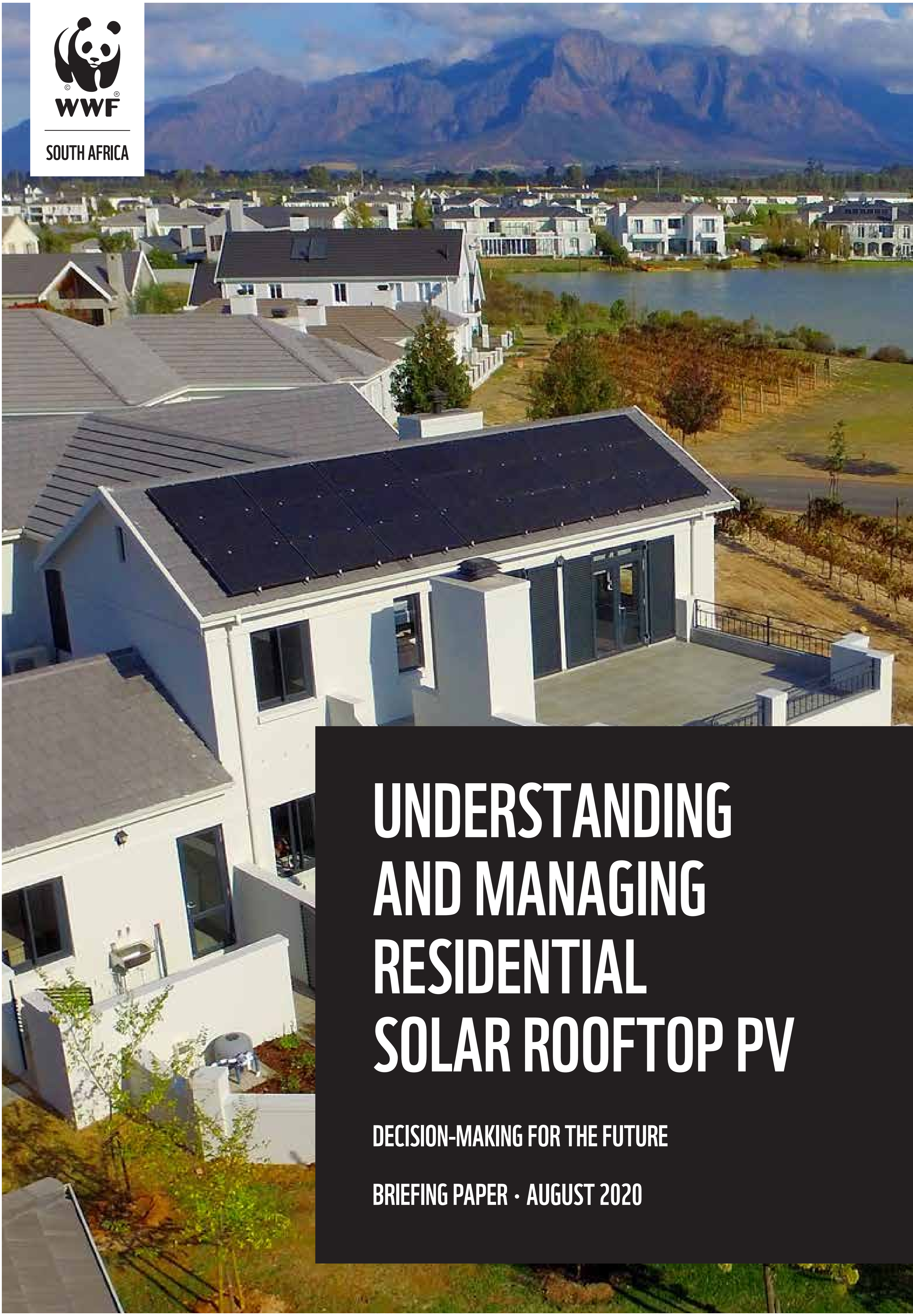

SOUTH AFRICA

UNDERSTANDING AND MANAGING RESIDENTIAL SOLAR ROOFTOP PV

DECISION-MAKING FOR THE FUTURE

BRIEFING PAPER • AUGUST 2020

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The Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University facilitates and stimulates research and capacity development activities to a viable renewable and sustainable energy sector in the southern African region.

Glossary

active energy charge:
electricity charged per kilowatt-hour consumed; this is the fee that people are most familiar with

capacity fees:
fees charged for both the maximum electrical capacity required by the customer, irrespective of whether this capacity is ever used, and for the maximum capacity used; these fees are charged for the actual peak demand in specific time periods when the grid is under strain

curtail:
to reduce the output of a generator from what it could otherwise produce given available resources; see nrel.gov/docs/fy14osti/60983.pdf

declining block tariff:
the price per unit goes down as more electricity is used in a time period

dynamic time-of-use (TOU) tariff:
the cost per unit dynamically changes according to the demand for electricity at any specific time

electricity tariff:
a predetermined rate at which electricity is sold, generally including fees per time unit, capacity fees and active energy charges

fees per time unit:
set fees charged per day, per week or per month; not dependent on the amount of electricity consumed

flat rate:
rate per kWh for electricity use in a period irrespective of usage

inclining block tariff (IBT):
the price per unit goes up as more electricity is used in a time period

kWp (kilowatts peak):
the rate at which a solar electricity system generates energy at peak performance, e.g. at noon on a sunny day

notified maximum demand:
the maximum electrical capacity required by the customer to provide for the maximum demand requirements in all time periods; penalties are imposed should this be exceeded in a specific time period

time-of-use (TOU) tariff:
units used in specific high-demand time periods (either daily or seasonally or a combination of these) are charged differently


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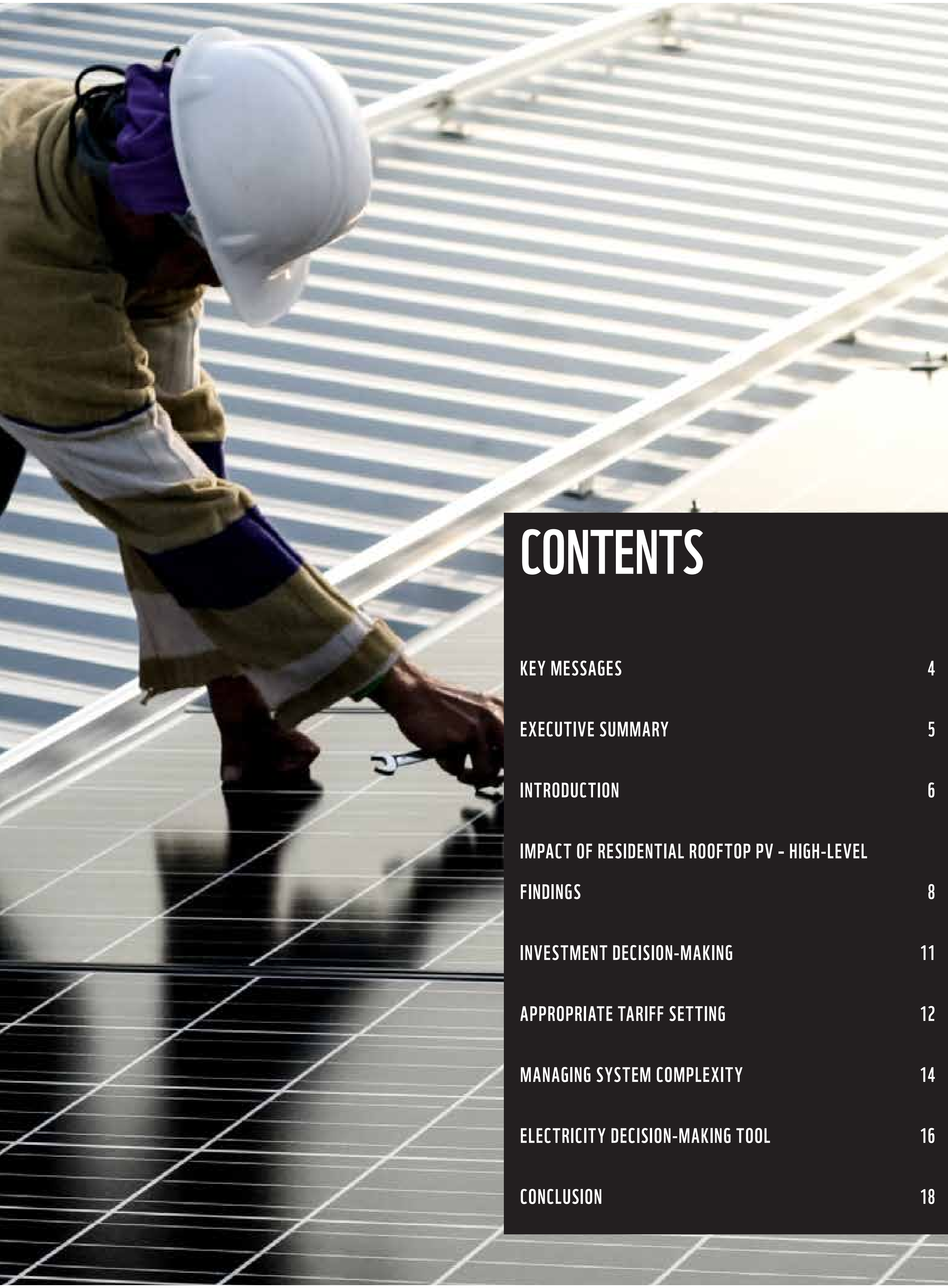

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KEY MESSAGES

- Municipalities are mandated to provide a liveable and resilient urban environment in line with South Africa's Constitution[1] and the United Nations Sustainable Development Goals.[2]
- Municipalities are best positioned to drive a local sustainable electricity system that is environmentally, financially and socially sound.
- Municipalities face many challenges in this regard (revenue, equity, technical) with no easy answers and many feedback loops.
- Appropriate tariff setting for electricity, which considers consumer behaviour (also to avoid disconnections from the grid), is needed.
- Transparency in tariff setting is important – residents need to know what municipalities use the tariffs for.
- It is important that owners of PV installations register their systems, not only for financial reasons but also for technical and safety considerations.
- Each municipality needs to understand its customers, and customers need to understand the municipality's dilemma as well as the value of the grid.
- The focus should be on common ground: all the parties want the same outcome, namely an electricity grid that is safe and dependable, electricity tariffs that are fair and an overall system that enables an urban environment that is pleasant and safe to live in and supports economic and leisure activity.
- A decision-making tool for municipalities, which takes into account all the agents in and complexities of the electricity system, is being developed. The aim is to provide municipal and other decision-makers (including Eskom and NERSA) with a practical application tool to help them deal with the dilemmas in the electricity system and design appropriate policies.

EXECUTIVE SUMMARY

As the utilities responsible for distributing 40% of electricity in South Africa, municipalities are at the centre of a rapidly changing electricity environment. Historically this was a linear system: municipalities purchased electricity from Eskom and sold it on to their customers. However, this system now includes small-scale embedded generators (SSEG), mainly in the form of rooftop solar photovoltaics (PV).

While municipalities support the transition to an environmentally sustainable power system and recognise the need to integrate renewable energy technologies, they also have the responsibility of addressing the potential revenue, technical and safety implications, as well as the social equity consequences of these installations.

Through the years, South African municipalities have come to rely on the revenue from electricity sales to high electricity-use customers to pay for the electricity provision of other customers. Municipalities also use surplus revenue from electricity sales for financial shortfalls in other services. This state of affairs adds to the existing complexity of electricity tariff setting, which is now even further complicated by the introduction of rooftop PV into the mix. Since the interests of rooftop PV owners and municipalities are misaligned, designing new electricity tariffs that are widely accepted to provide fair compensation for municipal electricity services[3] has proven to be difficult.

While municipalities with SSEG tariffs that include payment for electricity fed back to the grid view these as fair, rooftop PV owners often expect to receive the same compensation for their excess electricity as what they pay for electricity consumed from the grid. However, in reality this feed-in tariff is often much lower. This has the effect that it is financially more viable for prosumers[4] not to register their systems with the municipality and to let their meters "run backwards" (if they have mechanical disk meters), in effect setting their own (higher) net-metering tariff. This has led to many unregistered systems (as much as 75% of all households with rooftop PV installed), with resultant technical and financial implications for municipalities.

The misalignment between the view of rooftop PV owners and that of municipalities results from a general lack of understanding of the contribution that electricity from rooftop PV provides to the grid and the value of grid services. Municipalities must align their responsibility as electricity utilities – to ensure sustainable and equitable electricity services – to that of their electricity customers. These customers have always been price sensitive, but are now able to invest in their own electricity generation technologies.

Municipalities can influence electricity customer behaviour in two ways: through electricity tariff design, and through effective communication with customers about tariff setting and the inputs required to sustain a resilient electricity system. In spite of superficial conflicting interests, municipalities, electricity customers and rooftop PV owners essentially want the same outcome: an electricity grid that is safe and dependable, electricity tariffs that are fair and an overall system that enables an urban environment that is pleasant and safe to live in and supports economic and leisure activity.

This briefing paper introduces an electricity decision-making tool for municipalities that illustrates the interplay of decisions made by municipalities and their individual electricity customers. It highlights how individual choices are both influenced by the state of the system and influence the state of the system in turn. It further provides municipal decision-makers with information to develop appropriate responses to manage the trade-offs between the installation of rooftop PV and their own municipal interests in a manner that supports their constitutional mandate to provide services in an equitable way.[5] The electricity decision-making tool will assist municipalities in designing the best possible electricity system, vital for liveable and resilient cities and towns.

INTRODUCTION

Municipalities in South Africa that are responsible for electricity distribution within their jurisdictions are well positioned to drive a sustainable local energy transition from fossil-fuel-based electricity to renewable options. Increasing the percentage of renewable energy in the overall electricity mix is also well aligned with the constitutional mandate that urban areas need to provide services to its citizens in a fair and sustainable manner.

Revenue from electricity sales often makes up a significant portion of municipal revenue collection in South Africa. Municipalities often charge more for electricity than would merely recover the costs of providing this service. In this way they generate a surplus that can be used to supplement other, often underfunded, services. This cross-subsidising benefit is now being eroded by the increased installation of rooftop solar photovoltaics (PV) by commercial, industrial and especially residential customers. Rooftop PV installations reduce municipal electricity sales and, in turn, municipal revenue.

ROOFTOP PV INSTALLATIONS REDUCE MUNICIPAL ELECTRICITY SALES AND MUNICIPAL REVENUE

Rooftop PV is often seen as a win-win solution for the rooftop owner, the municipality and other electricity consumers as it is locally sourced, cheaper and cleaner than the fossil-fuel-generated electricity purchased from Eskom. However, while the municipality might save on the active energy charge on their Eskom bills due to the electricity being generated by rooftop PV, the fixed charges (often making up the larger part of the total bill) are not reduced at the same rate. The costs which the municipality incurs for the distribution of electricity over and above what it owes Eskom will also not be reduced by rooftop PV.[6] In fact, the additional administrative burden of these systems **adds** a cost to the municipality. The municipality also has to carry the costs involved in managing the integration of the electricity from rooftop PV into the grid as the grid becomes more complex. All these factors have the effect that the reduction in municipal revenue does not go hand in hand with an equal reduction in the costs of their electricity provision.

Private installations of rooftop PV may also have an impact on the equity objectives of municipalities to the extent that they can use the revenue generated through electricity sales to high-income households to subsidise the electricity usage of low-income households. As solar rooftop PV investments are largely determined by the ability of customers to afford the upfront investment costs,[7] it is mainly more affluent consumers who install rooftop PV systems

TABLE 1: THE EFFECT OF PV SYSTEMS ON MUNICIPAL INCOME AND EXPENDITURE

	Without PV systems	With PV systems
Income	Municipality earns revenue from selling electricity to residents	Less revenue is earned through electricity sales because some residents use PV
	Electricity sales to high-income households are used to cross-subsidise low-income and indigent households	Wealthier customers install PV so high-income sales at higher tariffs are lost
		All income is lost when customers decide to go off the grid completely
Costs	Payment to Eskom for electricity bought	Payment to Eskom for electricity bought is reduced by electricity generated from PV
	Electricity distribution costs (maintenance, infrastructure upgrades, call-outs)	Electricity distribution cost is not reduced despite lower sales but might even increase due to increasing complexity of the grid
	Administrative costs (metering, billing, registrations, etc.)	Higher administrative cost due to PV
	Fixed charges on the Eskom bill	Fixed charges remain
Additional costs		Administration of PV systems
		Integrating electricity generated by PV into the grid
		Additional billing costs

and to whom electricity sales are lost. Rooftop PV owners are also most often high electricity consumers who consume at higher tariffs, which are used to subsidise free basic electricity for indigent households. It is even more deleterious to municipalities when households decide to migrate completely off the grid and become energy self-sufficient. These effects on municipalities are summarised in Table 1.

TO ATTAIN THE COMMON END GOAL OF SOUTH AFRICA'S TRANSITION TO A RENEWABLE ENERGY FUTURE, COMMUNICATION AND TRANSPARENCY ARE CRUCIAL

Despite a perceived misalignment between the interests of municipalities as electricity providers and the business case of a solar rooftop PV owner, there is common ground in that the end goal is South Africa's transition to a renewable energy future. In pursuing the goal of a liveable and sustainable urban environment, mutual understanding becomes increasingly important.

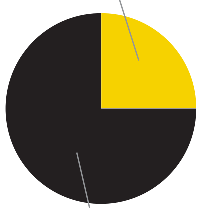
Municipalities need to understand their customers better, but customers, in turn, need to understand not only their municipality in its role as the electricity distributor but also the role and value of the grid. To attain this mutual understanding, communication and transparency are crucial. The municipality needs to explain why it introduces certain tariffs and communicate for what it uses the revenue collected from electricity sales. In the end, any income the municipality earns should be used in the best interest of all citizens living in its jurisdiction and in line with constitutionally mandated municipal objectives.

The rest of this briefing paper is set out as follows: the next section looks at the impact that investments in residential rooftop PV might have on municipal revenue. This is followed by an overview of key drivers that determine decisions regarding residential rooftop PV investments. A case is made for appropriate tariff setting as a management tool to support the long-term sustainability of the electricity system. A decision-making tool that can guide municipalities in managing complexity in their electricity systems is introduced, followed by the conclusions.

IMPACT OF RESIDENTIAL ROOFTOP PV – HIGH-LEVEL FINDINGS

Many South African municipalities have application processes in place for residents planning to install rooftop solar photovoltaic (PV) systems. These processes typically include sign-off by a suitably qualified engineer, installation of an advanced metering system (both typically paid for by the electricity customer), and the migration to a small-scale embedded generator (SSEG) electricity tariff.

25%
OF HOUSEHOLDS REGISTER THEIR PV SYSTEMS



75%
OF HOUSEHOLDS GO AHEAD WITHOUT INFORMING THE MUNICIPALITY

50%
OF ALL SYSTEMS IN CAPE TOWN ARE NOT REGISTERED

Depending on their size, all commercial and residential solar rooftop PV systems must be registered with the municipality or with NERSA.[8] However, only 25% of households that have rooftop PV installed comply with these municipal regulations; the vast majority opt for going ahead without informing the municipality, as their electricity provider, of their installations.[9]

Furthermore, mechanical disk electricity meters installed at many residences are often able to "run backwards" when electricity is fed back into the grid, reversing the unit count of electricity consumed within a period. Unbeknown to the municipality, this effectively puts the customer on a "net-metering" tariff. As a result, the business case for rooftop PV for households is substantially better for many residential customers when the installation is not registered with the municipality.[10]

There are substantial safety issues and other technical impacts at play when the municipality as electricity distributor is unaware of rooftop PV

Box 1: City of Cape Town by-law

The City of Cape Town introduced a by-law in 2018 in accordance with which the electricity supply would be cut to all customers with unregistered rooftop PV systems, at a "disconnection fee" of R6 426. The City said it would only reconnect homes to the grid again once the system was registered and complied with safety standards – or was entirely removed – and after the disconnection service fee had been paid. This process was widely reported in the media, with most reports being critical of the City's actions.[16]

The deadline for registrations was initially set for February 2019 but was later extended to May 2019. While this by-law and the accompanying awareness campaign resulted in many residents applying for registration of their rooftop PV systems, it is estimated that about 50% of all rooftop PV systems in the city are still not registered.

installations. These range from the possibility of live wires when technicians work on the network, to other problems that occur when systems are not installed according to the necessary safety standards and regulations. Furthermore, as people are social beings and easily influenced by their social environments, the solar rooftop PV installations are often clustered together as neighbours follow one another's lead. This can cause the failure of subsections of the municipal grid due to overloading when the electricity from these clustered systems is fed back into the grid. Unless the municipality is informed of the installations, this problem is impossible to mitigate.

Where and when electricity generation and consumption take place in the electricity system also affects the cost of PV systems to the municipality. Electricity generated when there is a high demand is more useful and thus more valuable than electricity generated in a low-demand period. If electricity generated by the PV installation is not used by the household when generated, the excess electricity will be fed into the grid. The location of the PV installation where electricity is generated and excess electricity is exported into the grid in relation to where the demand exists determines the costs or benefits of the PV installations to municipalities. The longer the distance between the point of export and the point of consumption (demand), the more electricity is lost. The total electricity demand at a specific time and the capacity of the electricity grid determine whether and how much electricity needs to be curtailed (see glossary).

Lost electricity sales due to rooftop PV installations are mainly from affluent electricity consumers who can afford the upfront costs of PV systems. These consumers are also most often high electricity consumers who consume electricity at higher tariffs. The municipality uses this income to subsidise the free basic allocation to indigent households.

Due to the prevalence of the inclining block tariff (IBT) used by municipalities for the billing of electricity, the installation of rooftop PV systems makes more sense for high electricity users (see Box 2). The inclining block tariff means the price per unit goes up as more electricity is used in a time period.

Electricity sales to high electricity users also often generate more revenue for municipalities from the residential sector[11] because these users consume electricity at higher tariffs. This income is now being diminished, compromising municipal efforts to keep prices low for low electricity users – mostly low-income consumers – through the inclining block tariff.

The problem of revenue impact and fairness implications due to increased rooftop PV installations is a worldwide phenomenon experienced by electricity utilities. However, these problems are more pressing to South African municipalities due to the socio-economic context in which they operate. Many municipalities have a smaller group of high electricity consumers and a much larger group of low electricity consumers and indigent households.

Box 2: Inclining block tariff

The inclining block tariff that is often used by South African municipalities for residential electricity users evolved from an interim measure to protect the poor against the steep electricity price increases since 2010.

The inclining block tariff 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.[17] The inclining block tariff was intended as a progressive financial mechanism with a social outcome to make electricity more accessible and affordable to low-income consumers. It is also said to encourage energy efficiency by discouraging high electricity usage.

However, with the disruption caused by rooftop PV systems, the inclining block tariff now has an unsocial or regressive outcome where wealthier electricity consumers save on the highest-priced electricity units and municipal electricity revenue from higher-priced kWh sales is lost.

Municipalities have a constitutional obligation to provide services to all citizens in a fair and sustainable manner.[12] The stark contrast between the affluent and the poor in South Africa makes the challenge even more complex. Many consumers are dependent on cross-subsidisation to have access to free or affordable electricity rates. Figure 1 and Figure 2 illustrate the complexity that municipalities have to deal with.

FIGURE 1: AVERAGE kWh CONSUMPTION PER SUBURB

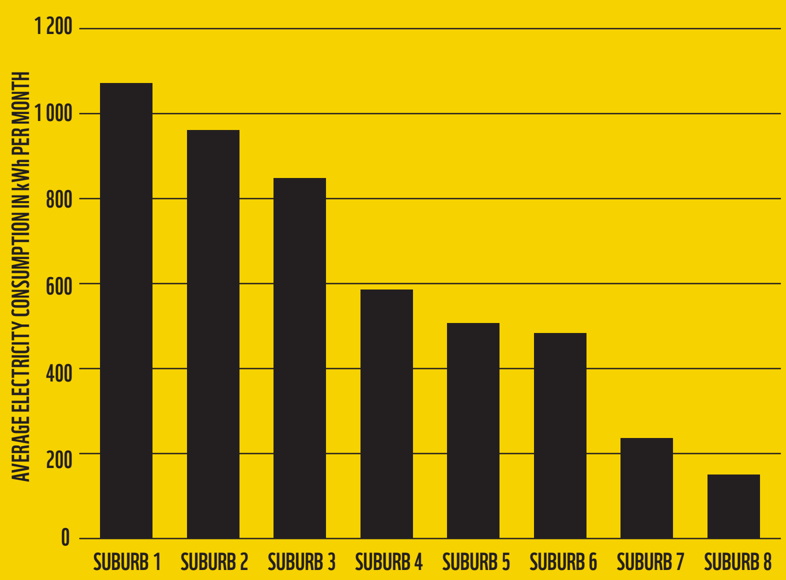


Figure 1 shows the average electricity consumption in kilowatt-hour (kWh) per suburb in an example municipality. There is a significant difference in the electricity consumption of high- and low-income areas. Households in a low-income area (suburb 8) are using on average just below 200 kWh per month. This stands in stark contrast to households living in more affluent areas, such as suburb 1, which consume more than 1 000 kWh on average. Households in the lowest electricity-use area (suburb 8) are consuming on average only 15% of that of the highest electricity-consuming areas (suburb 1).

FIGURE 2: ELECTRICITY METERS AND AVERAGE USAGE PER SUBURB

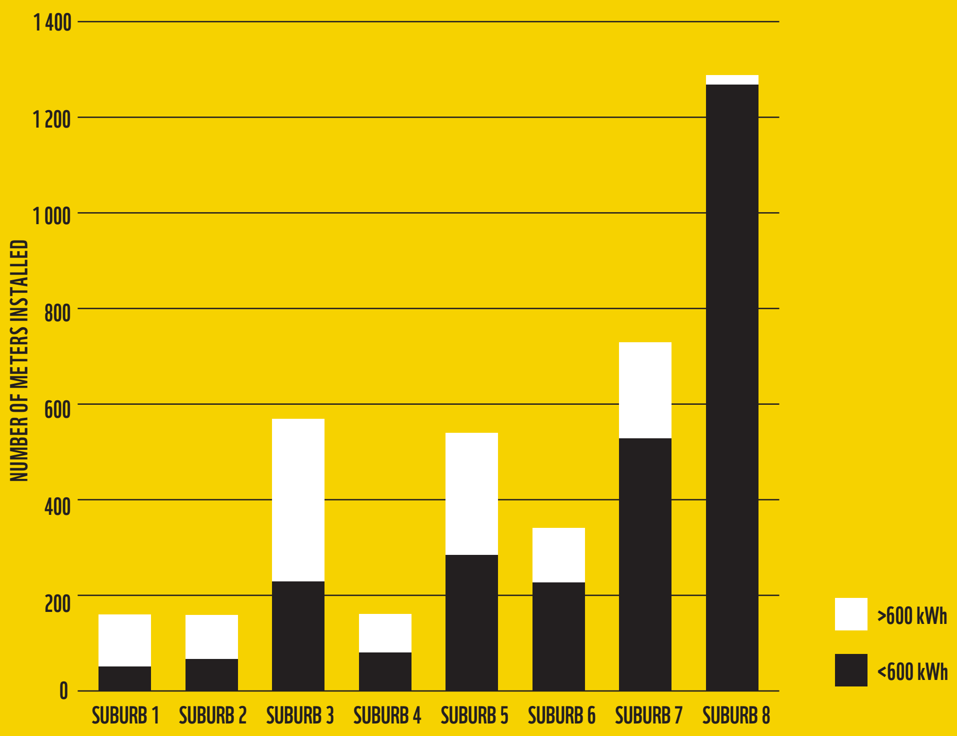


Figure 2 shows the number of meters installed per suburb. The meters that register a usage of less than 600 kWh per month on average are indicated in black and the meters that register a usage above 600 kWh per month are indicated in white. Even though suburb 1 (with fewer than 200 individual customers) has fewer meters, 66% consumes above 600 kWh on average per month. Suburb 8 (with more than 1 200 individual customers) has significantly more meters and consumes on average less than 200 kWh per month. Only 1,5% of electricity consumers in the low-income suburb (suburb 8) consume above 600 kWh per month.

Apart from the potential pressures of increased electricity prices on poor households, municipalities are increasingly left with a consumer base that is less able to absorb the increased costs of the Eskom electricity network.

INVESTMENT DECISION-MAKING

As mentioned before, municipalities must provide services in a manner that makes a liveable and resilient urban environment possible. This requires the capacity to respond to the needs and actions of citizens and design appropriate policies to ensure a technically and operationally well-run electricity system that is fair and sustainable.

Given the fact that municipalities are highly dependent on the revenue they generate from electricity sales to affluent households, it is critical for them to understand the investment decision-making of rooftop PV owners as well as the reluctance of these owners to register their systems. Reasons for not registering could include not wanting to pay a higher tariff, a reluctance to pay the registration fee and pay for a new meter, or simply not wanting to do the administration. But by not registering, owners compromise the safety of the overall system and could endanger the lives of municipal workers who might assume that wires are dead when they are in fact live.

MUNICIPALITIES ARE HIGHLY DEPENDENT ON THE REVENUE THEY GENERATE FROM ELECTRICITY SALES TO AFFLUENT HOUSEHOLDS

A survey conducted by WWF South Africa and CRSES[13] made it clear that the decision-making of households to invest in solar rooftop PV depends on various factors:

- The falling cost of the technology
- The rising cost of electricity
- An increasing awareness of the need to reduce consumption of electricity generated from the burning of fossil fuels
- Continued load-shedding experienced in South Africa
- The ability to pay for the high upfront costs of the technology
- Influences from the social environment, i.e. their neighbours[14]

However, the most important factor is that the business case to make the investment worthwhile needs to make sense. Whereas there are many factors that determine the viability of solar rooftop PV installations, the upfront cost of the system and the active energy charge component of the electricity bill are the most important from the investor's perspective. When a municipality's active energy charge per unit is high, this encourages the installation of rooftop PV systems as investors can reduce this component of the bill by substituting kilowatt-hours from the municipal grid with self-generated kilowatt-hours. The higher the tariff municipalities charge per unit of electricity consumed, the more people will save on electricity expenses by reducing their total kilowatt-hour usage. These savings will in turn shorten the payback period of the investment in rooftop PV installations.

APPROPRIATE TARIFF SETTING

While municipalities by and large cannot control solar rooftop PV installations, they determine the electricity tariff. This offers an opportunity for the municipality to intervene by adjusting or redesigning their tariff system.

Electricity tariffs can be designed in a multitude of ways, ranging from a set monthly (or yearly) charge irrespective of electricity use, to charges for metered energy use only. Table 2 provides a summary of the different tariff attributes applicable to residential electricity customers and the expected effect these will have on electricity use as well as on the decision to invest in rooftop PV.

TABLE 2: TARIFF ATTRIBUTES FOR RESIDENTIAL ELECTRICITY USE[15]

Type	Name	Unit	Attribute	Signal	Impact on rooftop PV investment
Set charges	Access charge	Day/week/month/year	Simple set charge per time unit irrespective of capacity or active energy use	No signal for usage or capacity saving	Electricity bill the same before and after rooftop PV installation
Capacity charges	Network capacity charge	kVA	Time-period charge based on capacity access irrespective of capacity use	Signal to reduce capacity used (however, often based on initial capacity application and infrastructure installed)	Electricity bill the same before and after rooftop PV installation
	Excess network capacity charge	kVA	Charge for exceeding notified maximum demand	Signal to reduce capacity used to protect municipal infrastructure	Rooftop PV only has an impact on capacity charge reduction if peak usage coincides with sunshine
	Peak demand charge	kVA	Peak capacity utilised within a billing period (month) – often only charged for highest average maximum demand in high-demand periods	Signal to reduce capacity used to protect municipal infrastructure	Rooftop PV only has an impact on capacity charge reduction if peak usage coincides with sunshine

Type	Name	Unit	Attribute	Signal	Impact on rooftop PV investment
Active energy charges	Flat rate	kWh	Rate per kWh for electricity use in a period irrespective of usage	Signal to reduce electricity use per time period	Rooftop PV reduces electricity usage from the utility, so the electricity bill reduces accordingly
	Flat rate based on usage	kWh	Rate per kWh for electricity use in a period based on historic usage	Signal to reduce electricity use per time period (month) as well as over a longer duration (year)	Rooftop PV reduces electricity usage from the utility, so the electricity bill reduces accordingly Higher users pay a higher rate, incentivising them to invest in rooftop PV
	Inclining block tariff	kWh	Rate per kWh based on usage for the time period – higher usage leads to a higher per-kWh charge in blocks	Signal to reduce electricity use per time period (month)	Rooftop PV reduces electricity usage from the utility, so the electricity bill reduces accordingly Higher users pay a higher rate, incentivising them to invest in rooftop PV
	Declining block tariff	kWh	Rate per kWh based on usage for the time period – higher usage leads to a lower per-kWh charge in blocks	Cost-reflective tariff as highest cost to the utility is for infrastructure investment and service	Rooftop PV reduces electricity usage from the utility, so the electricity bill reduces accordingly Lower users pay a higher rate, incentivising lower users to invest in rooftop PV
	Time-of-use (TOU) tariff	kWh	Rate per kWh based on usage differentiated by when the electricity is used Higher usage is predetermined and based on expected high-demand times	Signal to reduce electricity use in times of expected high demand	Rooftop PV reduces electricity usage from the utility, so the electricity bill reduces accordingly If peak demand times coincide with sunshine hours, investment in rooftop PV is incentivised
	Dynamic TOU tariff	kWh	Rate per kWh based on usage differentiated by when the electricity is used Higher usage is dynamically determined based on actual high demand	Signal to reduce electricity use in times of high demand	Rooftop PV reduces electricity usage from the utility, so the electricity bill reduces accordingly If peak demand times coincide with sunshine hours, investment in rooftop PV is incentivised

By changing the electricity tariff, municipalities can manipulate the rooftop PV installation market by either stimulating installations or discouraging investments. At the same time, the design of the electricity tariff also influences the ability of the municipality to recover costs and might allow possible surplus generation.

Municipalities can use tariffs to influence consumer behaviour and safeguard their cost recovery from the electricity service. They could, for example:

- Incentivise investment in rooftop PV by offering a higher rate for the "green" electricity generated by rooftop PV and fed into the grid
- Use tariffs to act as an incentive to maximise self-consumption of the electricity generated by rooftop PV, by offering prosumers a low feed-in rate

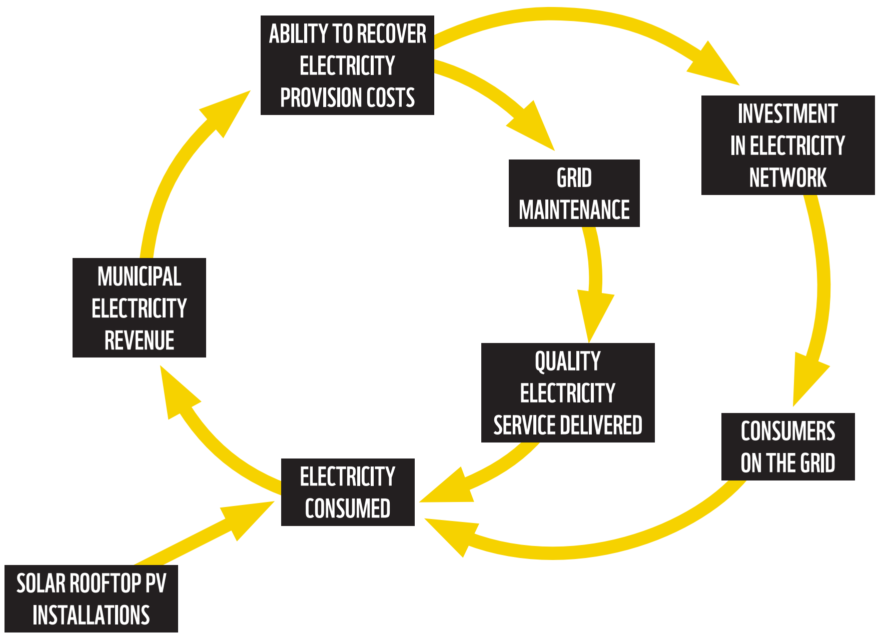
However, it must be borne in mind that different tariff designs can also have unintended consequences, for example changing the behaviour of consumers in unforeseen ways that might be difficult to reverse. The decision by a customer not to register their PV system is a case in point. Once most people do not register, it will take a massive effort to get them to do so. Communication between the municipality and its customers therefore remains crucial at every step of the process so that customers can understand why they should register.

MUNICIPALITIES CAN USE TARIFFS TO INFLUENCE CONSUMER BEHAVIOUR

MANAGING SYSTEM COMPLEXITY

Municipalities, just like other electricity utilities in the world, are dealing with a complex problem that has multiple reinforcing feedback loops.

FIGURE 3: THE IMPACT OF ROOFTOP PV ON MUNICIPAL REVENUE AND SERVICE DELIVERY



There is a multitude of cost-recovery safeguards available to municipalities to protect their revenue. One such a method is to incorporate separate charges for capacity or maximum demand, regardless of how much electricity customers purchase (or not) from the municipality. However, while this solution might safeguard municipal revenue, it reduces the business case for rooftop PV installations for the homeowner because fixed charges cannot be reduced by self-generated electricity. In South Africa, this has been a strong driver for the non-registration of systems and also might encourage households to disconnect from the grid or municipality and become self-sufficient, which would then impact even more severely on municipal revenue.

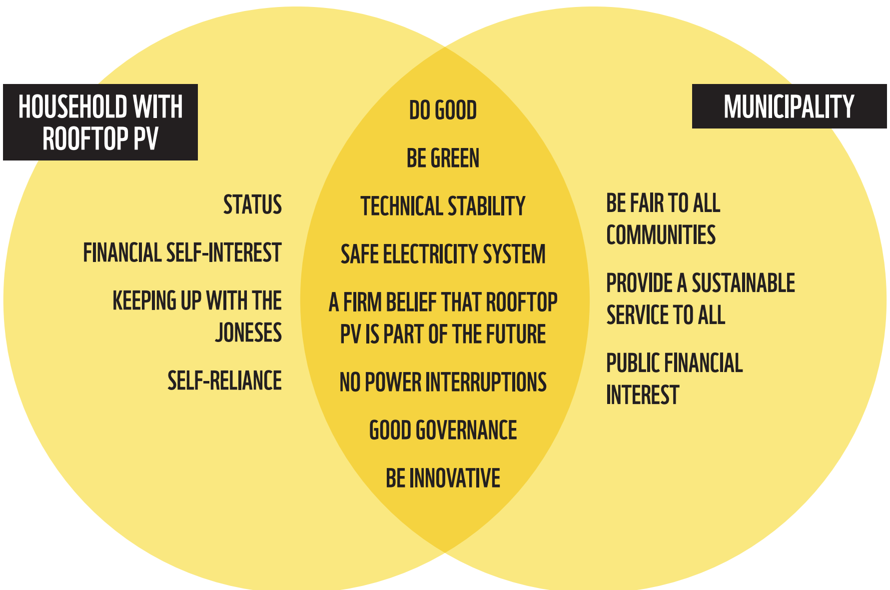
SKILLED ELECTRICIANS IN JOHANNESBURG, WORKING ON HIGH-VOLTAGE POWER LINES WHILE SERVICING THE ELECTRICITY GRID.

Municipalities could also change the inclining block tariff into a cost-reflective tariff in the form of declining block tariffs (see Table 2). However, this option would also reduce the business case for rooftop PV investment as the tariff for the substituted electricity would then be lower, making the payback period for the PV investment longer.

It is clear that the rapid increase of rooftop PV installations has resulted in a host of economic, social and technical challenges that have not been resolved yet. Moreover, these challenges are often not understood by all parties in the same way. An example is the financial aspect: while 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. Similarly, there are also technical safety concerns, as was highlighted previously.

Despite the reluctance of homeowners to register their PV installations, on the one hand, and the inability of municipalities to communicate their strategy clearly enough to customers, including the reason for the charges, on the other, there is some common ground on which to base a workable solution. This is illustrated by the overlapping area in Figure 4.

FIGURE 4: MUTUALLY DESIRED OUTCOMES BETWEEN MUNICIPALITIES AND ROOFTOP PV OWNERS



ELECTRICITY DECISION-MAKING TOOL

While clear communication that focuses on the common ground between stakeholders could assist in aligning the interests of municipal utilities and owners of solar rooftop PV installations, municipalities still face the challenge of managing a system that is becoming increasingly complex.

This complexity relates mainly to the shift from a linear system of electricity procurement and provision to one involving multiple actors. This introduces a new dynamism and uncertainty into the system. It is in this context that a decision-making tool can support municipal utilities to maintain a resilient electricity system for urban areas.

"PROSPEROUS" IN THIS SENSE MEANS FINANCIAL VIABILITY ON ALL THE LEVELS, INDIVIDUALLY AND TOGETHER, WHICH INCLUDES A HEALTHIER AND MORE RESILIENT POWER SYSTEM THAT IS SOCIALLY EQUITABLE AND FAIR

Responding to this need, a computerised electricity decision-making tool is under development by a team of researchers from the Centre for Renewable and Sustainable Energy Studies (CRSES) at Stellenbosch University to assist municipalities in dealing with the dilemmas inherent in a complex electricity system. This tool is based on simulation modelling, where the intention is not to find an optimal system design, but rather to envision the performance of the system over time and space, given certain assumptions. It will help users to explore possibilities for a stable and more prosperous electricity system design, and to visualise how changes in rooftop PV installations and different policy conditions mutually influence each other and how these changes affect the electricity system. "Prosperous" in this sense means financial viability on all levels, individually and together, which includes a healthier and more resilient power system that is socially equitable and fair.

The decision-making tool mimics rooftop PV market development over time and will measure scenario outcomes for:

- Financial implications, including the business case for each entity
- System stability, including system overload at the local level
- Environmental impact, focusing on the level of greenhouse gas emissions

The different operators in the electricity system are represented in the tool as “agents”. These agents influence the electricity system by the decisions they make. The agents employed in the tool are electricity consumers, the owners of PV installations, neighbourhoods, the electricity generation utility, the transmission utility and policymakers, as illustrated in Figure 5.

All these agents make their own decisions independently of one another, but are influenced by the decisions of the other agents they observe. Most agents do not have perfect knowledge of the entire system but are only affected by the part of the system that is visible to them. However, even in the case where agents have perfect knowledge, it does not necessarily follow that their actions and decisions are rational or to the benefit of all electricity providers and consumers.

The electricity decision-making tool measures how, and to what extent, individual choices about the installation of residential rooftop PV are both influenced by the state of the system and influences the state of the system. The tool mimics the installations of residential rooftop PV systems over time under different conditions to better understand the complex interaction between consumer investment decisions and the tariffs charged by the municipality.

The computerised decision-making tool includes inputs that affect the system, such as:

- Rising electricity tariffs
- Changes in electricity tariff structures
- The falling cost of rooftop PV
- Municipal regulations
- National regulations
- Power-supply interruptions
- Punitive measures for unregistered and non-compliant PV installations

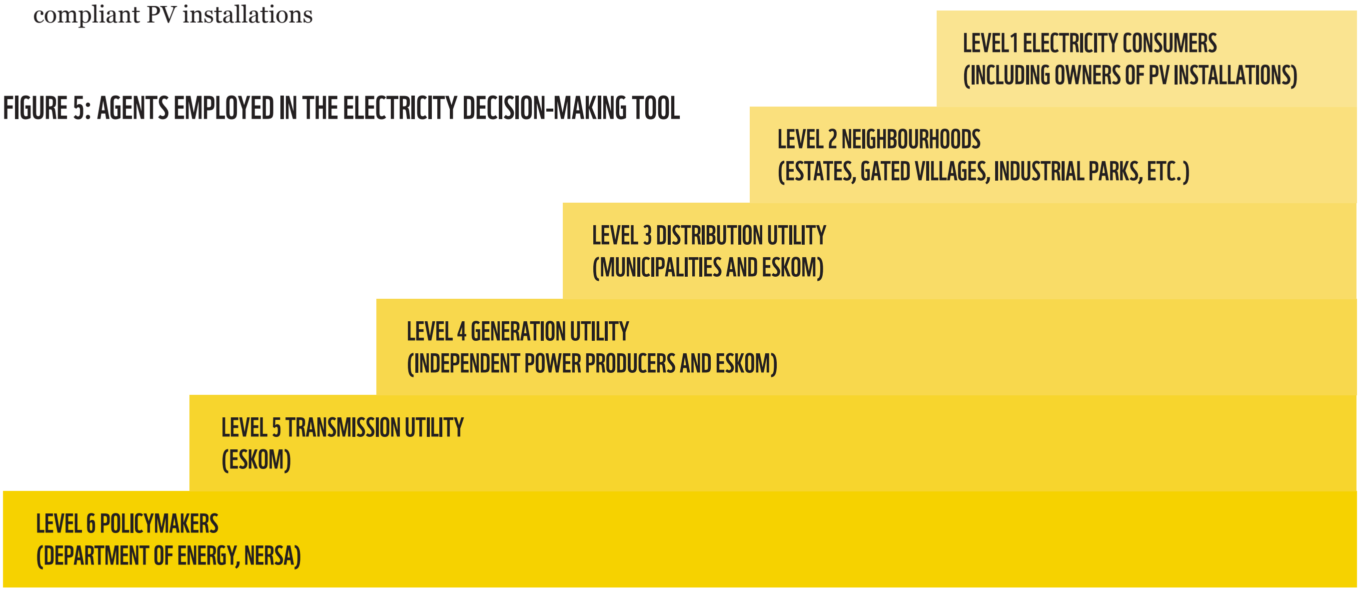
THE TOOL MEASURES THE INFLUENCES ON - AND THE INFLUENCE OF INDIVIDUAL CHOICES ABOUT - ROOFTOP PV

The tool measures the effects these changes have on the system by running different simulations in the model with user-defined inputs to determine likely outcomes (both intended and unintended) of specific policy decisions over time (20 years). It demonstrates the inherent qualities of the system and makes explicit the foundational change from a system controlled by a single agent to one controlled by numerous agents. Given the interactions between the different variables in and emergent properties of the electricity system, the aim of the tool is to enable decision-makers to develop a better understanding of the dynamics of a system that consists of many independent decision-makers, including the policymakers themselves.

The decision-making tool will offer support to policymakers by simplifying and visualising the complex interactive nature of independent decisions by entities in the electricity system. At the same time, it will demonstrate the impact of relevant feedback loops, i.e. the impact of electricity tariffs on the rate of rooftop PV installations, as well as the impact of the rate of rooftop PV installations on future electricity tariffs.

This platform will be of great assistance to decision-makers who have to deal with the dilemmas surrounding PV installations to make the best possible decisions to develop policies that will promote the best possible electricity system – a system that is fair, sustainable, financially viable and technically safe.

FIGURE 5: AGENTS EMPLOYED IN THE ELECTRICITY DECISION-MAKING TOOL



CONCLUSION

While it is obvious that municipalities want the best possible electricity system for all their customers, the recent changes from a linear electricity system to one with multiple actors – brought along by the installation of solar rooftop PV systems by homeowners – has increased complexity by many orders of magnitude. This has made it difficult to maintain an electricity system that is stable, financially viable and responsive to the need to reduce the dependence on fossil-fuel-generated electricity in South Africa.

MUNICIPAL DECISION-MAKERS AND ELECTRICITY CUSTOMERS OFTEN HAVE A VERY DIFFERENT UNDERSTANDING OF THE ECONOMIC, SOCIAL AND TECHNICAL CHALLENGES AND HOW TO RESOLVE THESE

Moreover, the rapid increase of rooftop PV installations opened up a Pandora's box of economic, social and technical challenges that have not yet been resolved. Municipal decision-makers and electricity customers often have a very different understanding of these challenges and their solutions. These differences relate to the nature of the system, electricity pricing and tariffs, as well as the importance of electricity revenue in subsidising electricity provision to indigent households and supporting other municipal services, among others.

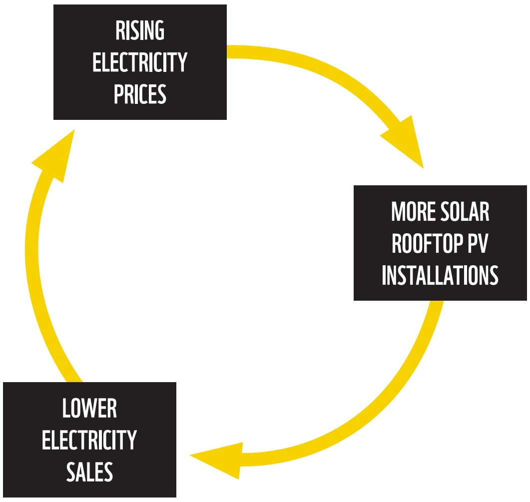
The failure to acknowledge that there is indeed some common ground means that existing perceptions are further entrenched, driving households with PV installations and municipalities further apart. This can lead to suboptimal decisions by both policymakers and households alike.

In an ideal world, all actors would make decisions that support shared or common ground. In this instance, it would be the most stable, fairest and most sustainable electricity system that works not only for households with PV installations, but for everyone.

Municipalities need to improve communication with their electricity customers, and in particular with those with rooftop PV installations. Building a better understanding will also require municipalities and these customers to enter into a conversation to make sense of the multiple feedback loops in the system. An example is the feedback loop of rising electricity prices leading to rooftop PV installations becoming more financially viable, leading to lower electricity sales and increased tariffs, leading to more PV installations (Figure 6). Another example is the increase in the fixed part of the electricity tariff that makes rooftop PV installations less financially viable, leading to more unregistered systems.

Municipalities can use targeted communication as well as appropriate tariff design to influence customer behaviour to support the overall goals

FIGURE 6: CURRENT FEEDBACK LOOP – A STALEMATE



of the electricity system. However, customer behaviour and the aforementioned responses to these tariffs will need to be carefully considered. While some of the drivers for investment in rooftop PV installations are self-evident, responses to new tariffs are sometimes not that well understood.

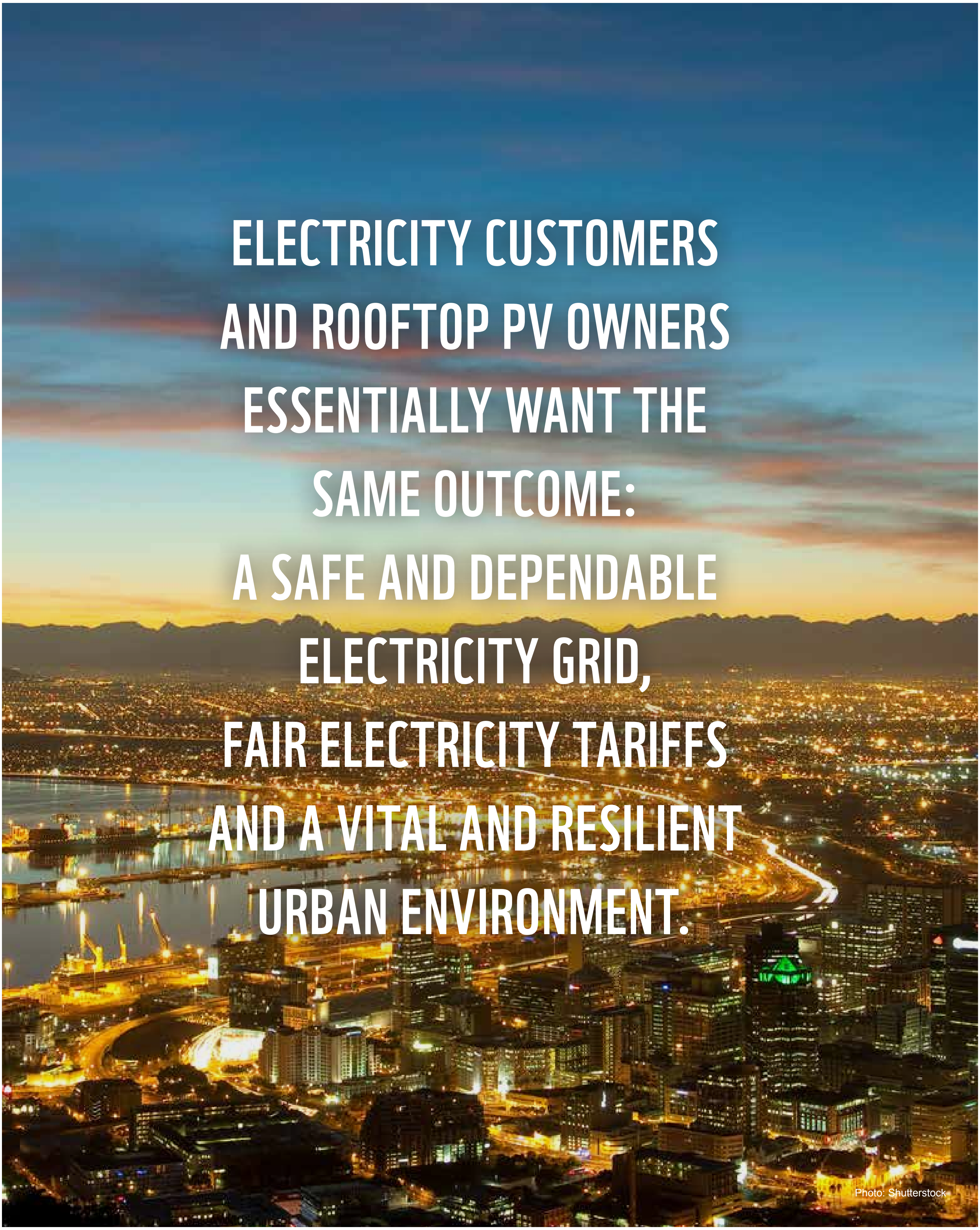
To support municipal officials and policymakers who are dealing with residential rooftop PV installations, a computerised electricity decision-making tool is being developed to navigate the complexity of decision-making in the electricity system.

The decision-making tool will be able to illustrate how the decisions of different agents (e.g. electricity consumers, municipal decision-makers, policymakers), both individually and collectively, affect the electricity system. It will also show how decision-making changes over time as the electricity system changes. The tool can also illustrate how individual choices are influenced by the state of the system and in turn influence the state of the system.

By making the complexity of the system evident, the decision-making tool will enable decision-makers to act in a way that is to the benefit of the whole system. This applies especially to the observation of the emergent properties of the electricity system and the interaction between events that are within the municipality's control, and the ever-changing decisions of their customers.

Endnotes

1 Sections 24 and 152 of the Constitution of the Republic of South Africa, 1996.
2 Especially Goal 7: Affordable and clean energy, and Goal 11: Sustainable cities and communities – see un.org/sustainabledevelopment/sustainable-development-goals
3 The entire electricity provision service includes capital needed for expansion, repairs and call-outs, maintenance, billing services, salaries, other admin costs and the Eskom bill, which is often seen as the only expense.
4 A term derived from "prosumption", meaning "production by consumers".
5 Schedule 4B of the Constitution of the Republic of South Africa, 1996. See also Section 152 Objects of local government in the Constitution:
"(1) The objects of local government are—
(a) …;
(b) to ensure the provision of services to communities in a sustainable manner;"
6 See n 3.
7 Korsten, N., Kritzinger, K. and L. Scholtz. 2018. *Understanding Solar Photovoltaic Investment Decisions in the Residential Sector: Outcomes from the Household Solar Energy Survey*. 26th AMEU Technical Convention held in Pretoria.
8 Solar rooftop PV systems under 100 kWp need to be registered in terms of the relevant municipality's by-laws, whereas those above 100 kWp need to be registered with NERSA. Systems below 1 MW do not need to apply for a generator licence. See Licensing Exemption and Registration Notice in terms of the Electricity Regulation Act 4 of 2006 (GN 402 in *GG* 43151 of 26 March 2020), cer.org.za/wp-content/uploads/2020/03/ERA-Licensing-Exemption-gg43151-2020-GOV_nn402.pdf
9 Korsten et al., 2018 (n 7).
10 Kritzinger, K., Scholtz, L. and N. Korsten. 2019. *Integration of solar energy into the grid: Technical or social challenge? Building a collective vision*. Southern African Solar Energy Conference.
11 Kotzen, K., Raw, B. and P. Atkins. 2014. *Distributed generation in municipal networks: The revenue impact of solar generation*, 2–5.
12 See n 1.
13 WWF. 2019. *Residential investment in rooftop solar PV: What does it hold for the future?* Energy Briefing Paper. wwf.org.za/our_research/publications/?30201/residential-investment-in-solar-pv
14 For more information on household investment decision-making, see WWF, 2019 (n 13).
15 See the Glossary for the explanation of some of the terms.
16 iol.co.za/capeargus/news/outrage-as-cape-town-residents-face-fines-over-unregistered-solar-panels-18279389; businessinsider.co.za/cape-town-fines-residents-r6000-if-they-fail-to-register-their-solar-panel-2018-11#:~:text=The%20DA%2Drun%20City%20of,apply%20to%20solar%20water%20heaters; thesouthafrican.com/news/cape-town-solar-panel-how-to-register; sabcnews.com/sabcnews/c-town-residents-to-register-solar-panels-or-face-penalties; businessinsider.co.za/cape-town-residents-have-four-more-days-to-register-solar-pv-panels-with-the-city-or-else-2019-5
17 AMEU. 2016. *Guideline document to municipalities on the design of a domestic inclining block rate tariff.*



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