Tariff Setting Principles for Hybrid Solar and Storage Embedded Generation Systems

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Abstract

The revenue impact of solar embedded generation is now well understood and many municipalities as well as Eskom are clearly adjusting their tariffs to ensure cost recovery is maintained despite the rapid uptake of solar embedded generation. However, with the ongoing loadshedding, many households and businesses are now opting to install battery storage alongside rooftop solar to ensure energy resilience throughout loadshedding. Because of the improved functionality of lithium-ion batteries, many customers are cycling these batteries daily to arbitrage against utility tariffs and further reduce their utility electricity bill. This is especially financially attractive to customers on time-of-use tariffs, and it will have noteworthy implications for electricity distributors as the load profile of a customer with a hybrid system differs vastly from that of a customer with only solar generation. Drawing on a comprehensive modelling exercise, this paper interrogates the impact of hybrid systems on municipal revenue for a range of battery algorithms. In doing so, we determine tariff setting principles to ensure (i) that customers can maintain their business case for installing hybrid embedded generation systems, and (ii) that municipalities recover the costs of maintaining their grid infrastructure to enable sustainable service delivery.

1. Introduction

Numerous signatories of the "Paris Agreement" from across the globe are incentivising renewable energy generation to achieve their emissions reduction targets. This had led to a massive growth in solar and wind energy generation. Due to its modular nature, solar photovoltaic (PV) systems can be built in multi-megawatt utility-scale solar farms or within a customer's premises, known as embedded generation (EG) as it is embedded within the distribution grid. Continually declining technology costs, alongside continually increasing grid electricity costs, have created a booming market for rooftop solar. The total installed capacity of rooftop solar is estimated to be in excess of a gigawatt.

There has been a growing trend in recent years of customers installing battery storage with their rooftop solar to have backup energy during power outages. South Africa's energy supply crisis (and incessant loadshedding), coupled with the remarkable cost reduction of lithium-ion batteries, has led us to the point where almost every single residential rooftop solar system is installed with storage. However, because of the long lifespan of lithium-ion batteries – typically lasting 10 years or 10 000 cycles – customers discharging their batteries daily to increase solar self-consumption and reduce their grid electricity purchases. As a result, the impact of hybrid solar and storage systems on municipal revenue differs considerably from a customer with only a solar system. Some commercial and industrial customers may also install hybrid solar and storage systems, but this is less common than residential hybrid systems.

As such, this paper investigates the impact of residential hybrid solar and storage systems on municipal revenue and proposes tariff setting principles to ensure revenue is protected while simultaneously ensuring customers continue to have a business case for installing these systems. We do this by providing an overview of the operation of hybrid EG systems. The role of cost of supply studies are highlighted in determining appropriate tariff structures for EG customers. A modelling methodology is described to evaluate the impact of EG on municipal revenue, and a publicly available spreadsheet modelling tool is shared. We then provide a case study analysis of a few municipalities and close by proposing principles for tariff setting for hybrid solar and storage systems.

2. Overview of hybrid solar and storage systems

Due to the feed-in capability of solar PV systems connected to the utility grid, the utility grid can be used as a virtual storage. In recent years, however, low (or zero) utility export credits and power export limits enforced by the grid operator have made it less prudent to feed excess PV power into the utility grid. The deployment of battery energy storage system (BESS) is a viable solution to reduce the end-users' electricity bill and to maximise the self-consumption of onsite generated PV energy [1].

A BESS can generate cost savings in a variety of ways. These include (1) demand load shifting: the BESS is charged with inexpensive off-peak power and discharged during peak hours; (2) PV self-consumption maximization: the BESS is charged with surplus solar power and discharged to reduce the power import from the grid. To maximize the cost benefits of the BESS, it is advocated to combine various value propositions, also known as value stacking. The typical value stacking of hybrid solar and storage systems in South Africa is (1) provide backup during loadshedding, and (2) maximise PV self-consumption. BESS can also be advantageous for the provision of ancillary services, such as frequency control and operating reserves (spinning and non-spinning) but extracting this value requires a market for these services [2] which South Africa is yet to establish.

To understand how hybrid solar and storage systems impact utility revenue, we must first establish how the systems operate. The systems are managed by a hybrid inverter, sometimes called the "brains" of the system. The inverter manages the generation and storage to supply the household loads, and it draws on the utility grid when required. The typical algorithm of hybrid inverters is as follows:

- If solar power is available:
    - Priority 1: supply the household load with solar
    - Priority 2: if households loads are supplied and excess solar power is available, charge the battery
    - Priority 3: if household loads are supplied and battery is fully charged, export into the grid
- If no solar power is available:
    - Priority 4: discharge battery to supply the household loads (owners typically set the inverter to keep reserve storage in case of loadshedding, so batteries will discharge to say 40% and then stop discharging)
    - Priority 5: if batteries are empty, draw power from the grid

To illustrate a hybrid system operation, consider Figure 1 below and note the following:

- 0h00-06h00: Entire household load is supplied by the utility
- 06h00-14h00: Solar power supplies household load, battery is charging, utility sees no load
- 14h00-18h00: Battery is fully charged and systems exports into the utility grid
- 18h00-23h00: Battery discharges to supply household load, utility sees no load
- 23h00-06h00: Battery is empty and entire household load is supplied by the utility

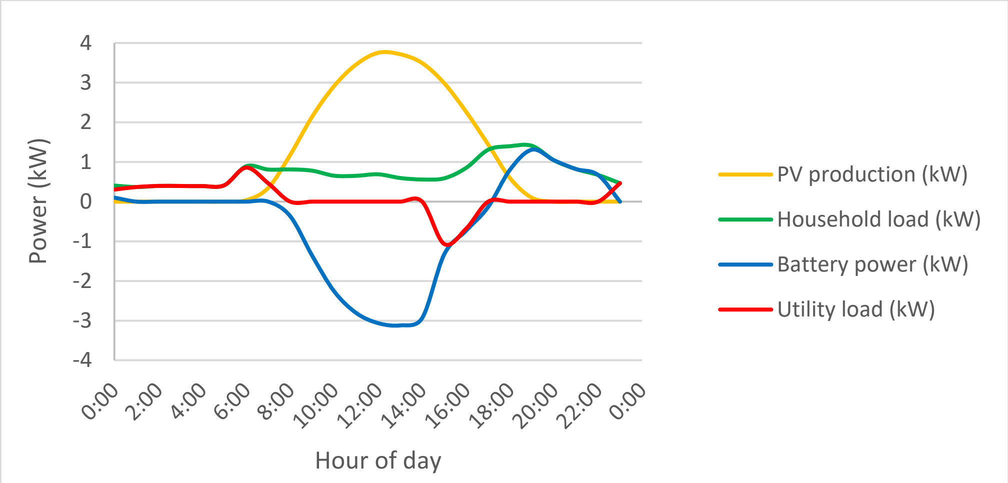

Figure 1: Typical residential hybrid solar and storage system load profile

Key observations:

1. This graph illustrates a sunny summer day when solar generation is high. On cloudy days, the system will draw more from the utility grid.
2. The system only draws from the utility late into the evening once the battery is fully discharged. Solar only systems draw from the grid as soon as the sun sets, whereas hybrid systems can draw on the battery for several hours after the sun sets.
3. Exports into the utility grid only occur in the late afternoon once the battery is fully charges, whereas solar only systems export into the grid as soon as solar output exceeds household loads.

Consider the difference in load profile of a normal residential customer (green line of Figure 1) compared to a customer with a hybrid solar and storage system (red line on Figure 1). The changing pattern of electricity consumption brought about by hybrid systems requires utilities to re-evaluate the way tariffs are set for these customers.

Utilities should not penalise customers with hybrid systems, but rather incentivise customers to install these systems while finding smart ways to recover utility costs.

3. Cost of supply studies

A Cost of Supply (COS) study informs the design of electricity tariffs that are implemented to provide the service required by customers and recover costs incurred by licensees [3]. The objective of the COS study is to apportion all costs required to service customers amongst each customer class in a fair and equitable manner.

All customers within the distribution network must pay for their contribution to the utility costs. A cost of supply study is essential to quantify these costs and design rates that will ensure full recovery of costs incurred [4]. There are fixed costs the utility needs to recover every month and variable costs that are dependent on the energy consumption of customers. Fixed costs are costs that stay constant regardless of output volume and are primarily related to capital expenditures. Fixed costs consist of investment-related costs such as return and taxes, as well as some operation and maintenance expenses such as labour and administrative expenses [5]. Variable costs are expenses that change with output volume. Primarily, variable expenditures consist of fuel costs. Variable expenses include the non-labour element of certain O&M expense items, such as materials and supplies.

Because of their reduced energy consumption, customers with EG may reduce their contribution to the variable energy costs of the utility and should see a commensurate reduction in their utility bills.

However, they contribute equally to the fixed costs of the utility as non-EG customers and must contribute to these costs for the sustainability of the utility [6]. The main challenge with most South African municipalities is that they do not have cost reflective tariffs that have been informed by COS studies. Costs that should be recovered through fixed monthly charges are currently being recovered through a variable kWh charge. With the increased uptake of EG, municipalities may see less volumes of energy being sold to their customers and the bundled R/kWh charge is proving unsustainable and exposing these municipalities to volume risk. It is therefore integral that municipalities conduct COS studies in order to unbundle rates to ensure fixed charges are fully recovered from all customers within their supply areas.

COS studies require the collection and analysis of data and the keeping of proper accounting and asset records. NERSA has identified that municipalities are not submitting compliant COS studies include the following[5]:

- Updating physical asset registers with asset replacement costs, useful lives and depreciated replacement costs.
- General ledger accounts do not reflect correct data e.g. incorrect units (kVA, Rands, kWhs etc.) used when capturing data.
- Inactive meters are included in the determination of customer service and billing costs.
- Lack of capacity and financial muscle to appoint consultants
- High municipal staff turnover
- Poor advice from service providers

It is quite evident that there are many issues that are hindering the completion of compliant COS studies in South African municipalities. However, without being oblivious to external hindrances, municipalities must find ways to develop indicative studies and unbundle tariffs. The uptake of EG is happening at a fast rate and municipalities must react at the same speed with cost reflective tariffs for their customers.

3.1. Recommended tariff structure for EG customers with storage

The recommended tariff structure for EG customers with storage is no different from EG customers without storage:

EG customer bill = Basic Charge (R/month) + Energy Charge (R/kWh) – Export Credit (R/kWh)

As established in section 2, the presence of storage alongside EG enables customers to self-consume a higher percentage of their EG generation. This means that the utility is likely to sell less energy to customers that have EG with storage. Secondly, because excess solar energy is used to charge batteries, storage means that customers are less likely to export electricity into the utility grid. As such, the presence of storage further exacerbates the volume risk associated with normal EG. The rapid uptake of storage is heightening the urgency to move customers onto a tariff with a fixed component and an export component.

3.2. Export Credit Calculator

The export credit that a municipality offers to its customers for feeding into the grid has a significant impact on customer perceptions around EG. Municipalities with a higher export credit generally find that their customers are more willing to follow municipal registration processes. As such, by offering a generous export credit, municipalities can go a long way towards obtaining the buy in of their customer base.

The Electricity Pricing Policy (EPP) states that export credits should be informed by the avoided purchase costs of the utility. What this means is that when a EG customer feeds into the grid, and the utility receives a kWh of energy to on-sell to its other customers, the utility must determine what it would have paid for that unit of energy had it purchased it from the wholesale market. While the principle of avoided costs is clear in the EPP, NERSA is currently not approving export credits, saying that “NERSA lacks both statutory and regulatory jurisdictions over the proposed activity between municipalities and EG customers”. As such, municipalities only need to obtain Council approval in order to implement an export credit.

To calculate the avoided costs, an export credit calculator has been developed[1]. For customers on a time-of-use (TOU) tariff, calculating the avoided costs is straightforward as it is simply the utility's wholesale TOU purchase price, i.e. Megaflex. The EPP recommends that all EG customers be on a TOU tariff and that export credits be done on a TOU basis. However, many municipalities are still implementing flat EG tariffs, especially for residential customers with limited metering infrastructure. As such, determining the weighted average avoided purchase cost is of relevance when implementing a flat export credit. A flat export credit should be informed by the weighted average solar PV output across the TOU periods, along with the wholesale energy price in each of the TOU periods. The principle is that solar EG customers can only feed electricity into the grid when the sun is shining, so they should only be compensated to the value of what energy is worth to the municipality at this time of day

Table 1 shows a typical solar PV output per TOU period as a percentage of total annual generation. These percentages were informed by using the irradiance across 16 locations in South Africa for the 2021 calendar year (including public holidays). The weighted average avoided purchase cost can then be calculated by taking the sum-product of these values. The below table is populated using the Megaflex purchase price of a municipality in the Western Cape and the weighted average avoided purchase cost is calculated as 122,6 c/kWh.

Table 1: Proposed Export Credit Calculation Approach

	Megaflex (c/kWh)	Typical solar PV output per TOU
Low Season Offpeak	66,57	19%
Low Season Standard	104,90	46%
Low Season Peak	152,42	12%
High Season Offpeak	76,89	5%
High Season Standard	141,57	15%
High Season Peak	467,25	2%
Weighted Average Avoided Purchase Costs (c/kWh)		**112,66**

So, for each unit of energy that an EG customer feeds into this municipality's grid, the municipality will see an average reduction in its Eskom account of R1,12. The municipality may want to set an export credit slightly lower than this figure in order to create a new revenue stream based on the cost savings. Municipalities often implement export credits in the range of 80-90% of their avoided purchase costs. More advanced avoided purchase cost calculations can also consider the reduction in technical losses associated with exported energy into the distribution grid. This further increases the avoided purchase cost and shows that exported energy has an even higher value to municipalities than the figures above.

4. Determining the Financial Impact of EG with Storage

The case study was performed using the excel-based SSEG Tariff Tool[2] which (1) measures the proposed EG tariffs and battery energy storage on municipal finances; and (2) evaluates the business case for customers who have installed EG systems with storage based on the municipality's EG tariffs.

Figure 2 illustrates the basic architecture of the model. Overall impact on municipal finances considers both the reduction in revenue (from EG and storage) as well as the associated decrease in costs. Revenue is reduced because of (i) reduction in sales volume to EG customers that are self-consuming, and (ii) the payments from the municipality to customers for exported electricity. At the same time the municipality's costs decrease because of (i) a reduction in bulk power purchases from Eskom, (ii) a reduction in technical losses from these purchases, and (iii) cheaper electricity from EG customers can

[1] The avoided cost calculator is freely available: https://www.sseg.org.za/avoided-costs-calculator-tool/
[2] The SSEG tariff tool is freely available: https://www.sseg.org.za/sseg-tariff-excel-tool/

be sold to other customers, the margin between the Eskom tariff and the EG tariff constitutes a cost saving.

Grid support benefits of BESS such as reduction or shifting of peak demand, improving efficiency and reliability of the distribution system, lowering of grid infrastructure costs and provision of ancillary services were not analysed in the modelling. Similarly, the additional costs of administration for EG billing, the potential grid upgrades to host EG, and the personnel time to process EG applications were not considered. Only the changing patterns of energy flow and the associated impacts on energy charges are modelled.

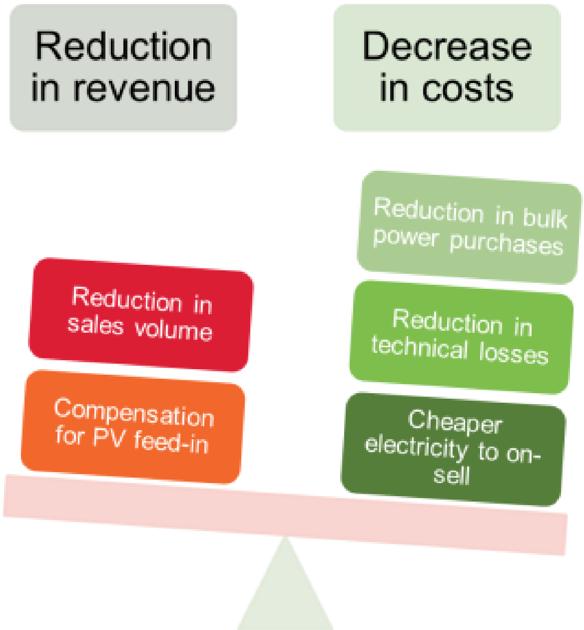

Figure 2 Architecture of the financial impact model

Calculating the reduction in municipal revenue requires the calculation of municipal revenue before and after implementation of EG tariffs and BESS. The model does these calculations for one representative customer before consolidating the bills to determine its total revenue.

In order to calculate the decrease in revenue resulting from EG tariff and BESS, the difference between the total revenue per annum prior to the introduction of EG tariffs and BESS, and the total revenue per annum from the whole population after the implementation of EG tariffs and BESS. The latter is the sum of the revenue from solar PV customers and the revenue from non-PV customers. The difference for a selection of uptake percentages of solar PV i.e. 1%, 5%, 10% or 20% of customers on the given municipal tariff was calculated.

The Value of Solar (VOS) components of the model were calculated as follows:

- *Reduction in bulk power purchases*. For each uptake scenario (i.e. 1%, 5%, 10% or 20%) the model determines how much electricity is produced by solar PV customers (for self-consumption and export to the grid). This is the amount by which the municipality is able to reduce their purchases from Eskom. The value of this electricity is determined by TOU period, and this is a cost saving for the municipality.
- *Reduction in technical losses*. Because the municipalities bulk power purchases from Eskom are reduced, the technical losses will be reduced as well. This calculation is simply the assumed percentage of technical losses for each customer category multiplied by the rand value of the savings in bulk power purchases for the municipality.
- *Cost savings from reselling exported electricity from EG customers*. The model assumes that all excess electricity generated by solar PV customers fed on the grid and then sold by the

municipality to other customers. Because the export tariff should be lower than the tariff paid by the municipalities to Eskom, the difference between these two tariffs represents a saving to the municipality. The model calculates this by determining the difference between the bulk power purchase tariff and the export tariff for each TOU period and then multiplying the amount of electricity feed onto the grid (in each TOU period) by this margin.

The value of solar is calculated as follows:

VOS = RB+RT+XP

Where:

RB = Reduction in Bulk Purchases

RT = Reduction in Technical losses

XP = Cost savings from reselling exported electricity from EG customers

4.1. Case Studies of South African Municipalities

Export credits were calculated for residential customers in two Metropolitan Municipalities and two Local Municipalities. The customers had fixed monthly charges (R/m), a variable energy charges (R/kWh) and one municipality had a monthly demand charge (R/kVA). It was assumed charges are cost reflective. The variable export energy charge (c/kWh) was calculated as Megaflex tariff less 20%. It is proposed that all EG customers be on Time-of-Use tariffs like the Eskom Megaflex tariff but the modelling also analysed customers with flat tariffs as shown in **Error! Reference source not found.** below. The disadvantage with the flat EG export credits is that during off-peak, the municipality would be purchasing energy at higher rates than Eskom Megaflex. See **Error! Reference source not found.** for Eskom Megaflex tariffs.

Table 2 Residential EG Export Credits

Type of Tariff			Export Tariff:			
Residential Customers			Metro 1	Secondary City 1	Metro 2	Secondary City 2
TOU, IBT or flat			TOU	FLAT	TOU	TOU
Summer	Fixed monthly charge	R/m	739,35	1 680,00	164,67	348,91
	Monthly demand charge	R/kVA		-	-	16,81
	Peak	c/KWh	108,74	73,22	108,74	108,74
	Standard	c/KWh	74,85	73,22	74,85	74,85
	Off-peak	c/KWh	47,47	73,22	47,47	47,47
Winter	Fixed monthly charge	R/m	739,35	1 680,00	164,67	348,91
	Monthly demand charge	R/kVA	-	-	-	16,81
	Peak	c/KWh	333,31	213,00	333,31	108,74
	Standard	c/KWh	100,97	174,03	100,97	74,85
	Off-peak	c/KWh	54,84	174,03	54,84	47,47

4.2. Revenue Impact of customers with reverse feed blocking

Figure 3 below illustrate the revenue impact of customers with EG installations but reverse feed blocking. All solar energy is self-consumed, which reduces the energy purchased from the municipality and ultimately reducing the municipal revenue. We see a less than 1.5% decrease in revenue for each customer category in all municipalities because the value of solar (VOS) to the municipality is slightly less than the reduction in municipal revenue. The higher the uptake of EG, the bigger the gap between the reduction in municipal revenue and value of solar (VOS).

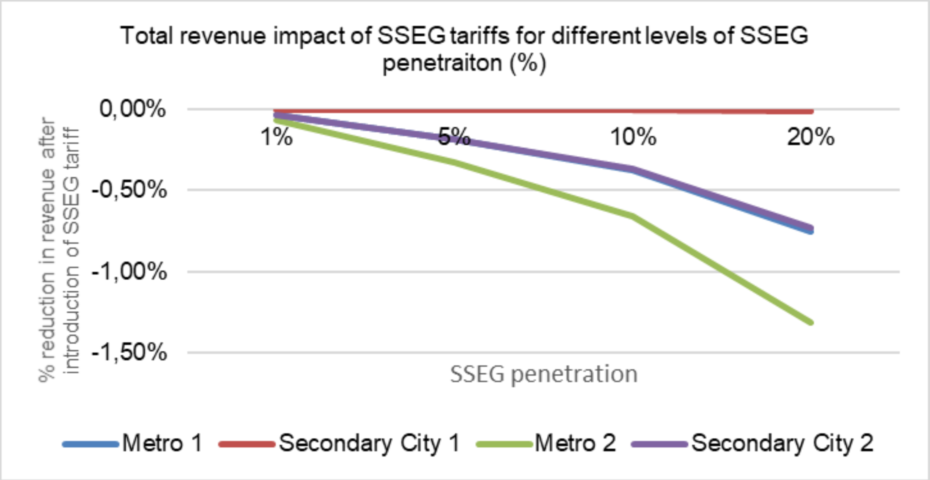

Figure 3 Revenue Impact of reverse feed blocking

4.3. Revenue Impact of customers with EG Tariffs

When the municipalities allow reverse power feed onto the distribution grid from EG customers and have unbundled cost reflective tariffs, the value of solar starts to significantly exceed the reduction in municipal revenue. This increase in the value of solar is based on the municipality purchasing exported energy from EG customers and reselling at a price that is 20% less of Megaflex prices. Residential customers are expected to export more during solar generation hours because the residential load profiles show the peak of these customers to be outside the PV generation hours. Figure 4 illustrates the positive effects of purchasing energy from EG customers and reselling to customers. For large businesses or industrial customers, there would hardly be a positive revenue impact before and after allowing reverse feed. This is because all energy generated is produced on site and no excess power is feed onto the grid (except on weekends or public holidays).

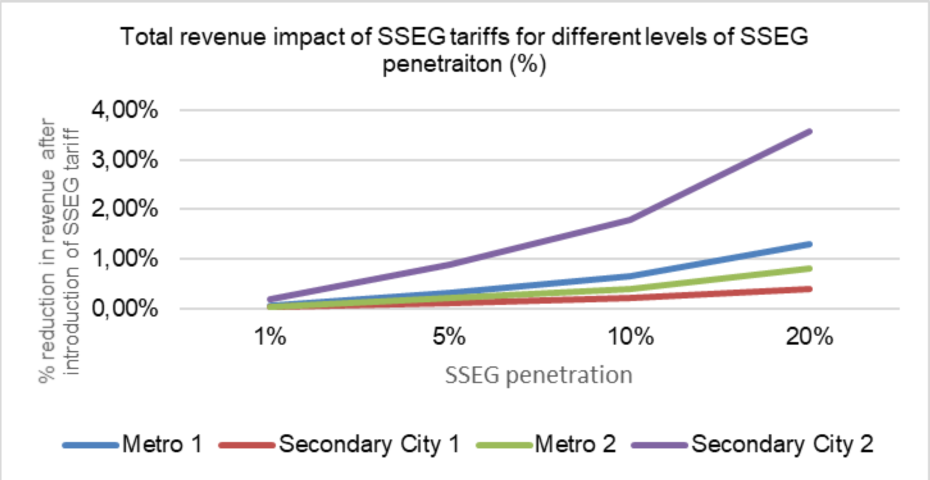

Figure 4: Revenue Impact of purchasing export power from EG customers

4.4. Revenue Impact of customers with EG Tariffs and BESS

We then investigate what would happen if all the excess solar power is not exported to grid but stored for times during the day when solar generation is unavailable (night time and mornings). Because residential peaks occur when solar generation is not available, these customers are automatically using batteries for price arbitrage. They charge the batteries during the day with solar PV excess power and discharge the batteries during peak hours when TOU tariffs are highest. Figure 5 shows that if EG customers install BESS, the municipality may see less kWh volumes being sold to these customers.

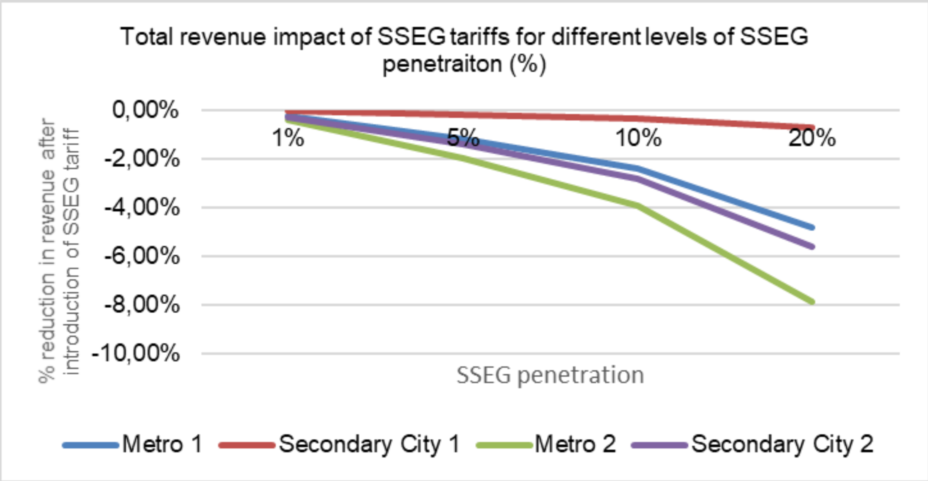

Figure 5: Revenue impact of EG customers with BESS

5. Conclusions

5.1. Cost of Supply Studies and EG Tariffs

With the rapid uptake of EG, it is important that municipalities unbundle their tariffs to adequately recover fixed costs and variable costs. Once costs are known and unbundled, municipalities can then set EG tariffs that are cost reflective and will not expose the municipalities to revenue risks. However, most municipalities in South Africa do not have Cost of Supply studies in place and are recovering fixed costs through variable charges. There is evidence in the case studies that EG with storage systems further reduce the kWh volumes sold by municipalities to their customers. Without unbundled cost reflective charges, revenue required to cater for fixed costs may not be sufficiently recovered. For utility sustainability, it is time to start thinking about ToU tariffs for all customer categories to fully benefit from exported energy from EG installations.

What is also quite evident in the case study is that blocking reverse feed in not beneficial to the municipality. There is opportunity to reduce bulk purchase costs by purchasing energy at a cheaper price from EG prosumers. Municipalities should allow prosumers to export excess energy on to their distribution grids and have export credits that are attractive. Export credits are also motivators to EG customers to register their EG installations with the municipalities and that helps the municipality to take account of all EG installations within its distribution network. This accounting of EG installations ensures that no technical violations which may cause safety and reliability risks are present in the networks.

5.2. Revenue Impact of EG Tariffs and BESS

Although BESS systems are still expensive, there is certainty that these prices will drop in the near future and these systems will play a significant part in municipal distribution networks. This foresight is what prompted the need to investigate these future scenarios and what they mean for utility sustainability. The modelling results show that municipalities are bound to sell less kWh volumes and generate less revenue as more customers install hybrid solar and BESS systems. All the energy that would be exported would now be stored in BESS for consumption when the sun is not available or for price arbitrage. With cost reflective tariffs, one can argue that municipalities will still remain sustainable because they will manage to cover their month-to-month fixed costs. This argument is strong in municipalities that have ring-fenced electricity departments and in countries of low inequality. A decrease in electricity revenue for South African municipalities means that there is a sustainability risk. Electricity revenue is often used for operations outside the electricity department and cross-subsidization. With the increasing poverty and unemployment in South African communities, municipalities are faced with the risk of providing services to customers who have no means of paying. The customers with the highest buying power will rely less and less on the municipalities for electricity services due to EG and BESS. Municipalities need to start ringfencing services departments and cross-subsidies should be factored into fixed charges to customers.

The model assumes all customers will act in a coordinated manner and does not investigate the financial impacts of ancillary services and other technical benefits BESS might offer the municipality. Additionally, customers may apply value stacking and reduce municipal revenue even more. Future iterations of the study will analyse these factors and see if BESS will certainly cause revenue risks for South African municipalities.

Acknowledgement

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