Defection vs Connection – Exploring the costs of true grid defection and the benefits of remaining connected to the grid.

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Abstract:

The last ten years have seen a rapid increase in the adoption of solar PV installations in the residential and commercial sectors. South Africa's high solar irradiance and the decreasing costs of solar and battery storage, coupled with ongoing load-shedding have encouraged the investment in solar energy. The growth of residential and commercial solar has raised concerns of 'grid-defection', where customers entirely disconnect from the municipal utility's grid and rely instead on the combination of solar power and battery storage to meet their energy needs.

True grid defection threatens the revenue of municipal electricity distributors, which is vital for providing reliable network services to customers. The growing need for utilities to introduce fixed capacity charges to recover fixed network costs strengthens the business case for grid defection. This threat may require municipalities to consider how best to charge the full cost of network services, reflecting the grid's true value, whilst retaining customers.

This paper presents the findings of a comprehensive modelling exercise that investigates the real cost of going off grid, and, consequently, the likelihood of grid-defection for residential and commercial customers. The data revealed that grid defection is unlikely due to the cost of batteries, with grid only electricity and hybrid solar PV systems providing much more attractive business cases. Despite the current low likelihood of grid defection high fixed charges and/or low grid reliability have the potential to encourage residents and businesses to defect from the grid. Thus, it is important that sustainable grid management and correct tariff design remain a priority in the coming years.

1. Introduction

The last ten years have seen a rapid increase in the adoption of solar PV installations in the residential and commercial sectors. South Africa's high solar irradiance and the decreasing costs of solar and battery storage technology make investing in solar energy an increasingly attractive investment. Furthermore, load-shedding in South Africa has significantly increased solar energy's popularity as residents and businesses seek reliable and sustainable power alternatives to frequent electricity outages. The increase in the installation of solar PV has the potential to improve grid resilience by decentralizing power generation, thereby reducing strain on the national grid and enhancing overall energy security in the country.

Despite solar PV's noteworthy benefits, the way it is integrated into the South African energy mix is of the utmost importance. The reduction in electricity sales from commercial and residential customers poses a potential threat to municipal distributors who rely on this revenue to provide essential electrical services to their customers. Municipal electricity distributors use the revenue generated from electricity sales to upgrade and maintain municipal electricity infrastructure as well as to provide electricity to poor households. As electricity sales decline, the share of municipal cost recovery is shifted on non-solar customers.

The risk of municipal revenue under-recovery is most pronounced when the business case for solar reaches a point where customers opt to defect from the grid, commonly referred to as going 'off-grid'. The municipal revenue loss associated with grid defection can lead to increased tariffs for the remaining grid-connected customers which could convince more customers to defect, further escalating electricity costs. This phenomenon is known as the "utility death spiral".

The notion of going 'off-grid' is has become increasingly popular globally and South Africa is no exception. This paper investigates both the residential and commercial business cases for true grid defection compared to that of a grid only and hybrid supply models. The exploration, drawing on a Days of Autonomy (DOA) approach, considers the economic efficiency of such investments and discusses how best to ensure optimal sector investment in the context of tariff setting and utility management.

2. Methodology and Scope

2.1. Research Design

Grid defection occurs when customers entirely disconnect from the municipal utility's grid and rely instead on the combination of solar power, battery storage and fuel-powered generators to meet all their energy needs. This study employs a quantitative research design to compare the costs of three energy systems—off-grid, hybrid, and grid-only—using the Net Present Value (NPV) approach over a 20-year period. The analysis will be conducted in two distinct geographical locations in South Africa, using typical monthly electricity consumption data for three scenarios: a typical residential household, a small office, and a medium sized mall. By examining these distinct consumer types, the study aims to provide a comprehensive comparison of long-term costs associated with each energy system under different consumption patterns and scales of operation.

The definitions of the three energy scenarios are listed below:

- Off-grid - These systems are completely independent of the main electricity grid and rely on self-generated power, typically from solar panels and generators, combined with batteries for storage.
- Grid-only – Power is supplied by the main electricity grid and there is no storage or self-generation

- Hybrid - Hybrid systems combine grid connection with self-generation and battery storage.

In order to investigate the likelihood of true grid-defection, this study uses the off-grid consumer's desired 'days of autonomy'. Days of autonomy (DOA) refers to the number of days the battery bank in a standalone PV system can solely provide power backup for the load connected to the system without being recharged.

2.2. Data and Assumptions

2.2.1 Electricity Consumption Profiles

Electricity consumption patterns vary considerably from one consumer to the next and designing a solar PV system for a consumer requires accurate consumption data. For the purposes of this study, approximate 'typical' consumption values are used to give an indication of the costs associated with different power supply strategies across the customer types[1]. The assumed monthly consumption values are listed in Table 1.

Table 1: Typical sizes and monthly energy consumption of different property types.

Property Type	**Gross Leasable Area (m^2)**	**Energy consumption**
Residential	*n/a*	*1200 kWh/month*
Commercial – Small Office	*175*	*20-30 kWh/m^2/month*
Commercial – Regional Mall	*65000*	*200-500 kWh/m^2/month*

When designing solar PV systems, the consumer's load profile influences the system size as properties that consume electricity in non-peak sun hours will have to rely on alternate sources of energy such as battery storage or grid back-up. For simplicity, this study uses monthly consumption values associated with typical load profiles per customer type in the calculations.

2.2.2 Regional Sunlight Hours, Climate and Reliability

Since most of South Africa has an annual average of at least five peak sun hours, this study uses five peak sun hours in all solar PV system calculations. (More detail about South Africa's solar irradiation and climatic zones is featured in Appendix A). In order to design an off-grid solar PV system the DOA must first be determined. The DOA is closely linked to local climate as the likelihood of consecutive days without sun influences the size of the battery bank. Higher probabilities of consecutive days without sun demand a larger and more robust solar PV system to ensure reliable power supply.

This study considers the consecutive days without sunshine for two large towns situated in the south-western and central/eastern climatic zones, namely Paarl and Mbombela. In both cases, the rainy season presents the highest likelihood of consecutive days without sunshine and thus provides the basis for determining the DOA for a solar PV system. Data from the South African

[1] The study assumed that residential customers that would consider investing in a full off-grid system would tend to be high power users and would consume 1200kWh per month. In the case of small office and a regional mall, the industry standard is to use the gross leasable area (GLA) to determine the energy consumption per square meter per month. In keeping with values from SANS 10400-XA V1, this study assumes that a small office should consume 20-30 kWh/m^2/month and a mall's consumption would range from 200-500 kWh/m^2/month. Furthermore, this study uses generic GLA values for a typical small office and a regional mall.

Weather Service was utilized to estimate the general probabilities of consecutive sunless days during the rainy season in each zone.

Table 2: Probabilities of consecutive days without sun.

Days with no sun	**0,5**	**1**	**2**	**3**	**4+**
Paarl Probability	85%	35%	15%	8%	3%
Mbombela Probability	60%	15%	8%	3%	0%

The probabilities in Table 2 were used to design off-grid solar systems for each town.

2.2.3 Grid-Only Power Supply

Typical South African *residential* electricity tariffs comprise of an energy charge (c/kWh) and occasionally a fixed component (R/month). Many municipalities have not yet introduced a fixed charge and rely only on volumetric energy charge. This study assumes two distinct scenarios for a residential customer that is only connected to the local distribution grid: the first scenario is a grid only charge without a fixed component that resembles a typical municipal rate (R2.87/kWh); the second scenario uses the same energy rate and a fixed charge of R100 per month residential customers. For commercial customers the study uses the same energy charge as residential and assumes fixed charges of R1200 per month small offices and R2500 per month for malls. For simplicity's sake this study does not include time-of-use or inclining block tariffs (IBT) and instead uses a flat rate. The study assumes an annual tariff escalation of 10% for the energy charge and 9% for the fixed component[2]. Moreover, this study ignored the possible changing ratio of fixed to energy charges[3].

2.2.4 Solar PV System Sizing Methodology

The methodology employed to design a solar PV system, whether hybrid or off-grid, involves sizing the capacity of the system to cater to a specified energy demand. System sizing in the model is based on typically energy consumption per customer type (kWh/day or month), local solar irradiance and required days of autonomy, as well as other localised considerations. The system's components—solar panels, inverters, and battery storage (for off-grid or hybrid systems)—are then sized to meet the energy demand, solar resource, and desired autonomy and costing is based on industry standards[4]. Table 3 lists the costs of solar PV system components.

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[2] The tariff escalation rate is drawn from tariff trajectory work underway in the sector and were considered defensible. The model can of course be run using a range to test sensitivity to this key input.
[3] Eskom has indicated that currently their wholesale tariffs are 40:60 fixed: variable ratio and the real ratio would be 60:40; with this tipping towards an even greater fixed component in the future.
[4] Standard costs for components were checked with industry players including SunCybernetics and Solink.

Table 3: Costs of solar PV system components.

Component	**Cost**
PV Panels	R8 per Wp
Inverter	R2000 – R5000 per kW
Batteries	R5000 – R6000 per kWh
BOS (Balance of system components)	10% of total cost
Installation	10% of total cost
Operation & Maintenance	1% of total cost per annum

2.2.5 Off-Grid and Hybrid Systems

The off-grid systems used in this study were designed using the assumptions stated in the previous sections and an assumed DOA of two days. Since system sizes can vary considerably, this study uses both a conservative cost estimate and an unconstrained cost estimate to provide a range of off-grid system costs.

Hybrid systems were designed to have six hours of battery backup (for stage 4 load shed reliability) and then to use grid supplied electricity thereafter. The tariff used by a hybrid consumer was assumed to comprise of a fixed charge and an energy charge as well as a feed-in tariff (or export credit). For this study, the feed-in tariff is set to R1.00, based on the approach of setting the rate at around 80% of Eskom Megaflex. In terms of the amount of energy exported back to the grid, it was assumed the consumer would consume 95% of the energy produced by the solar PV system and only export the remaining 5%.

2.2.6 The Role of Liquid Fuel Generators

Diesel or petrol generators are a popular alternative power source to the grid to counter lack of grid reliability and are commonly used in both residential and commercial settings. Generators have considerably lower upfront capital costs when compared to solar PV systems however they are more expensive to run, and the running costs fluctuate according to fuel prices.

Due to the increased complexity that generators add to power supply mix of off-grid and hybrid power systems they are excluded from this study: generators are typically designed to supply power for relatively short periods of time and prolonged use tends to be very costly due to fuel costs and wear on the machine; they also have much shorter lifespans than solar PV systems and as such their replacement costs need to be considered when investing.

2.2.7 Net Present Value Calculations

To compare the three unique energy supply options, the study uses each option's net present value of a twenty-year period. The NPV of an investment is the way to calculate the value of the investment over time. The NPV is sum of all future cash flows over the investment's lifetime, discounted to the present value.

This study assumes a discount rate of 10% per year as well as interest on a loan for the initial solar PV system capital cost of 15%.

3. Results and Analysis

3.1. The Cost of Reliability for Off-Grid Systems

3.1.1. Consecutive days without sun

To design an off-grid solar PV system, the required DOA must first be determined. In terms of a solar PV system, reliability refers to the system's ability to consistently generate and supply the required amount of electricity under varying conditions, such as changes in sunlight, weather, and seasonal variations. A reliable solar PV system ensures minimal disruptions in power availability, even during periods of low solar radiation, by incorporating adequate energy storage and system capacity to meet energy demands consistently over time. Reliability is directly linked to DOA and can be established by considering the likelihood of consecutive days without sun. Figure 1 plots the plots the probabilities of consecutive days without sun (as per section 2.2.2) for Paarl and Mbombela.

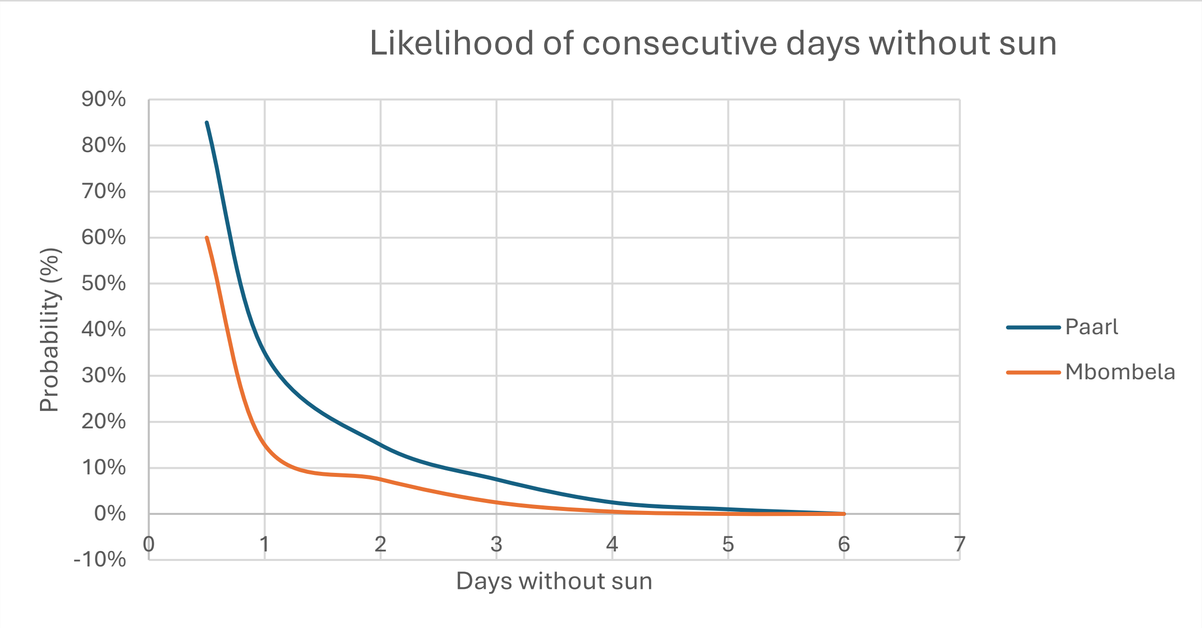

Figure 1: Likelihood of consecutive days without sun for Paarl and Mbombela.

As Figure 1 illustrates, in both cases the likelihood of two and three consecutive days without sunshine is low but still significant and would need to be considered when designing for the reliability of an off-grid solar PV system.

3.1.2. The Cost of Reliability

The reliability of an off-grid system stems from the system's ability to provide power when there is no sunlight available. Typically, power in low-to-no light situations is provided by batteries that were charged during sunlight hours. The longer a system is required to last without sun, the greater the number of batteries are required. As the number of batteries increases, so do the costs of the system. In essence the customer is paying for *reliability* and not energy. Figure 2 illustrates how the cost of an off-grid system increases in response to an increase in reliability.

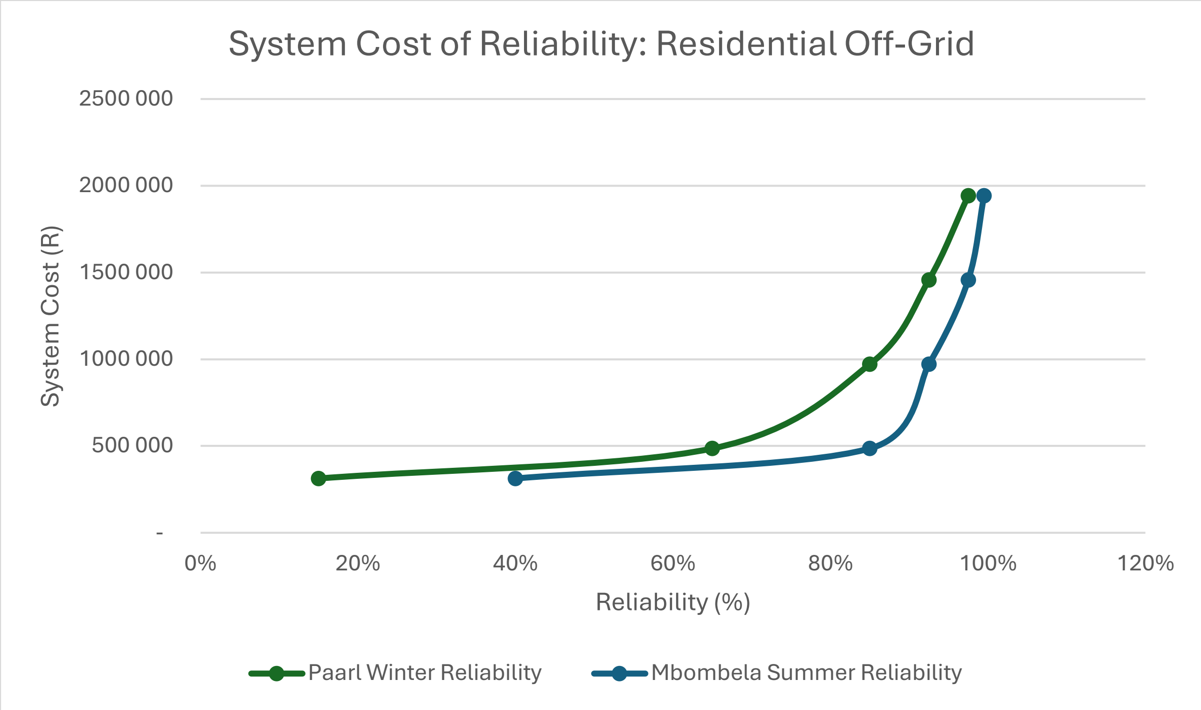

Figure 2: Curve showing the cost of increasing reliability for residential off-grid solar PV systems in Paarl and Mbombela

As Figure 2 illustrates, the cost of a residential solar PV system increases exponentially as desired reliability increases. The cost of a system designed to provide two days of cover is double that on a system designed for one DOA. Furthermore, in Paarl's case increasing the reliability of a system from 85% to 93% cost approximately the same amount as increasing the reliability from 65% to 85%. However, what also stands out is that in Mbombela, it is relatively cost effective to achieve an 85% reliability.

This results broadly highlight how the cost of off-grid systems increase hugely as the system's reliability nears 100%. Although Figure 2 is an example of a residential system, the same trend is true for commercial spaces, except the costs involved are far larger. In essence, this means that a consumer who values reliability will have to incur much greater costs to provide cover for a weather event that occurs very seldom.

3.2. Power Supply Cost Comparisons

This section assumes that a consumer is designing an off-grid system with two days of autonomy and compares the costs thereof to grid only and hybrid power supply scenarios with equal power consumption (bearing in mind that 2 DOA provides different levels of reliability in Paarl and Mbombela respectively).

Table 4 shows the total system costs for hybrid and off-grid systems based on the cost and energy usage assumptions discussed in section 2.

Table 4: Cost ranges for hybrid and off-grid solar PV systems for various consumer types.

System Type	Residential	Commercial – Small Office	Commercial – Regional Mall
Hybrid	R200 000 – R250 000	R800 000 - R900 000	R 100 - R400 million
Off-grid	R350 000 - R700 000	R 1 – 1.4 million	R 15 billion

3.2.1. Residential Consumer

The cost comparison of three power supply scenarios—off-grid solar, grid-only power, and a hybrid solar system—for residential consumers using 1200 kWh per month reveals significant differences in both upfront and long-term expenses. Each scenario presents unique trade-offs in terms of initial investment, ongoing operational costs, and potential savings. Table 5 shows the NPV of the total cost incurred for each system over a 20 year period.

Table 5: Summary of NPV cost calculations for off-grid solar, grid only power and a hybrid power supply over 20 years for a residential property

System Type	NPV Cost – 20 Years
Off Grid System – High End (R700 000)	R 26 420 647
Off Grid System – Low End (R350 000)	R 13 210 324
Grid Only Costs	R 2 399 937
Grid Only Costs (incl. Fixed Charge)	R 2 468 667
Hybrid System Savings (incl. Fixed Charge and Feed-In Tariff)	R 7 762 152
Hybrid System Cost (incl. Fixed Charge and Feed-In Tariff)	R 8 614 108

Table 5 shows that even a very conservative cost estimate for a fully off-grid residence is much more expensive than the grid only charges over a twenty-year period. The cost of extra battery storage that corresponds to increased DOA escalates the cost of off-grid systems to such an extent that they are not an attractive investment in the short or long term. It is worth noting that the fixed charge does not significantly increase the long term cost of a grid only consumer, however the impact of this requires further study and a more detailed understanding of different customer consumption patterns within tariff categories. Furthermore, despite major investment, off-grid customers do not benefit from export customers since they cannot feed electricity back into the grid. Figure 3 plots the cumulative costs of each system over a 20 year period.

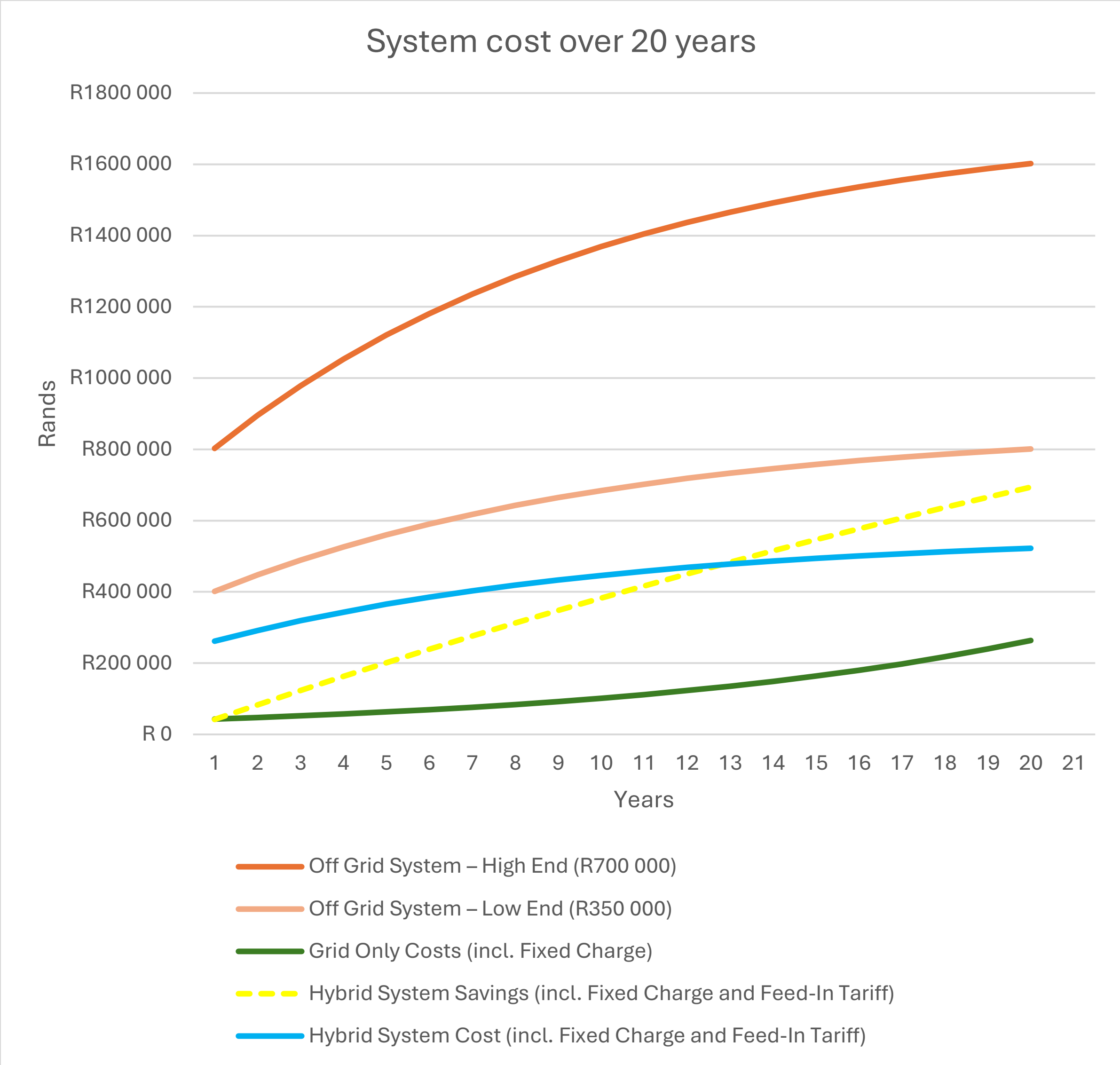

Figure 3: Graph illustrating different residential system costs over a 20 year period.

This graph shows electricity supplied by the grid costs considerably less than investing in off-grid solar power over a twenty-year period. Provided that the grid maintains high reliability and that electricity tariffs don't escalate exorbitantly, there is a compelling case to use the grid as one's primary source of power – and in particular reserve or back-up power. Despite the high initial costs of a grid-connected hybrid system, the reduced reliance on grid supplied electricity coupled with a feed in tariff results in a favourable NPV after about twelve years. Conversely, the cost of a fully off-grid system with enough battery storage to provide two days of cover is significantly more costly and is not considered a good investment unless the grid's reliability decreases dramatically. This is equally true for consumers in Paarl as it is for Mbombela as two days of autonomy accounts for a reliability of 85% and 93% respectively.

3.2.2. Commercial Consumer – Small Office Building

The cost comparison of the three power supply scenarios for small commercial offices consuming 172 kWh per day yields similar results to the residential case. Again, off-grid systems are substantially larger than hybrid and grid-only systems. The grid only scenario is the cheapest option with the hybrid system attaining positive cashflows after twelve years. Table 6 shows the NPV of the total cost incurred for each system over a 20-year period.

Table 6: Summary of NPV cost calculations for off-grid solar, grid only power and a hybrid power supply over 20 years for a typical small commercial office space

System Type	NPV Cost – 20 Years
Off Grid System – High End (R1 400 000)	R52 841 295
Off Grid System – Low End (R1 000 000)	R37 743 782
Grid Only Costs	R8 999 764
Grid Only Costs (incl. Fixed Charge)	R9 824 524
Hybrid System Savings (incl. Fixed Charge and Feed-In Tariff)	R29 108 070
Hybrid System Cost (incl. Fixed Charge and Feed-In Tariff)	R32 302 905

A graph of the payback period can be found in Appendix B.

These results show small business should consider a hybrid solar PV system, either with or without battery storage depending on their unique business cases as there is a positive payback. It is unlikely that business in these office settings will defect from the grid due to the large upfront capital investment that is required.

3.2.3. Commercial Consumer – Regional Mall

The cost analysis of three power supply options—off-grid solar, grid-only power, and a hybrid solar system—for a commercial mall approximately 65000m^2 in area reveals clear differences in both upfront investment and ongoing operational costs. Grid power is once again the most affordable option. Grid-tied solar PV systems without storage for areas this large are economically viable and have become increasingly popular. The business case for hybrid solar PV systems without storage is attractive, however the current cost and sheer number of batteries required to provide cover for grid outages makes investing in storage an unattractive investment. The size of the solar installations on malls this size vary widely depending on the financing available. The result of this is varied payback periods, however hybrid solar PV systems without storage typically have a payback period of less than ten years when there is an export credit available[5]. Off-grid systems for malls of this size require considerable upfront investment and do not provide a good business case at all. Table 7 summarises the results of the NPV calculations for a commercial mall.

Table 7: Summary of NPV cost calculations for off-grid solar, grid only power and a hybrid power supply over 20 years for a 65000m^2 commercial mall.

System Type	NPV Cost – 20 Years
Off Grid System – 12 hours autonomy	R15 561 925 994
Grid Only Costs (incl. Fixed Charge)	R 2 001 665 774

A graph of the payback period can be found in Appendix B

[5] As confirmed by industry experts including SunCybernetics and Solink.

4. Discussion

The results of this study clearly show that grid defection is an economically inefficient decision from a consumer's perspective, especially in cases where a high degree of reliability is required.

While grid supplied electricity is the least costly option for consumers in terms of capital requirement, the data show that grid-connected hybrid solar PV systems provide a good business case to consumers in the residential sector. The business case for commercial hybrid systems with battery storage also depends on the area of the property and consumption patterns, however generally speaking, systems with battery storage are more suitable to smaller commercial properties with lower energy consumption as the batteries are major cost drivers as the scale increases. Commercial properties with larger areas and high consumption are more likely to consider a grid-tied solar system without battery storage to reduce grid supplied electricity consumption and mitigate the risks of power outages.

The study also shows how geography can influence the likelihood of grid defection. Grid defection in Mbombela is more likely than in Paarl because the chance of more than two days without is much lower in Mbombela's case and as such, the cost of a solar PV system that with reliability greater than 90% is cheaper. This can be said for many areas of the country that have less rainfall than the south-western Cape. Therefore, there are areas for which the cost of going off-grid is less than the two examples in this study.

The study indicates that the grid currently still offers the most economic system reliability. For optimal system efficiency it is therefore important to offer a secure and reliable grid 'battery' to customers. Should grid reliability be greatly reduced through lack of maintenance and refurbishment, or persistent vandalism, customers may make the sub-economic decision to go off-grid. This might also be encouraged through tariff signals that fail to value the energy contribution of solar PV systems to the grid – either through prohibitive fixed charges or no/minimal export tariff. As illustrated in the Figure 4 below, this would set us on a sub optimal path.

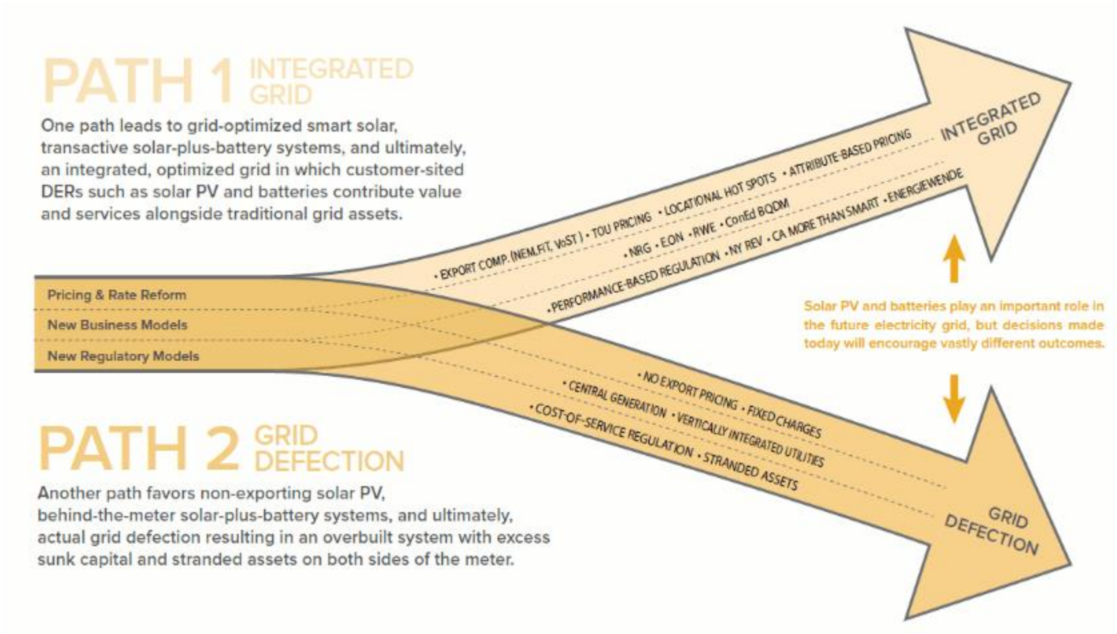

Figure 4: Possible trajectories for electricity grid evolution[6].

Tariff design can play a significant role in the potential of grid defection. In this study, fixed charges were shown to have a limited effect on the total NPV cost to the consumer. However, work by leading US-based electricity transition academic Gorman[7] indicates that the shift to fixed costs can influence customer behaviour towards grid defection, in particular those customers with low levels of consumption but high fixed costs may reach a point where grid defection makes financial sense. This would particularly apply to customers who may already be solar PV customers.

Used in the correct manner, fixed charges allow utilities to recover the fixed portion of their revenue without negatively affecting customers. Tariffs need to tend towards cost reflectivity, but further work is required to explore at what level fixed charges levied on low energy consuming customers might influence defection. In the meantime, excessively high (yet cost reflective) charges must not be pursued without consideration of potential negative impacts such as grid defection and uneconomic investments.

Feed-in tariffs are also important as they will encourage consumers to remain connected to the grid, however the tariffs must not be so high that grid-only consumers are forced to subsidise those with hybrid systems. Municipal utilities might also consider fees that inhibit grid defection, such as high disconnection and reconnection fees. This is 'fair' as the property value is based on the blanket provision of services and these sunk infrastructure costs must be recovered.

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[6] Rocky Mountain Institute, *The Economics of Grid Defection: When and Where Distributed Solar Generation Plus Storage Competes with Traditional Utility Service*, 2014.
[7] Gorman et al, *Should I Stay Or Should I Go? The importance of electricity rate design for household defection from the power grid,* 2020.

5. Conclusion

The conclusion of this study is that due to the high cost of off-grid solar systems, rational consumers are unlikely to defect from the grid and are more likely to opt for a hybrid or grid only system under current conditions. However, given South Africa’s high irradiance levels, and a future with unknown disruptive events impacting our grids, suitable days of autonomy can be met off-grid more readily than many other parts of the world. This, coupled with loadshedding and declining condition of our distribution grids, resulting in lower levels of reliability, means that grid defection is something that requires careful attention.

Grid defection is shown in the study to be a sub optimal economic outcome for all parties. In order to avoid this outcome municipal utilities need to ensure that the distribution grid offers an acceptable level of reliability to customers, whilst keeping costs below that of alternatives. This may require that tariffs set cost-reflective fixed charges with due consideration of the need to retain customers. Given that it would be unfair to shift these costs onto other customers, utilities may need to collect outstanding costs through rates. An alternative could also be to introduce fees (disconnection and reconnection) that inhibit grid defection.

Appendix A

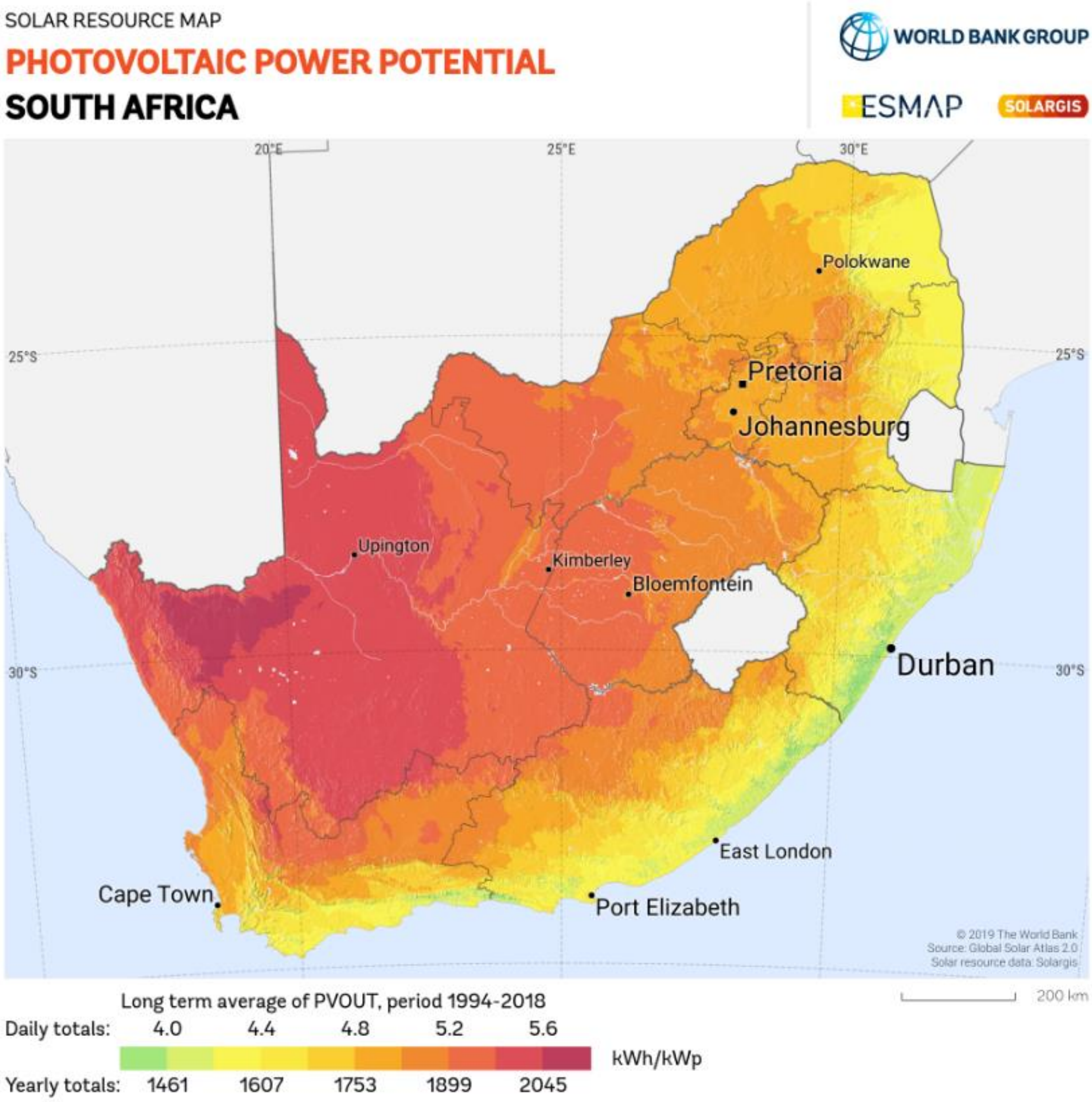

Figure 5: Solar irradiation potential in South Africa[8]

South Africa has many different climatic zones with varied solar irradiance; however, these climatic zones can be broadly separated into three generalised categories. The south-western part of the country receives winter rainfall and has dry hot summers. By contrast, the central and eastern parts of the country receive summer rainfall and have dry winters. The north-western part of the country is semi-desert and has a high solar irradiance. The two climatic zones that contain majority of the country's population are the south-western and central/eastern climatic zones.

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[8] *Solar resource map © 2021 Solargis, https://solargis.com.*

Appendix B

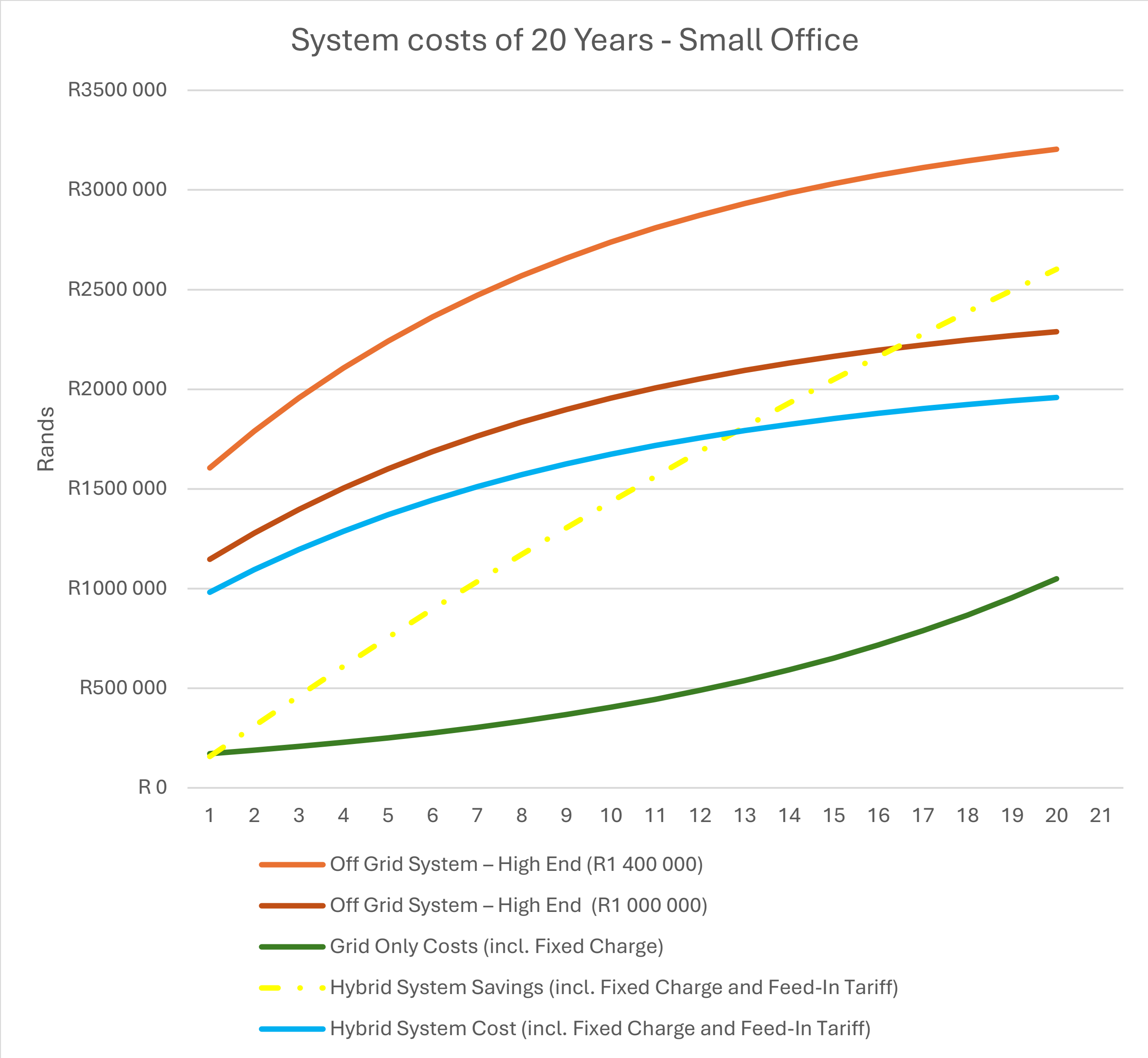

Figure 6: Graph illustrating different commercial small office solar PV system costs over a 20 year period.

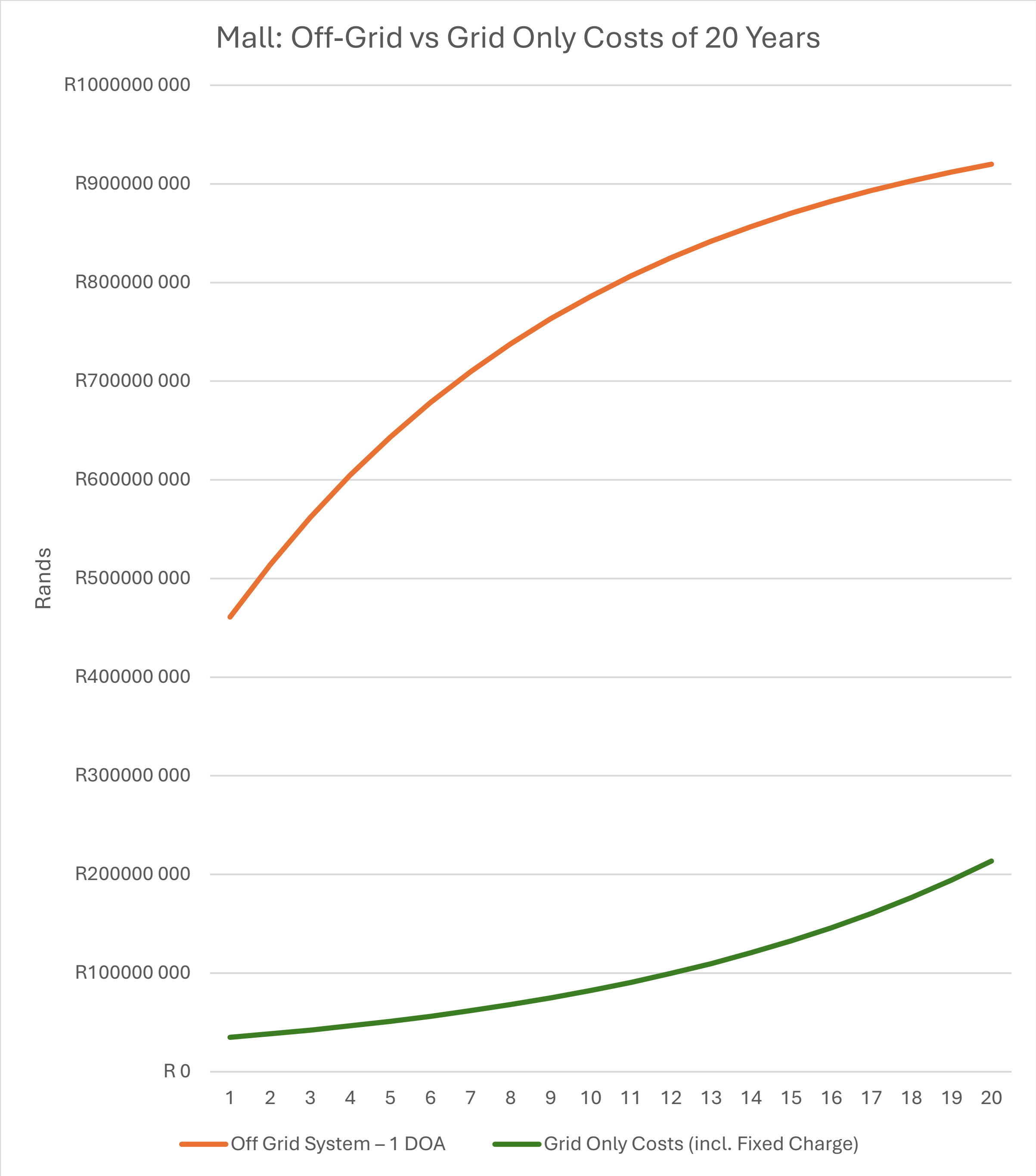

Figure 7: Graph showing the cost comparison on grid only connection compared to and off-grid system with one day of autonomy for a regional mall