PV installations opened up a box of economic, social as well as technical challenges that have not been resolved yet. These are also often not understood by all parties in the same way.

In the first instance, the financial implications of rooftop PV installations from the household and the municipal point of view are not in sync, as demonstrated by the case study above. Whilst municipalities are of the view that they are compensating rooftop PV owners fairly for their contribution to electricity generation, rooftop PV owners do not consider the compensation as fair. This was as also confirmed by a survey conducted in 2018, reported in [4], where it was reported that only 25% of rooftop PV owners in South Africa have their systems registered with their electricity provider. The other main findings from this survey are that; the upfront cost is a barrier to investment, with households who have access to capital more likely to install and; PV installations have a strong contagious effect, with households who know someone with rooftop PV more likely to install same.

However, even though there is little alignment between municipalities and rooftop PV owners with respect to expectations relating to technical safety and financial compensation, leading to low levels of registration of installations, there is much common ground on a number of aspects with both parties actually wanting the same outcome, see Figure 12. This common ground is most often not acknowledged.

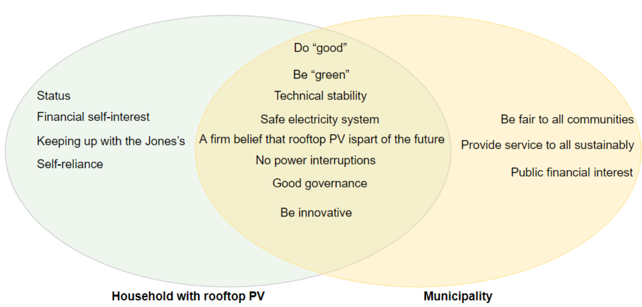

Figure 12: Venn diagram depicting the 'wants' of households with rooftop PV and the municipality from [3]

Arguably this disconnect between the perception of the municipality and that of the rooftop PV owner stems from the misunderstanding of the value of electricity generated by rooftop PV resulting from the overly positive story, painting a picture of PV owners saving money because they buy less electricity from the grid. At the same time, the municipality is saving money because it does not need to provide the PV owners with the electricity they are now generating themselves. In addition, the municipality has fewer assets to purchase and maintain in order to meet the customer load in the future. If this was the case, it would be a win-win for everyone: the rooftop PV owners save money, the municipality saves money, and it is environmentally sustainable.

However, research increasingly disproves this story. In many cases, rooftop PV drives up the costs of electricity provision by utilities [14]. Moreover, rooftop PV cannot provide an environmental benefit when the electricity generated is curtailed. In addition, rooftop PV installations are often more beneficial to high income electricity users and have the potential to penalise low income households [15].

Electricity generation from rooftop PV is dependent on a number of factors: the efficiency of the technology; the location; the orientation and angle; and the type of installation (flush on the roof or on a stand). More importantly, electricity generation by PV is not possible without sunlight and thus dependent on when the sun shines. Unfortunately, the electricity generated in the daylight hours by rooftop PV installations, is most often not in sync with the typical electricity use of South African households, with its distinct morning and afternoon peaks. Rooftop PV is often put forward as a way to eliminate electricity losses by using the electricity close to the source of generation. In the case of solitary rooftop PV installations, it is possible that the excess electricity could be used by neighbours, however, should rooftop PV be installed in clusters due to the already mentioned neighbourhood effect, this excess electricity might also not be evacuated where it could be consumed and even has the potential to overload the system.

There is also a perception that the sustainable electricity generated by rooftop PV and not self-consumed, will be fed back into the grid to be consumed by another user instead of fossil fuel generated electricity. This would then raise the percentage of electricity generated by a sustainable energy source and a PV owner would thus contribute to lower the carbon emissions.

However, if there is an overload of solar powered electricity during certain times of the day that overshoots the demand, this generated electricity will be curtailed. While this could be avoided by batteries, this option is still expensive and often not environmentally friendly. In addition, in the case of South Africa, there is technical and safety regulation (NRS 097-2-

series) that determines that only a small percentage of embedded generation can be fed back onto the grid per transformer. If more households in the neighbourhood connected to the same transformer install rooftop PV, the excess electricity fed back into the grid might overload the equipment. The dilemma that the municipality faces looking forward is to decide who, and how much, rooftop PV could be allocated to each household. Will this be a '*first come first serve*' basis? Or is there a more equitable way of to allocate the approval of these systems?

There is also a general misconception that electricity generated by rooftop PV, despite being for personal gain, is also universally good because it is more sustainable and cheaper and allows grid connected consumers to access cheaper and greener electricity. However, research now shows that rooftop PV can be inequitable and work against low income electricity customers that cannot afford to invest in rooftop PV. Investments in rooftop PV can lead to unfair economic distribution towards the higher income part of society and a scenario in which the socio-economic vulnerable are left behind. In fact, in some scenarios there is evidence that non-PV owners, including lower income households, are subsidising rooftop PV owners, the latter being mostly economically well off households [15].

Research has also shown that these costs, if no different tariffs structure is in place, might now be transferred onto other rate paying customers that don't have rooftop PV installed. Once rooftop PV started to become financially accessible to the public, whether or not stimulated by lucrative policies, the consequences were felt by utilities, both financially as well as technically. Rooftop PV installations led to a reduction of electricity sales by utilities, and thus caused a reduction in income of utilities. This would not have been a problem if the costs of electricity provision by utilities would decrease at a similar rate. This however, does not always happen. On the contrary, the financial and technical challenges will increase as the complexity of the network increases when many new actors with rooftop PV are connecting to the existing electricity network. If the costs are then distributed to the remaining rate payers, this will increase the rates for everyone, including the poor households. This cost shifting of PV owners towards non PV owners and its impact on the low income households have been studied across the world and has led to a backlash.

Challenges related to decentralised rooftop PV, as aforementioned, might even be greater in a specific socio-economic context such as South Africa with its stark contrast between rich and poor and with many customers dependent on cross-subsidisation to have access to free and/or affordable electricity rates in accordance with municipalities' constitutional obligation to service all citizens in a fair and sustainable manner.

5. Conclusion

Although there is common ground on the end goal of transitioning towards a renewable energy future, there is a non-alignment of interests between South African municipalities and households with rooftop PV installed largely related to issues of registration of systems and payment for electricity delivered to the grid by households. This is compounded by poor understanding on the part of households of their own usage patterns and the extent that their own usage is covered by their PV rooftop system. This is evident from the low percentage of rooftop PV owners who inform their municipalities of their installations.

This paper investigates the financial implications of the current electricity tariff regime in South Africa (including SSEG tariffs) with the aid of a case study. The household data used in this case study correlates well with the electricity use of a South African household who will typically install rooftop PV, both with respect to total annual electricity consumption and with respect to daily demand curves. The rooftop PV electricity generation and the household electricity consumption does not coincide seasonally, with the high electricity usage in the winter months and high electricity generation in the summer months. In addition, the rooftop PV electricity generation and the household electricity consumption do not coincide either on a daily basis or intra-hour.

Rooftop PV is perceived by homeowners as a sustainable option of providing electricity to the constrained municipal electricity system. They would, however, like to be fairly compensated for this. However, municipalities have a mandate to provide services in a fair and sustainable manner to everyone all in their jurisdiction. In this regards, household rooftop PV installations, mostly by higher income households who are resistant to registering their systems, are perceived by the municipality as acting only in self-interest for their own financial gain, rather than supporting and strengthening the overall electricity system.

However, registering their systems do not benefit households in certain instances, either. By analysing the electricity consumption in conjunction with rooftop PV installations ranging between 1 kWp and 4 kWp, it is concluded that not informing the municipality of the installation and letting the electricity meter 'run backwards' is financially beneficial for all tariff regimes in all the municipalities investigated. This financial benefit is perceived by households as unfair bullying tactic from municipalities and not supportive of their efforts to diversify the electricity mix. Without understanding the full extent of municipal obligations and constraints, they then use the argument that the municipality does not care about sustainability as justification for flaunting regulations.

As most municipalities have policies and targets in place for a just energy transition, there is arguably more common ground on this issue than malalignment. The focus for an effective dialogue between rooftop PV owners and municipalities will need to focus on this common ground for a solution to this dilemma to be reached.

Acknowledgements

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