SCIREA Journal of Management
ISSN: 2995-777X
http://www.scirea.org/journal/Management
February 18, 2025
Volume 9, Issue 1, February 2025
https://doi.org/10.54647/management630162

EXPLORING SUSTAINABLE FINANCING SOLUTIONS FOR PHOTOVOLTAIC SYSTEMS AND SMALL-SCALE INVERTERS IN SOWETO, SOUTH AFRICA

Siphamandla Mnyani [1], Dr Joseph Sigauke [1]
[1] Nelson Mandela University Business School
Email: s224374915@mandela.ac.za (Siphamandla Mnyani); hiejose@yahoo.com (Dr Joseph Sigauke)

ABSTRACT

This study aimed to investigate and develop a framework for financing sustainable investments in photovoltaic (PV) systems and small-scale inverters for local communities in Soweto, South Africa. It also analyzed the impact of energy supply challenges on community well-being, socio-economic development, employment opportunities, and human development. A quantitative research approach was employed, involving data collection from Soweto residents and City Power employees through simple random sampling. A response rate of 92% was achieved. Pearson correlation and Chi-squared tests revealed a positive relationship between the value of funding for PV solar systems and the installation of small-scale inverters in Soweto Township. The analysis demonstrated that funding PV solar system installations can contribute to affordable, sustainable energy and economic growth in the region. These findings highlight the importance of exploring funding models that can facilitate the adoption of clean, sustainable energy solutions in townships.

Keywords: Photovoltaic solar systems, Funding Models, Economic growth, Sustainable Development

1. INTRODUCTION

South African residents as well as businesses operating in South Africa (SA) have been subjected to Year-on-Year (YoY) escalating electricity tariff rates above inflation. This phenomenon has led to sluggish economic growth, largely affecting marginalised communities such as Soweto (Walker, 2020). Soweto is a township located on the periphery of Johannesburg metropolitan area, and it consists of predominantly low to middle income households (Maarten, Jansen, Ubarevenience and Tammaru, 2021). It is one of the communities where many residents are struggling to pay for domestic electricity due to socio-economic struggles. Soweto Township owes the city of Johannesburg power company R8.3 billion of unpaid electricity tariffs and non-compliant interest (Daily Investor, 2023).

The perpetual udercovery of electricity tariffs is not financial sustainable, hence City Power utility (a City of Johannesburg entity responsible for electricity distribution) occasionally cuts Soweto's electricity supply, leading to intermittent power supply, thus exacerbating the socio-economic challenges in Soweto Township. Walker (2020) alludes that, sporadic electricity cost escalations threaten the socio-economic balance, resulting in water and food security threats as well as a decline in economic growth. It is thus imperative to develop a policy framework that considers the socio-economic impacts of energy supply specifically for the communities in Soweto.

The high electricity cost is a concern for South Africans, especially the marginalised communities such as Soweto, as they are not only subjected to power interruptions but to frequent increase in electricity tariffs as well (Galal, 2023). Considering the current energy challenges that South Africa is facing, this study provides a possible solution to reduce the energy crisis. This basis, lead to the development of the below research objectives and hypothesises.

2. RESEARCH HYPOTHESIS

Hypothesis 1

- ✓ H_0: There is no positive impact between energy availability and economic growth in Soweto Township, South Africa

- ✓ H_1: There is positive impact between energy availability and economic growth in Soweto Township, South Africa

Hypothesis 2

- ✓ H_0: There is no positive impact between financing the installation of PV systems and economic development in Soweto Township, South Africa
- ✓ H_1: There is positive impact between financing the installation of PV systems and economic development in Soweto Township, South Africa

Hypothesis 3

- ✓ H_0: There is no impact between long-term sustainability of PV systems and community involvement in Soweto Township, South Africa.
- ✓ H_1: There is positive impact between the long-term sustainability of PV systems and community involvement in Soweto Township, South Africa.

Substantial number of inhabitants in areas such as Soweto are unable to procure alternative energy such as PV solar systems due to affordability. As a developing economy, it is imperative for SA to analyse the socio-economic impact and the inequality that might be exacerbated if the communities in the townships are left on the periphery when the renewable energy policy framework is being implemented. To realise potential positive impacts, it is necessary to adopt a system that enables the marginalised communities to have access to a sustainable energy supply.

Similar studies by González, Domenech, Gómez-Hernández and Ferrer-Martí (2017) focused on marginalised community identified gaps which include, challenges related to long term sustainability and adequate transfer of operational skills. In South Africa, studies have been conducted on operational efficiencies of renewable energy technologies (Walwyn, 2017), and a research gap was observed on the financial modeling and sustainability of PV systems in Soweto. Therefore, this study focused on financial modeling and sustainability of PV systems in marginalised communities such as Soweto. This research aimed to close the gap, provide insights into the long-term sustainability of photovoltaic systems in townships. The intended outcome of the study was to establish the long-term financial sustainability of the PV systems and small-scale inverters, establish whether the PV systems contribute to economic growth and analyse the economical funding models that can be adopted.

The study also aimed to encourage energy policy makers, technocrats, investors and government institutions to work in collaboration and facilitate the implementation of an integrated energy model that will improve access to reliable, clean, affordable and “sustainable energy for all”, which is enshrined in the UN (United Nations) sustainable development goals (González et al., 2017). According to Mnyani (2024), in order to improve the socio-economic challenges of the marginalised communities, it is imperative that municipalities consider the viability and long-term sustainability of financing small-scale inverters for local communities. The data from Power Optimal illustrates that electricity tariffs have increased above inflation year-on-year (Moolman, 2022). The high electricity cost is a concern for South Africans, especially the marginalised communities such as Soweto, as they are not only subjected to power interruptions but to frequent increases in electricity tariffs as well (Galal, 2023).

Investing in small-scale inverters with a PV (photovoltaic) system could potentially contribute towards supplying cost effective and sustainable energy in the long-term. A small-scale photovoltaic system is a system that uses natural sunlight to generate electricity, mainly for residential homes (Mnyani, 2024). Solar panels absorb the heat energy from the sun, which get converted to AC (Alternative Current) or DC (Direct Current). Below is the schematic layout of the Solar Photovoltaic system (Han & Zhang, 2016).

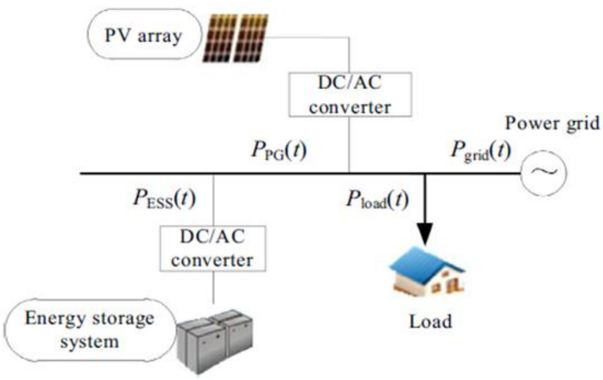

Figure 1: Photovoltaic Schematic layout (Source: Han & Zhang, 2016)

3. LIRERATURE REVIEW

3.1 The relationship between energy availability and economic growth

Prior studies by Akinola and Akinsade (2022) indicate that, there is a positive relationship between adequate, reliable energy and economic growth. Akinola and Akinsade (2022) observed that it is imperative for marginalized communities to have adequate energy in order to eradicate socio-economic matters. Reliable energy is important for economic growth and human development (IseOlorunkanmi, 2014; Walwyn, 2017; Akinola, 2022;). According to Best and Burke (2018), there is a positive relationship between electricity availability and economic growth. Best and Burke (2018) further state that it is important for low to middle income countries to implement micro economic policies that contribute towards better access to energy.

This is further supported by the economic data. The decline in South African Gross Domestic Product (GDP) is largely attributed to load shedding (Loewald, 2023; BusinessTech, 2023). Electricity is also an important factor for many production processes, contributing to GDP growth and employment (Best & Burke, 2018). According to the World Bank (2014), South African communities in the townships such as Soweto are faced with high levels of unemployment and poor economic growth. Moreover, due to population growth, urbanisation and industrialisation, there is a need to supply adequate energy in line with the integrated energy mix (Department of Mineral Resources and Energy, 2011).

3.2 The relationship between financing the installation of PV systems and economic development

Prior studies indicates that, there is a significant relation between affordable financing of PV solar system and economic development (Acquah & Ahiataku, 2017). Acquah and Ahiataku (2017) state that there are various financing models that can be considered for the PV solar system. Furthermore, Acquah (2017) and Walwyn (2017) posit that the PV solar system has the potential for payback provided that the installation costs are kept to a minimum and the inverter efficiency and the panel size are considered. Akinola (2022) asserts that the Total Life Cycle cost (TLCC) of the PV system becomes cheaper over time, since the operational and maintenance costs are low. According to Walwyn (2017) and National Treasury (2023), public funds in the form of electrification grants, tax incentives or the use of subsidised feed-in tariffs could be used to fund these initiatives.

Walwyn (2017) further states that, the social grants could also be partly converted to fund these PV systems. González et al. (2017) state that, access to sustainable energy is necessary to overcome poverty and promote socio-economic development. Akinola and Akinsade (2022) further state that, it is fundamentally impractical to operate in a modern economy without a reliable and affordable energy supply. It is therefore imperative for local municipalities and other government agencies to develop a framework that will enhance the implementation of sustainable energy systems (Ferrer-Martí, 2010; González et al., 2017).

3.3 The relationship between long-term sustainability of PV systems and community involvement.

Ferrer-Martí, (2010) and González et al. (2017) observed that there is a significant relationship between long term operational sustainability of micro grids PV energy and community involvement. Countries such as Bolivia, Colombia, Ecuador and Peru have implemented micro-grid systems with the aim of supplying electricity to marginalised communities (González et al., 2017). Moreover, these countries also embarked on studies to analyse the impact of the micro-grids in less privileged communities. González et al. (2017) found that solar photovoltaic (PV) systems and micro-grid systems with small inverters and battery banks contributed to economic development. Additionally, for these projects to be sustainable, the active participation of the communities is needed, as well as management models that gradually transfer full ownership to the communities (Ferrer-Martí, 2010; Acquah & Ahiataku, 2017; Walwyn, 2017).

According to González et al. (2017) and Pode (2013) some of the projects in the Andean countries were not successful due to lack of community involvement and prevalent socio-economic issues. Walwyn (2017) emphasised the importance of community involvement for the long-term sustainability of solar and micro-grid projects. In line with this, González et al. (2017) observed that some PV micro-grid system installation projects were not sustainable, and this was attributed to lack of community stakeholder integration.

4. METHODOLOGY

This research adopted a quantitative research method and questionnaires were randomly distributed to Soweto Township residents and to the City Power employees, who are responsible for energy distribution and supply. One hundred questionnaires were distributed to the study population and 92 of the respondents completed the survey, resulting in a 92% response rate. The data was tested for reliability and validity. Data analysis consisted of descriptive and inferential statistics. Cronbach's alpha, sample t testing, Pearson correlation tests as well as Chi^2 hypotheses statistical models assisted to interpret the results of the research study.

5. RESULTS

5.1 Assessment of measurement model

This section aimed at establishing and analysing the relationship between the variables as highlighted in the hypothesis developed. The descriptive statistics which summarise the overall scores derived from the survey are presented below in line with the research objectives. To facilitate analysis, the strongly agree and agree scores were added together. The same process was followed with the strongly disagree and disagree scores.

5.1.1 Reliability of the results

Cronbach's alpha test was used to estimate the reliability, or internal consistency of the tested items. Cronbach's alpha coefficient factors are presented in the table below.

Table 1 Cronbach's Alpha Coefficient

Factor	n	Alpha
Impact of renewable energies (PV)	81	0.61
Adequate Energy Supply	82	0.80
Sustainability	83	n/a*
Funding models	82	0.69
Economic development	83	0.70

From the table above, it is evident that Cronbach's alpha coefficient values meet the minimum requirement of 0.70 required for good reliability (Nunnally, 1978). The other two variables (funding models and economic development variables), were also analysed and were found to have fair reliability (0.61-0.69). According to Zikmund et al (2013), the reliability of these results is acceptable, as indicated by scores greater than 0.5..

5.2 Descriptive statistical factors

This section aims to provide an analysis of the descriptive statistical factors, with variables (1.2-2.59) considered as Low; (2.6-3.4), Moderate and High (3.41-5). The scores were categorised in accordance with the 5-point Likert scale that was utilised in the study, from (1.00-2.59) being low, (2.60-3.40) moderate and lastly, (3.41-5.00) considered as high.

Table 2: Descriptive Statistical Factors

Variables	Low 1.00 to 2.59		Moderate 2.60 to 3.40		High 3.41 to 5.00	
Impact of renewable energies	4	5%	22	27%	57	69%
Adequate energy	5	6%	16	19%	62	75%
Sustainability	4	5%	15	18%	64	77%

Funding models	5	6%	12	14%	66	80%
Economic development	7	8%	10	12%	66	80%

From the analysis, most of the respondents (80%), support that renewable energies (PV solar systems) contribute towards economic growth, thus improving socio-economic matters. Involvement of the communities also lead to sustainability of renewable energy projects in Soweto township. A significant number (…%) of respondents strongly believe that the installation of the PV solar systems will lead to adequate energy supply.

5.3 Inferential statistics for factors

5.3.1 Probability sample T-testing

A sample t-test was performed to establish whether the participants' mean scores on the variables of the factors tested can be described as negative, positive, or neutral with H_0being the Null hypothesis and H_1 being the Alternative hypothesis. The table below illustrates the results.

Table 3: Sample T-testing

Sample t-Tests: Factors (n = 83; H1: μ ≠ 3.40; d.f. = 82)							
Variable	Mean	S.D.	95%CI Lo	95%CI Hi	t	p	Cohen's d
Impact of Renewable Energies	3,77	0,70	3,61	3,92	4,78	<.0005	0.53 Medium
Adequate Energy Supply	4,02	0,79	3,84	4,19	7,07	<.0005	0.78 Medium
Sustainability	3,98	0,88	3,78	4,17	5,94	<.0005	0.65 Medium
Funding Models	3,99	0,85	3,80	4,17	6,29	<.0005	0.69 Medium
Economic Development	3,98	0,88	3,78	4,17	5,99	<.0005	0.66 Medium

The results in Table 3 indicate that all the mean scores for the factors can be described as positive (3.41 -5.00) (reference); that is, the mean scores range between 3.77 and 4.02 given the 5-point Likert scale that was used for the measurement. This illustrates variables with positive mean scores and practical significance (Cohen's d) (reference). The variables consisted of the following impact of renewable energies (M=3,77;d=0.53); adequate energy supply (M=4,02; d equivalent to 0.78); sustainability (M=3,988; d is equivalent 0.65); funding models(M=3.99;d=0.69); and economic development (M=3,98; and d=0.66).

This analysis indicates that the respondents are optimistic and highly positive that funding the installation of the PV solar system in Soweto will contribute towards adequate energy and economic development. Based on the findings by González et al. (2017), there is a positive correlation between installation of PV solar systems, economic development and adequate energy supply. According to González et al. (2017), renewable energy contributes to socio economic development. Akinola and Akinsade (2022) state that sustainable energy is fundamental to socio-economic development. The PV systems have the potential to deal with objectives such as localisation and economic growth in a country (Walwyn, 2017; USAID, 2019).

Chi-square Hypothesis

To further investigate the correlation among the variables, Chi^2 hypothesis tests were conducted. The Chi^2 method tests for independence and indicates whether there is a relationship between two or more variables.

Table 4: Hypothesis Testing: Adequate Energy Supply and Economic Development

Affordable, adequate Energy Supply								
Economic development	**Adequate Energy Supply**							
	Lower (<Q1)		Middle (Q1-Q3)		Higher (>Q3)		Total	
Lower (<Q1)	13	50%	10	38%	3	12%	26	100%
Middle (Q1-Q3)	7	18%	24	60%	9	23%	40	100%
Higher (>Q3)	1	6%	5	29%	11	65%	17	100%
Total	21	25%	39	47%	23	28%	83	100%

Chi²(d.f. = 4, n = 83) = 20.96; p < .0005; V = 0.48 Large; 1 added to each observed frequency to meet minimum expected frequency requirements

The analysis to test the hypothesis between Economic Development and Adequate Energy Supply indicated that there is a significant relationship between these two variables. The p-value obtained was less than 0.05. Han and Zhang (2016) further state that PV technology is becoming the preferred technology due to its contribution to economic growth. Based on the analysis, the relationship indicates that there is significant correlation between energy availability and economic growth. Therefore, Null hypothesis (H_o) is rejected in favour of (H_1), alternative hypothesis (Wegner, 2020).

Table 5: Hypothesis Testing: Sustainability and Community Involvement

Sustainability								
	Community Involvement							
	Lower (<Q1)		Middle (Q1-Q3)		Higher (>Q3)		Total	
Lower (<Q1)	13	50%	11	42%	2	8%	26	100%
Middle (Q1-Q3)	5	13%	25	63%	10	25%	40	100%
Higher (>Q3)	1	6%	5	29%	11	65%	17	100%
Total	19	23%	41	49%	23	28%	83	100%

Chi²(d.f. = 4, n = 83) = 24.15; p < .0005; V = 0.51 Large; 1 added to each observed frequency to meet minimum expected frequency requirements

Other variables that were tested are Community Involvement and Sustainability. The analysis also indicated that there is a significant relationship between community involvement and long terms sustainability. The p-value obtained was less than 0.05, which indicates the significance of these variables. According to Walwyn (2017), integration of the communities contributes towards sustainability. Based on the analysis, the relationship indicated that there is significant relationship between community involvement and long-term sustainability. Therefore, Null hypothesis (H_o) is rejected in favour of (H_1), alternative hypothesis (Wegner, 2020).

Table 6 Hypothesis Testing: Funding Models and Affordability

Affordability of the PV Systems								
Funding models	**Photovoltaic**							
	Lower (<Q1)		Middle (Q1-Q3)		Higher (>Q3)		Total	
Lower (<Q1)	14	54%	10	38%	2	8%	26	100%
Middle (Q1-Q3)	9	23%	25	63%	6	15%	40	100%
Higher (>Q3)	1	6%	9	53%	7	41%	17	100%
Total	24	29%	44	53%	15	18%	83	100%
Chi²(d.f. = 4, n = 83) = 15.54; p = .004; V = 0.41 Large; 1 added to each observed frequency to meet minimum expected frequency requirements								

Based on the analysis between Funding Models and Affordability, there was an indication that adequate availability of funding sources contributes towards affordable PV solar systems. The hypothesis testing indicates a significant relationship between these two variables, with p-value equivalent to $0.004 < 0.05$. According to Pode (2013), some of the funding mechanisms created for renewable energy offer loans at low interest rates, and these mechanisms are targeting marginalised communities. Based on the analysis, the relationship indicates that there is a significant correlation between energy funding models and affordability. Therefore, Null hypothesis (H_o) is rejected in favour of (H_1), alternative hypothesis (Wegner, 2020). Among the variables analysed such as funding models, adequate energy supply, a significant number of respondents agreed that there are various financing models that could potentially be adopted to fund the implementation of the PV solar system in Soweto Township. Respondents also believed that the cost of ownership reduces as technology becomes increasingly accepted. This is also supported by the study conducted by CSIR (Engineering news, 2023).

6. CONCLUSION AND RECOMMENDATIONS

The primary objective of this study was to analyze the impact of funding photovoltaic (PV) solar systems and smaller-scale inverters in Soweto Township, Johannesburg, South Africa. In South Africa, the funding models, renewable energy technologies, and micro-grid solutions for marginalized communities remain relatively unexplored. Consequently, there was a pressing need to test these models and construct prototypes for practical analysis and informed recommendations. The study observed that enhanced energy security significantly contributes to addressing the energy gap, positively impacting economic development. Therefore, it is imperative to prioritize the analysis of funding models that can facilitate the adoption of affordable, clean, and sustainable energy solutions in South African townships. This can be achieved through various strategies, including tax breaks, the establishment of green funds, and incentives provided by international organizations like the United Nations, development banks such as the Development Bank of South Africa, or national government initiatives such as tariffs introduced by the National Treasury (Walwyn, 2017; National Treasury, 2023). A key finding from the study was that respondents strongly agreed that inadequate energy supply negatively impacted economic growth. Conversely, improving energy security and supply significantly contributes to economic development. This was identified as a crucial aspect of ensuring affordable energy access in townships.

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