THE UPTAKE AND IMPACT OF EMBEDDED GENERATION INSTALLATIONS AT LARGE SUGAR CANE ESTATES IN ESWATINI

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Abstract

Internationally embedded generation (EG) exhibits significant growth in penetration levels. In Eswatini, however, its adoption is a recent phenomenon with especially the sugar cane electricity consumption sector recently installing EG (specifically solar PV and biomass) at aggressive rates. The sugar cane sector represents a significant share of Eswatini's energy consumption, therefore increased EG uptake in this sector may significantly impact the amount of electricity sold by the national utility, Eswatini Electricity Company (EEC). EG uptake may also indirectly impact the energy sold by South Africa’s Eskom, the main supplier of EEC. There are currently no available standards guiding the network’s EG hosting capabilities. This gap generates uncertainties concerning the EG growth rate, and the implications for the utility.

This paper sets out to investigate the likely future EG uptake at sugar cane estates in Eswatini and examines the financial and load impact thereof under two scenarios. The generous scenario considers full approval of EG applications already submitted to the Eswatini regulator plus a share of additional early adopters. The conservative scenario assumes solar PV EG adoption based on the South African NRS 097 standard as well as half of the capacity of currently applied-for biomass plants. The outcomes indicate an uptake of 39-76MW of PV and biomass, 22-46% impact on energy imports and 20-40% future decline in profits. The outcomes of this research demonstrate EG’s potential to significantly displace imports and utility profits.

Key words: *Eswatini; embedded generation; distributed generation; financial viability; utility finances; photovoltaic*

1. Introduction

1.1 Background

The Kingdom of Eswatini’s power market was unbundled in 2007 but is currently dominated by the national power utility, EEC, which undertakes power importation, transmission and distribution. Imported electricity accounts for 80% of the national electricity profile- approximately 70% of these imports are supplied by Eskom and the rest is supplied by SAPP markets, i.e. Day Ahead Market (DAM) and local Independent Power Producers (IPPs). One of the IPPs happens to be one of the large sugar estates, Ubombo Sugar Limited (USL), located on the eastern side of Eswatini, which contributes around 4% of ECC’s electricity supply through co-generation using biomass [1].

The free market structure, increasing electricity prices and EG viability are creating a conducive environment for EG uptake [2], with particularly solar PV and biomass gaining traction in Eswatini. The growth of this trend can be observed in the notable increase in the volume of large-scale EG applications for generating licenses with the Eswatini Energy Regulatory Authority (ESERA) as well as the increasing ongoing EG installations especially at sugar cane estates.

Information gathered from ESERA in 2018 indicates that the total applications for EG was 133 MW of which two-thirds came from sugar cane estates for both self-consumption and to a lesser extent export [3]. Strikingly, the 133MW proposed rated capacity presents 56% of the country’s peak national demand of 236 MW for the financial year (FY) 2017/18.

The increased (renewable) EG trend has several advantages, including financially viability to the owners, increasing the country’s local generation, reaching national renewable energy targets, as well as minimising the impacts of climate change [4].

On the flipside, however, a set of challenges emerge, such as the uncertainties on utility revenue impact, alignment to regulations governing supply quality, and network costs to upgrade and accommodate EG [5].

Considering the challenges highlighted, along with the current appetite for EG, pertinent questions arise about the estimated uptake of EG and its utility revenue impacts.

This study's aim is firstly to gain insight on the likely future uptake of EG (specifically solar PV and biomass generation technologies) by the sugar cane sector in Eswatini using a set of scenarios. The second aim is to estimate the impact of this EG adoption on the national load profile and utility revenue under generous and conservative assumptions.

The paper is structured as follows: section 2 elaborates on the significance of the sugar cane production sector and its members' position as potential candidates for increasing EG growth. Section 3 reviews existing EG (solar PV and biomass) installation potential studies relevant to Eswatini, as well as current regulations governing EG installations. The same section explores documented literature on the impacts of EG on utilities. Section 4 describes the data sources, assumptions and methodology used to assess the uptake of EG in Eswatini and quantify the financial and load impacts. In Section 5 the results concerning Eswatini PV and biomass generation potential in the sugar cane sector are presented. Finally, in Section 6 the results are discussed, and conclusions are drawn.

2. Significance of the sugar cane sector

Although the study could have investigated EG impacts from other electricity consumer categories, it was decided to constrain the paper's focus to the sugar cane sector for several reasons;

- The sugar cane irrigation patterns correlate well to PV generation profiles. A study by [6] indicates that 87% of sugar cane farmers irrigate during the day and this study's own analysis of system electricity data (supplied by EEC) indicates that the Eskom peak demand in 2018 of 187.39MW was reached around 14h00 on 17 January [7]. Moreover, most of the sugar estates are sited in high irradiance areas ranging from 1600-1800 kWh/kWp per year which is considered to be a feasible range for PV projects [8]
- The sugar cane industry contributes significantly to system demand and utility revenue. For FY 2017/18 the annual consumption of the sector was 434 GWh, representing approximately 30 % of total system consumption. Moreover, the sugar cane sector accounts for about 55 % of the revenue of the utility's major customers base [9]. Figure 2 provides a perspective of the sugar industry sector with the approximate locations of the sugar cane estates.
- In Eswatini the sugar farming industry have been early adopters of EG technologies in general and have plans to increase self-generation and to some extent export [10] whilst some large and medium scale estates have either applied or installed EG, suggesting increased consumer confidence in EG technologies.
- The industry is vulnerable to climate change induced drought along with rising electricity tariffs which threaten sustainable sugarcane production [11]. This position has compelled the industry to actively seek options to self-generate and become self-sufficient in order to reduce production costs and contribute to environmental sustainability [10].

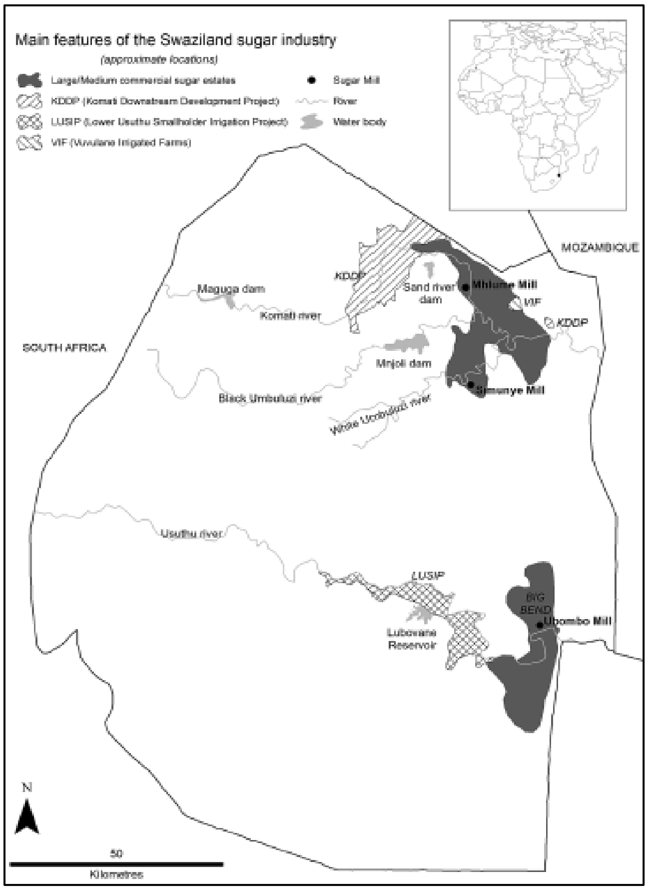

Figure 1. Main features of the Eswatini sugar cane belt [12]

3. Literature review

3.1 Solar PV and biomass technical potential

Studies estimating EG potential uptake for specific consumer categories in Eswatini are limited. In fact, a ministerial report notes that this gap in literature requires attention for holistic energy planning scenarios [13]. The EG potential uptake review conducted here will therefore be limited to a few high-level studies that have been carried out to estimate the renewable energy potential in Eswatini.

[14] carried out a countrywide exploration study for solar PV capacity and concluded that 155 MWp of solar PV EG could be installed in certain Eastern parts of the country. In another zoning study which included the eastern part of the country, carried out by IRENA [15] and the government, a potential uptake of 541.8 MWp was reported, based on satellite solar irradiation estimates of 4-6 kWh/m²/day.

The same report published biomass figures, concluding that Eswatini's sugar industry could be self-sufficient using bagasse for cogeneration during the milling season and further provide surplus power to the network, based on improved operational efficiencies. Furthermore, the report estimates increased energy generation in the region of 469 GWh -782 GWh per year.

The Ministry of Natural Resources and Energy recently released a report [16] which is consistent with the IRENA report in specifying planned generation capacities from the sugar industry at 125 MW. The capacity increase is attributed to factors such as ongoing sugar cane production expansion projects and improved mill efficiencies at the largest mills.

RSSC, a major player in the sugar cane industry, reports that they are progressing with adapting operations towards self-generation projects and becoming a net energy exporter in the long term [17]. According to [18], by global standards such projects are long overdue since sugar factories started progressing towards self-generation as far back as 2007.

3.2 EG electricity regulation landscape

The Eswatini electricity market was unbundled in 2007, with the Electricity Act of 2007 being one of the key instruments meant to stimulate and enable deployment of EG and increasing local generation capacity. The Act [19] created a framework for prospective power producers to connect to the existing grid infrastructure including the wheeling of power, and gave licencing powers to the regulator, ESERA. The regulator's licensing threshold is limited to EGs over 1MW.

It is unclear whether regulations that deals with the network hosting capacity of EGs exist for Eswatini. Given the lack of availability of a full set of Eswatini standards, hosting capacity assumptions in this paper are informed by two sources. The first is a CIGRE working group [20] set of benchmarks for the regulation of networks with increasing sources of PV- EG. The group set the benchmark for EG PV systems at peak ratings up to 15% of the peak load on a distribution network without an extensive distribution system impact study.

The second source is the NRS 097 standard, a South African regulation informed by best practices. The standard [21] is focused on technical limits that constrain the amount of generation by solar PV systems connected to a typical South African distribution network.

3.3 Impacts of EG on utility revenue

Although no EG impact assessment studies are available for Eswatini, there is a growing body of research in this field globally and to a certain extent regionally. At a regional level, specifically in South Africa the subject has had fair attention at a municipal level for mainly the domestic user category.

Therefore, considering that Eswatini has a small electricity sector that resembles South African municipalities as electricity distributor and net importer, it is safe to assume the relevance of municipal studies in this research. Therefore, the paper shall proceed and review several studies that have focused on investigating the impacts of EG on municipalities in South Africa.

[13] carried out a study on the (unregulated) potential of rooftop PV and its impacts on revenue at Riverdale, part of the Hessequa municipality. Impact calculations were limited to eligible domestic and industrial customer using a set of aggressive and constrained approaches. The results indicated a financial impact for both scenarios of less than 1%. A similar study undertaken by [14] for Drakenstein municipality found that the potential revenue impact would be approximately 3%.

Another investigation, launched by [15] proceeds to estimate the impacts of rooftop PV uptake amongst high-use residential suburbs in Stellenbosch municipality, constrained by the NRS standard. It estimates a revenue impact of 2.4%. Lastly [16] carried out a similar impact assessment in the inner city core of Johannesburg. The study determined an 0.31% effect on municipality revenue.

Overall the literature's EG capacity calculations have been limited to solar PV technology installed by residential customers constrained by rooftop size and the NRS technical network hosting capacity standard. Although these studies make different assumption when calculating financial impacts, one of the conclusions that can be drawn is that the impacts of solar PV EG on municipalities finances amongst the groups studied is insignificant.

4. Load and financial impact assessment of EG adoption in Eswatini

4.1 Methodology overview

To conduct the impact assessment of increased adoption of EG by sugar cane estates in Eswatini a four-stage approach is employed. The first stage presents two cases studies meant to illustrate the benefit of EG from the customers' perspective. The second and third stages of the methodology uses these case studies' concepts and develop a sector-wide EG energy production model. The model employs two scenarios, industry-based data and assumptions to model energy production. The fourth stage uses the results from the previous stages as inputs to assess the impact of EG on revenues and system and import electricity reductions.

4.2 Case studies impact at customer level

Two case studies, of a large and medium scale estate with recently installed solar PV EG, are presented to illustrate the EG savings that are motivating the industry to adopt EG. Using PV plant information and electricity consumption bills supplied by one of the estates [17], the impact assessment was carried out employing the methodology presented in Figure 2.

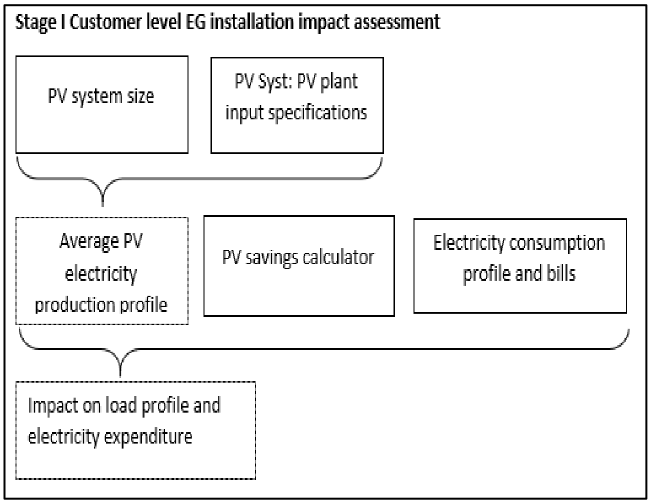

Figure 2. Overview of methodology for PV impact assessment customer level

For customer privacy, we shall refer to the customers as Estate A and Estate B. Both estates are billed on the Eskom Miniflex equivalent tariff structure. Estate data is summarised in Table 1 below.

Parameters	Estate A	Estate B
Min- Max demand	1410 kVA- 2000 kVA	280 kVA- 350 kVA
Annual consumption	6 840 MWh	1 174 MWh
Electricity expenditure	R 19.5 million	R2.8 million
PV system size	1500kWp	100kWp
System size: peak ratio	79%	29%

Table 1. Case study estates electrical data

4.2.1 Impact assessment at customer level

PV production for each estate was obtained by the simulating the PV system using PVsyst software. The input parameters were set optimally to 0 degrees for the azimuth (i.e. North facing) and 26-degree inclination angle.

Parameter	Estate A (1500 kWp)	Estate B (100kWp)
Performance ratio	82.95%	76.04%
Specific yield (kWh/kWp/year)	1687	1545
Produced electricity (MWh/year)	2530	154

Table 2. PV production output at sugar cane estate case study results

To estimate the financial savings for the customers, the hourly PV electricity production results was analysed alongside with electricity usage data and a PV savings calculator was used to compute the PV savings. The PV savings calculator is an excel model developed to calculate the cost reflective savings derived from a PV system.

The model inputs includes electricity generated and consumed per time of use, the tariff structure, PV system and irradiation parameters and the financial parameters.

Model assumptions:

- PV savings originate from active energy and demand charge savings.

- To get around the complexity of predicting demand savings, the model derives and assumes the average kVA of the PV system. This is reasonable if it is assumed that peak demand typically coincides with peak solar periods (mid-day).
- A PV system lifespan of 25 years.

Some of assumptions used as financial model inputs are presented on Table 3.

Financial parameter	Assumption
System Installed Cost per Wp	R12.46/Wp
Average EEC Tariff (year 1)	R1.44/kW
Capital Cost Rate	10%
Inflation	6%
Maintenance & Insurance	1.20%
Tariff increase	12.2% year on year for the first 5 years and 8% for the remaining years

Table 3. Financial assumptions for PV savings model

Figure 3 summarises the results from the PV savings model: the results show that Estates A and Estate B can potentially reduce their annual energy purchases by 37% and 13% respectively. Estate A saves a total of R3.7 million and R521 000 on their energy and kVA bill respectively. This translates into an IRR of 39% and project payback period of 5 years.

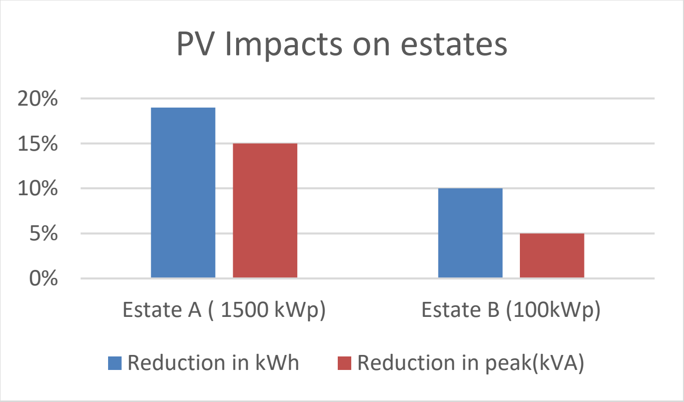

Figure 3. PV financial savings for sugar cane estate case study results

4.3 Impact assessment at sector level

4.3.1 Scenarios description

The impact assessment for the sugar cane industry is done under two scenarios, namely generous and conservative.

The generous scenario is driven by the following assumptions:

- All the EG applications with the regulator are approved and grid stability studies are in place.
- An additional PV capacity penetration level up to 25% of the peak load, which may come from the rest of the sugar cane estates.

Likewise, the conservative scenario is guided by the following assumptions:

- PV capacity penetration level is 15% of peak load, this adoption is guided by NRS 097 principles and additional grid stability studies are not done.
- Only 50% of the biomass capacity applications is approved.

Note that both scenarios use peak substation demand readings instead of individual feeder readings due to the unavailability of specific feeder data.

4.3.2 Data sources

EG applications data was gathered from primary sources at the regulator, ESERA. Substation metering records, system demand profile and top customers profiles were drawn from EEC. Information related to biomass plant operations was supplied by the USL mill. Case study data was gathered from the relevant estate owners.

4.3.3 Calculation of solar PV uptake potential

To estimate the potential capacity of PV, the metering data for the nine substations supplying sugar cane estates was collected along with the list of declared capacities. The datasets were processed to extract information such as the maximum demand and annual energy profiles. The final EG uptake capacity was then determined by applying the different scenario assumptions.

PVsyst was then used to calculate the yearly PV production after combining data from the different substations. The system was assumed to be sited at the centre of the sugar belt, i.e. Simunye area, with the system parameters set for North facing azimuth, 27 degree tilt, and site annual yield of 1702 kWh/kWp.

4.3.4 Calculation of biomass uptake potential

To simplify calculation of biomass potential, operating assumptions informed by the existing plant records of two local sugar cane biomass systems (supplied by [18]) were made: a conversion efficiency of 85% and capacity factor (CF) of 0.72. The capacity factor was used estimate the annual energy production as well as monthly averages. To obtain the hourly averages we estimated the number of hours the plants are in production as approximately 9 months.

This suggests that for a period equivalent to 9 months, the plant is in full operation and the remaining three months or 12 weeks there is minimal production. For further simplicity the study assumes the biomass plant production period to be from February to April yearly.

5. Results

5.1 EG capacity and production

The potential installable capacity for embedded generation in the sugar cane industry category in Eswatini under the generous scenario was found to be 75.5 MWp, and 39.4 MWp. under the conservative scenario. The associated annual generation potentials are 376.2 GWh and 183.9 GWh for the generous and conservative scenarios respectively. Table 4 presents the results summary.

Embedded Generator	Generous Scenario	Conservative Scenario
Solar PV capacity [MW]	25	10
Biomass capacity [MW]	60	30
Total capacity [MW]	76	39

Table 4. Summary for potential EG capacity by sugar cane estates

5.2 Electricity profile impact

The EG capacities determined in the previous section were simulated in PVSyst. The results showed that EG generation could reduce the total Eswatini annual system active energy profile (kWh) by 30% under the aggressive scenario and by 14% under the constrained scenario.

To estimate the impact on the maximum demand of Eskom imports, the study assumes EG power production coinciding with recorded Eskom maximum demand. It is also assumed that annual EG electricity production largely displaces Eskom electricity imports. Table 5 presents the summary of these figures.

System parameters	Generous Scenario	Conservative Scenario
Total System energy GWh	1269	1269
EG energy production GWh	376	184
Impact on total system energy	30%	14%
Eskom energy imports GWh	819	819
Impact on Eskom energy imports	46%	22%
Eskom (import) maximum demand MW	187.4	187.4
Coinciding EG production MW	66	28
Impact on Eskom import maximum demand	35%	15%

Table 5. Results summary for EG energy and demand impact

Figure 4 shows the impact of EG in sugar cane sector on system load profile for a typical summer day for the generous scenario. The green field represents the portion of the load that biomass generation displaces whilst the yellow field represents the load that solar PV production displaces.

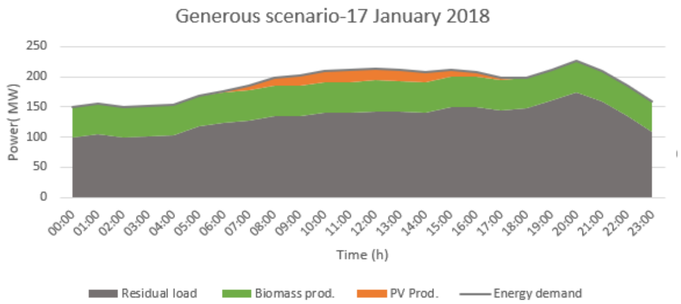

Figure 4. Potential EG impact on Eswatini system load profile 17 January 2018

5.3 Revenue, import costs and profit impacts

In order to calculate the impact on utility sales revenue and import costs, the study employs the results from the previous section and EEC annual financial report data for FY 2017/18 [19]. The calculations are conducted under the following assumptions:

- All energy generated by EG is Eskom import cost avoided.
- Electricity generated is all consumed on site therefore no wheeling charges present.
- Both active energy (kWh) and demand (kVA) charge and savings are considered.
- All the sugar cane estate accounts are billed on a time of use (TOU) tariff structure.
- EEC buys electricity from Eskom at the MegaFlex tariff.
- A reduction in revenue due to EG is offset by less electricity bought from Eskom – however, it is assumed that EEC's fixed costs do not decrease.

As shown in Table 6, EEC annual revenue would decline due to EG by 27.1% and 13.4% for the generous and conservative scenarios respectively. If ECC does not adapt their tariffs in response to increased EG, this decline in revenue represents a decrease in profit 40% and 20% for the generous and conservative scenarios respectively. The loss of profit was calculated as the difference between EG production as a function of EEC tariff and EG production as a function of Eskom tariff.

Financial Parameters	Generous Scenario	Conservative Scenario
EG production at EEC sales cost (R) million	526.7	260
EG production at import cost (R) in million	289.3	140.5
Reduction in profit (R) in million	237.4	116.4
EEC Revenue from electricity sales (R) million	1946	1946
% net loss in revenue	27.1%	13.4%
EEC Profit from electricity sales (R) million	592.9	592.9
% loss in profit	40%	20%

Table 6. EG revenue impacts on utility

6. Summary and Conclusions

This study set out to assess the impact of increasing EG (in the form of solar PV and biomass) adoption at large sugar cane estates in Eswatini.

The assessment focused on the impact on system energy profile, imported energy and maximum demand, and utility revenue and profit under two scenarios.

The results indicate that the Eswatini sugar cane industry can potentially install 76 MW_p capacity of EG and generate up to 376 GWh annually using PV and biomass technologies.

It further indicates that these installations displace active energy imports by up to 46%, utility revenues by up to 27% and utility profits by up to 40%.

Figure 5 represents the overall impact assessment results, which characterise a significant impact on imported energy, which may be due to EEC being a net-importer.

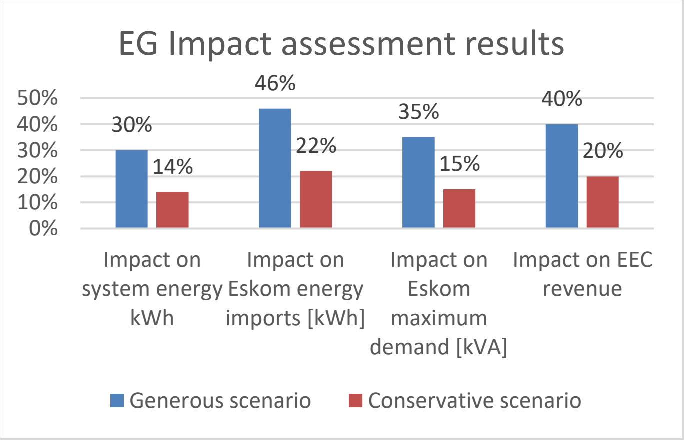

Figure 5. EG Impact assessment results overview

The study has also showed that both the PV and biomass production align with the maximum demand drawn from Eskom imports, resulting in significant annual demand charge reduction savings.

In conclusion the impact assessment results for solar PV are somewhat consistent with the literature reviewed, indicating an 2-4 % effect on the utility's revenue. Biomass plants production on the other hand represent a major impact on revenue (up to 36% in the generous scenario) and profit, but also plays a significant role in reducing import and system peak demand, which may lead to improved network efficiencies and increased life of network components.

Furthermore, since the study revealed major declines in volume of sales from the utility's perspective, this may pose implications on the business model by since the utility's operational costs are fixed.

Further areas of study highlighted through this paper includes the technical impacts of EG on the Eswatini distribution network, as well as a more detailed assessment of the risks and opportunities to the EEC's business model represented by the potential large uptake of especially biomass in Eswatini's sugar cane sector.

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