UNDERSTANDING SOLAR PHOTOVOLTAIC INVESTMENT DECISIONS IN THE RESIDENTIAL SECTOR IN SOUTH AFRICA: A TECHNICAL ANALYSIS

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Introduction

The traditional model of energy provision by South African municipalities is being challenged by the increased uptake of small scale embedded generation (SSEG), mostly in the form of solar rooftop photovoltaic (PV) installations. These installations impact on the existing municipal electricity business model and it is becoming increasingly important for municipalities to understand the drivers for the investment decision behind these installations in order to respond effectively.

The impact on the South African municipal business model, potential solutions to address it, as well as municipalities' role in the local renewable energy transition, has been studied extensively. In particular, many reports, articles and conference papers have been published that focus on the resultant threat to Eskom and municipal electricity income and the looming '*death spiral*' (Beer, Merwe & Merwe, 2018; Janisch, Euston-Brown & Borchers, 2012; Korsten, Brent, Sebitosi & Kritzinger, 2017; Kotzen, Raw & Atkins, 2014; Lekoloane, Wright & Carter-Brown, 2018; Magemba, Jaarsveldt & Evert, 2017). In spite of this attention, there is still no clear-cut guide to follow to tackle this issue. Over and above general fatigue related to the issues raised above, it could also be because officials feel overwhelmed by the complexity of the problem that has no simple and implementable solutions, due to the interconnectedness of many factors.

What is clear is that rooftop PV reduces electricity sales of the utility and thus the income municipalities derive from sales. The challenge, however, is that this reduction in income does not necessarily go hand in hand with an equal reduction in the costs of electricity provision. Many South African municipalities have responded to this challenge by implementing rooftop PV policies, including tariff structures, to accommodate rooftop PV owners for supplying electricity to the grid and at the same time to safeguard municipal revenue. While this provides some operational comfort, it does not adequately address the future impacts of these installations which remain a pressing concern to municipalities.

Internationally, utilities have taken measures to both facilitate decentralised renewable energy as well to safeguard their own finances such as tariff changes to counter the negative financial impact. National government bail-outs of utilities under financial stress are, of course, also possible to prevent their financial collapse. However, in the South African context, the municipal concerns are different. Even though we can learn from international 'best practise', appropriate interventions might look different in South Africa. It is therefore important to understand this problem in the local municipal context as well as to understand rooftop PV investment decision-making from the South African electricity consumers' perspective.

This paper contributes to existing knowledge by mapping out the South African energy transition, based on a household rooftop PV investment survey, conducted by WWF-SA and Stellenbosch University in 2018 (Korsten, Kritzinger & Scholtz, 2018) with a System dynamics modelling (SDM) approach. The South African case is contextualised and compared to investments in rooftop PV as well as the electricity tariff environment in Germany. Given the ability of SDM and specifically causal loop diagrams (CLD) to enhance in-depth understanding of causal relations within complex systems, it is an appropriate methodology to inform policy makers what interventions they could use to develop desired energy transitions scenarios (Qudrat-ullah, 2013). SDM has additionally been used in many studies to understand the complex dynamics in the energy and electricity sector (Ahmad, Mat, Muhammad-Sukki & Bakar, 2016).

1. Background

Electricity customers in South Africa are increasingly investing in rooftop PV (see Figure 1). This is due to a combination of factors; the falling cost of the technology (see Figure 2), the rising cost of electricity (Gucciardi Garcez, 2017; Islam & Meade, 2013) and continued load shedding (Korsten *et al.*, 2018). The disruptive effects of this technology on a once robust and predictable electricity system are well known. South African municipalities, who are responsible for managing electricity service delivery, are feeling the consequences and some of them have taken measures to prevent potential revenue erosion by implementing rooftop PV tariffs (Korsten, Brent, Sebitosi & Kritzinger, 2017; Kotzen, Raw & Atkins, 2014).

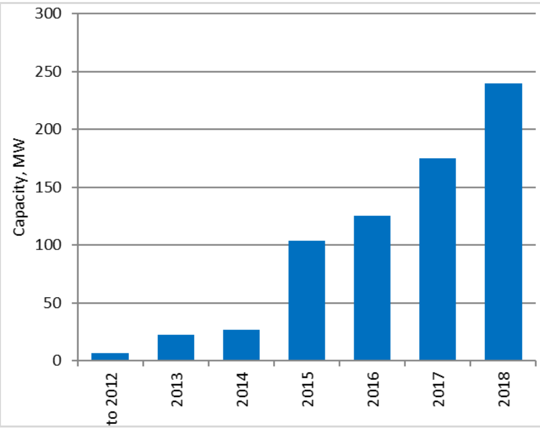

Figure 1: Additional rooftop PV installed in South Africa up to 2018 from (AREP, 2019)

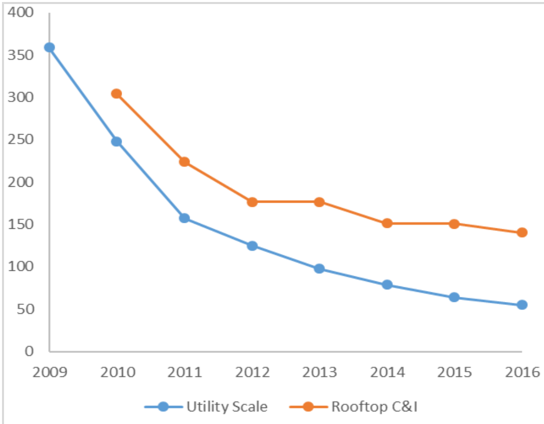

Figure 2: LCOE for solar PV in South Africa, 2009 to 2016 for utility scale and for commercial and industrial (C&I) rooftop installations, in USD per MWh adapted from (DoE, 2018)

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, and are charged at even lower rates for their electricity usage.

The practice of charging electricity customers largely for their active energy use leads to a fallacious belief on the part of consumers that their cost to the utility is accordingly reduced when they use less electricity. The utility cost, however, is not necessarily reduced in line with the lower active energy use. In addition the utility has to provide all customers with electricity when and if demanded. When a higher set tariff is charged, with an accordingly lower active energy charge, it limits the ability of the consumer to reduce the electricity bill by energy efficiency or rooftop PV and might in fact lead to higher electricity consumption. Thus, even though a higher set charge might be more cost reflective and economically appropriate to a utility, electricity tariffs evoke a behaviour response. The message received by customers from this tariff regime is that electricity saving as well as investments in energy efficient equipment and rooftop PV are actively discouraged.

Figure 3 provides the average electricity tariffs in South Africa and Germany for different monthly consumption rates. From this it is clear that low electricity users in South Africa are charged a lower tariff than in Germany. In Germany, the set charge and the active energy charge are relatively constant, resulting in low electricity users paying substantially more per kWh than high electricity users. German households also have a number of electricity providers to choose from, leading to competition in electricity tariffs.

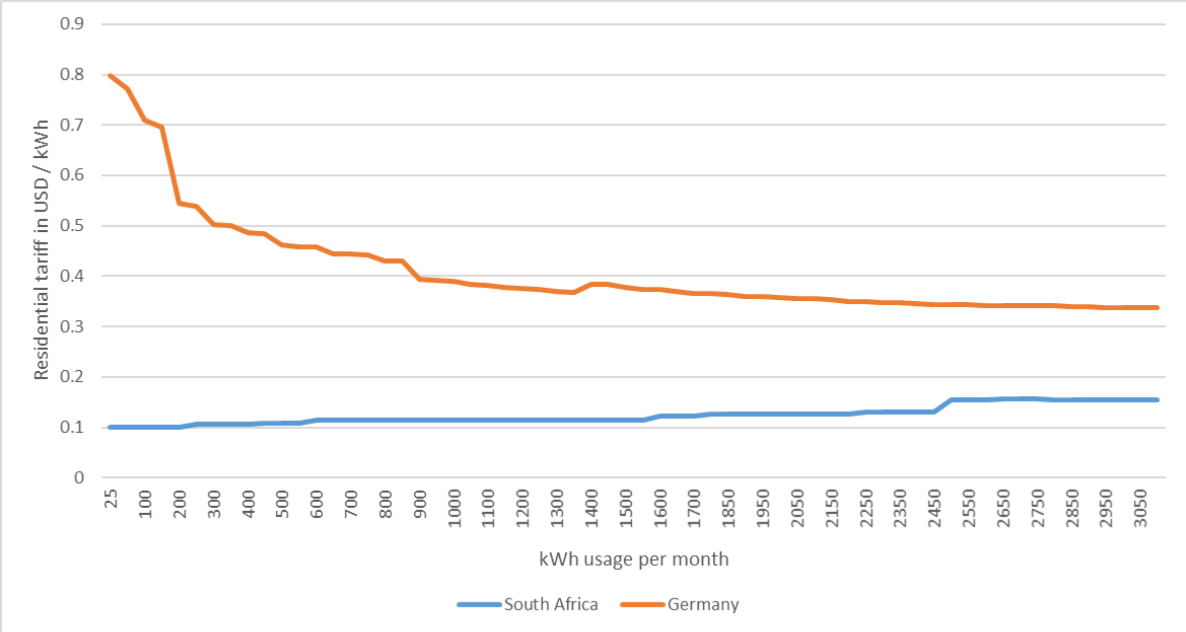

Figure 3: Average household electricity tariffs in South Africa and Germany

2. Stellenbosch case study

This challenge is clearly demonstrated when one looks at the data from Stellenbosch Municipality, a well-run, mid-sized municipality in the Western Cape.

With a gini-coefficient of 63, South Africa is regarded as one of the most unequal countries in the world (World Bank, 2018). According to a study conducted by Orthofer (2016) the wealthiest 10 percent own around 90 percent of all wealth in South Africa while the poorest 50 per cent earn only about 10 percent of all income and don't own any measurable wealth (Orthofer, 2016). This results in differences in economic purchasing power and affects the economic accessibility to basic goods such as electricity.

In terms of Section 152 of the Constitution of the Republic of South Africa, 1996 (Republic of South Africa, 1996), municipalities have a mandate to ensure the entire community within its jurisdiction is serviced in a sustainable manner. In order to do this, the municipality has to ensure it manages its finances well. This is documented in the Municipal Finance Management Act 56 of 2003 (MFMA) and the Municipal Systems Act 32 of 2000. The control of keeping up to the mandate of sustainable service delivery is weakened as more actors, in particularly high electricity consumers, are becoming co-producers of electricity that is used to generate the revenue to pay the costs of electricity service and to cross subsidise low tariffs for low income consumers.

The extent of both the contrast in electricity consumption and the extent of cross-subsidisation required are demonstrated for a municipality such as Stellenbosch Municipality is demonstrated in Table 1 and Table 2 below. The tables show the differences in average and maximum electricity consumption per neighbourhood in Stellenbosch. When looking at the average pre-paid consumption in Table 1, citizens living in Kayamandi are using on average 156 kilowatt-hours per month. This stands in stark contrast to households living in Uniepark and Karindal who consume 1071 kilowatt-hours on average. Table 2 shows an even starker contrast in electricity consumption levels. Of the 160 meters located in Uniepark and Karindal, 106 consume more than 600 kilowatt-hours per month. Despite Kayamandi having 1287 meters, only 19 of them consume more than 600 kilowatt-hours per month.

Table 1 Average and maximum consumption in different neighbourhoods (Korsten *et al.*, 2017)

Suburbs	Average consumption (kWh in a month)		Maximum consumption (kWh in a month)		Maximum consumption (kWh in a year)	
	Credit	Prepaid	Credit	Prepaid	Credit	Prepaid
Uniepark and Karindal	1 107	1 071	9 750	9 080	79 103	44 550
Dalsig and Brandwacht	1 048	963	7 725	10 895	71 300	78 998
Die Boord and Paradyskloof	881	854	10 924	15 774	100 919	76 505
Onder Papegaaiberg	726	597	5 032	5 645	36 379	17 588
Welgevonden	0	518	0	3 117	0	18 786
Idas Valley	653	483	4 518	3 790	40 283	30 247
Cloetesville	571	242	6 678	2 648	21 529	19 647
Kayamandi	422	156	1 198	2 679	10 593	16 235

Table 2 Number of households per suburb with a pre-paid meter installed and their electricity consumption (Korsten *et al.*, 2017)

Suburbs	Electricity consumption (kWh)							
	No. of meters	> 600	> 1000	> 2000	> 3000	> 4000	> 5000	> 10000
Uniepark and Karindal	160	106	73	34	18	8	6	0
Dalsig and Brandwacht	163	95	71	28	9	7	3	1
Die Boord and Paradyskloof	569	340	209	67	25	10	8	1
Onder Papegaaiberg	159	75	33	3	1	1	1	0
Welgevonden	546	258	63	3	1	0	0	0
Idas Valley	346	118	34	3	1	0	0	0
Cloetesville	728	197	37	1	0	0	0	0
Kayamandi	1 287	19	12	1	0	0	0	0

3. Understanding the complexity

The paper has already alluded to the complexity of the problem and why mere tweaking of tariffs, whilst addressing short term revenue concerns, is not an adequate long term response. In the main this complexity relates to the increase of privately owned generation in the electricity system, which introduces a set of variables that falls outside the ambit of municipal control. These are explained in more detail below.

The causal relationship between variables in the municipal electricity system is depicted with a CLD in Figure 4. Endogenous variables that influence the adoption of rooftop PV as well as the variables that impact the ability of the municipality to deliver electricity services in the future, are represented here.

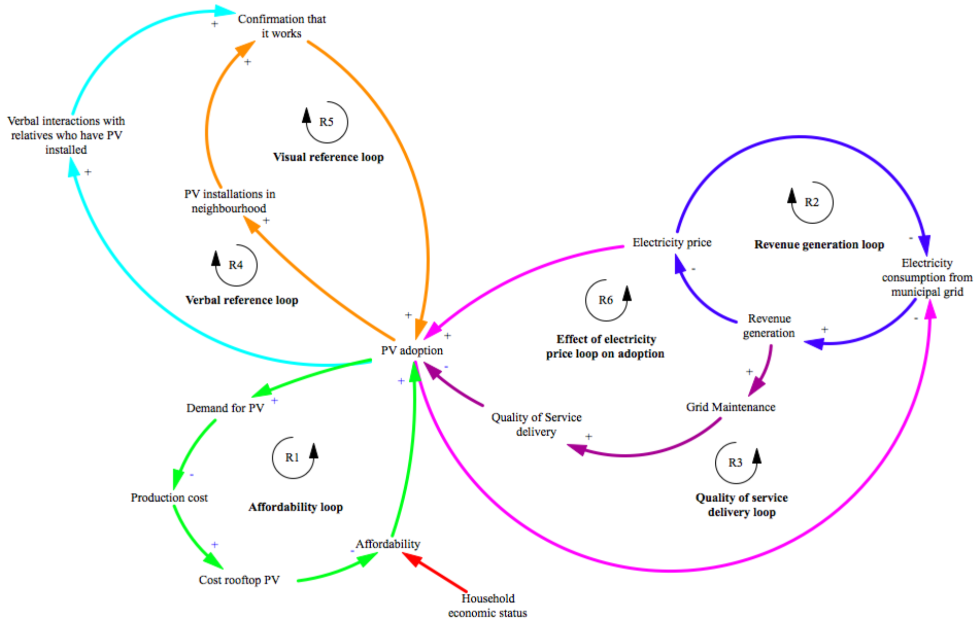

Figure 4: CLD of impact of rooftop PV on municipalities

R1 Affordability loop: Rooftop PV is becoming more affordable to households. However, affordability is not only determined by the cost, but also by the economic status of households. This is an exogenous variable that cannot be influenced by the municipality, but that influences rooftop PV adoption. However, increasing investment in rooftop PV can reduce the installation cost, making it more affordable to more people.

R2 Revenue generation loop: If the price of electricity goes up, at some point households will reduce consumption, which means the municipality loses sales on electricity, impacting its revenue. To counter this, the municipality will increase the electricity tariff in an attempt to compensate for this loss of revenue. Increased electricity prices in return leads to reduced electricity consumption.

R3 Quality of service delivery loop: Rooftop PV adoption will lead to reduced electricity consumed from the municipal grid, resulting in a loss in revenue for the municipality. Grid maintenance and new investments in electricity services then become harder to justify financially, leading to the quality of service delivery being compromised. This reduction in the quality of municipal services might lead to the electricity grid becoming unreliable, resulting in households investing in rooftop PV to become more self-sufficient in their electricity provision.

R4 Verbal reference loop: More conversations with people who have installed PV leads to a stronger confirmation that the installation of rooftop PV is worthwhile leading to an increase in rooftop PV adoption.

R5 Visual reference loop: More rooftop PV installations in a neighbourhood results in a visual confirmation that these system are worth investing in.

R6 Effect of electricity price on adoption loop: Higher electricity prices leads to more people seeking to reduce their electricity bill. One response is to invest in rooftop PV.

4. Making sense of the complexity

In Figure 5, a CLD is presented that shows the disruption that rooftop PV could have on the electricity business model of municipalities. Electricity consumers, who used to contribute to municipal revenue from electricity sales, are now generating electricity for their own use, reducing the kWh bought from the municipality. The self- generation and consumption of electricity by households reduces the ability of the municipality to recover costs of the electricity service. In order to recover the costs of the electricity service the municipality needs to make sure that enough revenue is collected to at least break even. This could be done by either selling more electricity or by increasing the tariff to existing customers. Enough revenue is also needed for investments in grid upgrades.

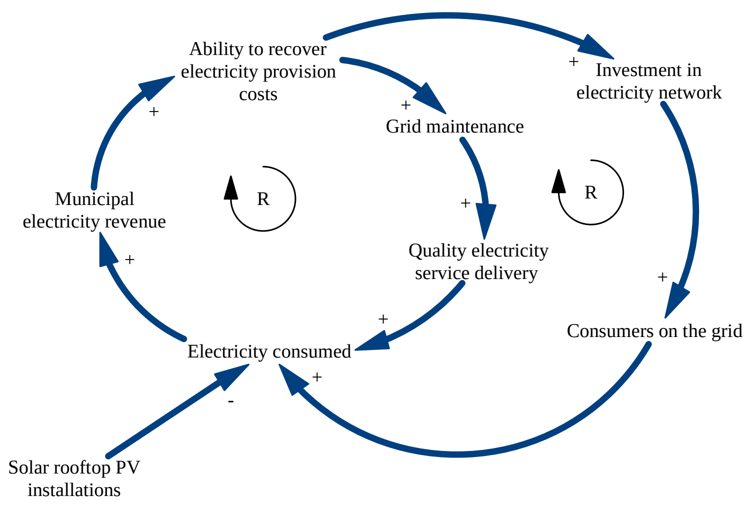

Figure 5: Rooftop PV as a disruptive force in municipal electricity service

The costs a municipality has on electricity service delivery (maintenance, distribution, etc.) do not necessarily decrease at the same rate as the decrease in electricity sales to consumers with rooftop PV systems. This is because the fixed costs of the electricity service are paid through charging mainly variable tariffs based on kilowatt-hours usage by the consumer. Moreover, the high upfront investment costs of an electricity network, is often repaid over decades. A reduction in kilowatt-hour sales will limit the ability to recover historic and present costs. In addition, it will become harder to justify future investments to safeguard an adequate quality of electricity supply that meets the demand.

This phenomenon, known as the utility '*death spiral*' has been well documented. However, context matters. As mentioned before, the *'death spiral'* in developing countries is different from that in developed countries, where there is a larger middle class who might be able to absorb the increased electricity prices. Given the lack of a 'fat' in the system in a country such as South Africa, municipalities require a much more granular understanding of the drivers of both existing and future investment in household rooftop PV. In order to understand the investment decisions of PV owners and potential PV owners within the South African context, a national household survey was conducted in 2018 by WWF-SA and Stellenbosch University.

The main survey conclusions were that the investments are mainly financially driven, coupled with a fairly strong influence of the social environment of the potential rooftop PV investors. The high upfront cost was indicated as the biggest financial limiting factor for those who have not invested in rooftop PV yet and the possibility of saving on future electricity bills and the rising electricity prices are not as important. This indicated that future saving is not as important as the upfront cost in the investment decision. For municipalities, the most important take-home insights are;

- When costs of PV come down, rooftop PV uptake will increase. Rising electricity prices plays a lesser role;
- The social environment has a significant influence and should be taken into consideration for technical grid management as geographical clustering of rooftop PV installations on the grid is most likely; and
- Only 25% of rooftop PV owners indicated that their electricity provider is aware of their installation.

Moreover, investments in rooftop PV are reliant on the ability to pay the high upfront costs, leading to investments by households with a higher disposable income. These households are also most often high electricity consumers who pay higher active energy charges. It will thus be the households in the highest income bracket who will first invest, as the initial investment costs is not so important to them. This phenomenon is also seen in practice. Following the high income households will be investment by the middleclass, largely driven by increasing electricity prices. People who cannot afford the technology are excluded from making the investment, are thus unable to access the long term financial gain and are destined to use electricity from the grid that is increasingly becoming unreliable, expensive and inaccessible. Furthermore, even though rising electricity prices impacts the poor the most, they are excluded from investments in rooftop PV, and high electricity prices might even lead to them substituting electricity with other, dangerous and/or unsustainable energy sources.

Frequent load shedding also increases investments in rooftop PV as households are seeking self-provision of electricity. Almost 70% of the people who completed the Household Rooftop PV survey (both those who already have PV installed and others) indicated that '*not trusting the government or Eskom*' is a clear motivation for them to seek alternative and independent ways of energy provision (Korsten *et al.*, 2018).

As people are influenced by their social environments (Korsten *et al.*, 2018), this could lead to a clustering of rooftop PV in certain neighbourhoods and a non-linear, mushrooming effect on the uptake of the technology. This will exponentially increase the impact of rooftop PV over time.

The aforementioned blend of factors has financial, technical as well as governance implications for electricity service provision for municipalities in South Africa. In addition to the already mentioned issue of non-alignment between the cost of electricity provision and the reduction in income due to decreased sales, the lost electricity sales due to rooftop PV installations in South Africa is mainly from wealthier electricity consumers who can afford the upfront costs of the rooftop PV investment. These consumers are also most often high electricity consumers who consume electricity at higher tariffs and subsidised thee free basic allocation to indigent households. For high electricity consumers, it makes sense to reduce high electricity usage by investing in rooftop PV.

The loss of high electricity users in the South African context has implications. Firstly, high electricity consumers are often responsible for a higher share in revenue generation from the residential sector (Kotzen *et al.*, 2014). Secondly, municipal efforts to keep prices low for low electricity users, mostly low-income electricity consumers, through a BiT, are now compromised. The BiT tariff evolved from an interim measure to protect the poor against the steep electricity price increases from 2010. The BiT allows for cross-subsidisation from high electricity users to low electricity users, and is thus used as a financial mechanism to create more egalitarian access to electricity (AMEU, 2016). If the total electricity provision cost is not absorbed by increased tariffs, this burden might unfairly fall onto low electricity consumers, due to prices for all consumers increasing even more because affluent households are opting out of the common electricity grid.

5. Interventions and unintended consequences

In order to counter the effect of revenue loss and unfair cost distribution to non-PV owners, municipalities can implement '*decoupling mechanisms*' to break the link between the recovery of utility's fixed costs and the kWh sales (Eto, Stoft & Belden, 1997; Xue, Sullivan, Peltola, Peters & Leiber, 2014). One revenue decoupling mechanism is the increase of fixed tariffs for rooftop PV owners. Certain South African municipalities have a fixed electricity charge for high electricity consuming households only. If such households reduce their electricity consumption (for instance by installing rooftop PV), then the municipality not only loses the sale of the higher-tariff kWh sold, but also the monthly set fees. Most South African municipalities that have an SSEG tariff for rooftop PV owners have introduced an extra monthly set charge for these households, sometimes over and above the already existing set charge. South African municipalities also typically have different and separately measured tariffs for import and export of electricity for households with rooftop PV.

The introducing a fixed monthly fee for rooftop PV owners might, however, lead to unintended consequences. The Household Rooftop PV survey showed that only 25% of respondents that have rooftop PV and who are consequently importing and exporting electricity at the new tariff rate have registered their system with their utility. The other 75% of survey respondents indicated that their utility is not aware of their rooftop PV system (Korsten, Kritzinger & Scholtz, 2018). This might indicate that rooftop PV owners are dissuaded to register their systems by what they conceive as a penalising SSEG tariff setting. In this case, the introduction of a fixed tariff to counter revenue erosion is an example of a '*fixes that fail'* archetype. See Figure 6. The unintended consequence of the fixed tariff is that rooftop PV owners avoid registration and when forced to register, they might disconnect from the grid altogether.

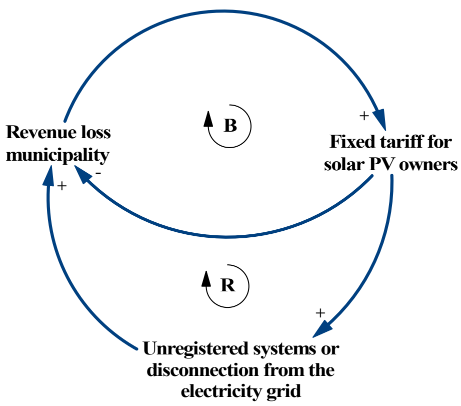

Figure 6: Fixes that Fail archetype: implementation of fixed tariffs

In addition, households with rooftop PV could in the future invest in mini-grids and so collectively disconnect from the municipal grid. This would create islands in society in which households with the economic power can invest in private electricity generation and distribution. Municipalities are then left with a consumer base that is less able to absorb higher electricity prices.

The municipal governance of electricity service delivery and the financing system that worked well for decades is being disrupted with installations of rooftop PV that challenges the governance of the municipality. On the face of it, it seems as if the municipality and households with rooftop PV have very different wants with respect to rooftop PV. This is emphasised by the resistance to register household rooftop PV systems at the municipality and a general distrust from both sides.

The City of Cape Town launched an initiative at the end of 2018 urging rooftop PV owners to register their systems with the metro. This initiative came with a strict warning that failing to register will lead to being cut off from the electricity grid and a hefty fine of over R6 000. Although the initiative received a reasonably good response, by August 2019 only an estimated 50% of households with already installed rooftop PV had applied to the City to register their systems. This initiative is perceived in the press as an unnecessary and aggressive action, implemented without inclusive dialogue or informatively communicating the reasons for their actions (Businesstech, 2018; Caboz, 2019a,b; Keli, 2019; Sicetsha, 2019).

Municipalities and citizens function in an environment where sustainability, including the transition to a more sustainable electricity system is the end goal. So, although it may seem that the '*wants*' of households with rooftop PV is far removed from the '*wants*' of the municipality, this arguably may not be the case. In Figure 7, the '*wants'* of the two parties are depicted in a Venn diagram. From this image, it is quite clear that there is agreement on most aspects. The two parties already have a strong common ground on; wanting a technically stable and safe electricity system with no power interruptions; wanting to be seen as innovative, '*green'* and '*good';* good governance; and a firm belief that rooftop PV is part of the future. This strong common ground might indicate that communication, including understanding of the impact of rooftop PV and the importance of registrations might resolve the matter in a more amicable way than with aggressive fines. Now might be the time to start a dialogue around the common ground of the '*wants'* to find the '*hows'* that benefits all fairly.

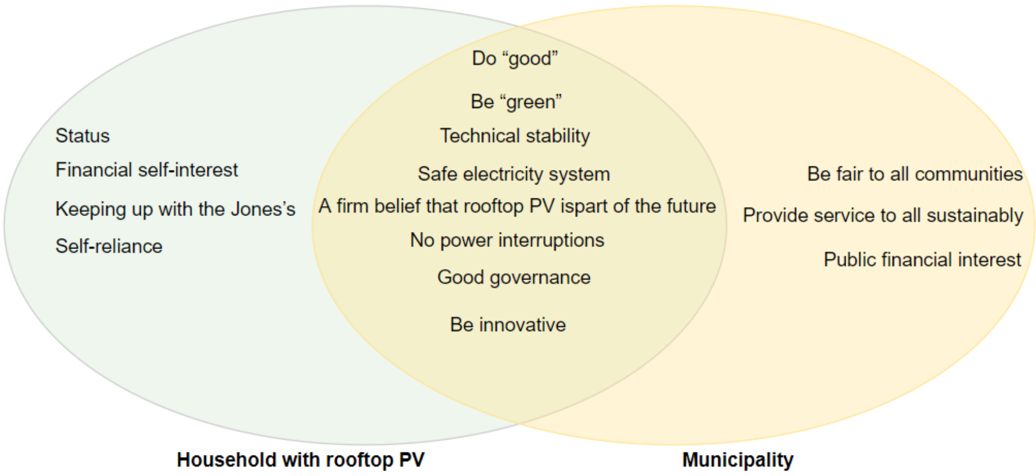

Figure 7: Venn diagram depicting the 'wants' of households with rooftop PV and the municipality

6. Conclusion

This paper discusses the unique South African municipal environment in the context of household rooftop PV installations and aims to understand the investment decision-making process from the household perspective. Municipalities and households alike view rooftop PV as a green, good, local and sustainable alternative to the remote generation of Eskom's coal-based electricity.

However, there is little consensus how decentralised rooftop PV can support a win-win situation for both municipalities and households. In fact, the individual financial gain of rooftop PV owners often does not coincide with a financial benefit to the wider public. On the contrary, in the current South African tariff regime (excluding specific SSEG tariffs), it comes as the cost to the greater society, benefitting those that can afford investment in PV systems over those that cannot. This conflicts with the South African Constitution that determines that electricity provision is a municipal mandate with no room for private sector engagement. In addition, municipalities have a responsibility to service all citizens in a fair and sustainable manner.

Internationally, government bail-outs, subsidies and electricity tariff regimes were often used as solutions to facilitate decentralised renewable energy, whilst safeguarding the utilities' finances. A similar implementation might not, however, work in the South African municipal context; the economic composition of the society is different with a smaller pool of tax-payers and a smaller pool able to absorb the costs of decentralised renewable energy.

It is clear that both South African municipalities and society at large want local decentralised rooftop PV. The way in which it is implemented currently, however, is often in conflict with the responsibility of a municipality to care for a common good. Fearing non-compliance with the municipal mandate, an aggressive approach is used by some municipalities to enforce rooftop PV registrations and shift these customers to an electricity tariff structure that safeguards municipal finances. This tariff structure, however, might not benefit the rooftop PV investor resulting in an avoidance of registration for personal financial gain.

Even though both municipalities and society at large want localised renewable energy that is reliable, there is, however, no common understanding of how this transition should be implemented in a financially and technically sustainable manner that benefits the entire community within the municipal area. In a pervading climate of aggressive stand-offs between municipalities and rooftop PV owners, this paper starts outlining a process of open dialogue between two parties (who already have a common goal and building on common 'wants'), on how to implement local renewable energy in a financially viable, technically stable and safe manner.

Acknowledgements

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