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Financial Investment Impacts in the Renewable Energy Sector: Case Study of a Micro-Grid PV System

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Abstract – *This article investigates the return on financial investment of one of the most famous renewable energy sources available in the majority of countries over the world when considering building a micro-grid station of 1MW namely the photovoltaic (PV) system. By bringing together information on the need to invest in a very promising field which is solar, the reasons that can motivate investment or not in the PV sector based on the global energy potential has been analyzed, climate agreements, technological development of the field and practical cases studied. The problem is at present that, there still are some reluctant investors who do not believe in investing in the renewable energy sectors. Society is divided on the environmental impact that most used energies presently have on human life. Whether it is coal, uranium or gas, many companies invest huge amounts of money in these forms of energy to increase their economical level while investment in the renewable energies stagnates. The results obtained from the proposed micro-grid deployed show that an initial investment of about US$1,564,286.71 allows the return of initial expenses from the ninth year with an overflow of US$54,989.83, and from year ten to have a net payoff of US$265,425.28 which can increase to US$391,805.71 in year fifteen.*

Keywords*: Financial Return, Micro-Grid, Renewable Energies, PV System, Solar Irradiation*

Nomenclature

AC''_x	Annual consumption for previous year
H	Annual solar irradiation
S	Covered surfaced by wind tower
P_{af}	Consumption after commissioning
P_{be}	Consumption before PV
CC	Cost of consumption in US$
c	Cent charge per 1 unit of energy consumed
γ	Degradation of the solar panels
r	Efficiency of the solar panels
AC'_x	Energy cost for the current year
Es	Energy saving in percentage
h	Fall height of water
Q	Flow rate
g	Gravity
P_H	Hydraulic power
i	Increase rate
x	Index of corresponding financial year
NERSA	National Energy Regulator of South Africa
n	Number of weeks
REIPP	Renewable Energy Independent Power Producer
A	Total panel area
η	Turbine's efficiency
ρ	Water's density
P_W	Wind power
V	Wind speed
γ	Yield of the solar system

I. Introduction

The photovoltaic (PV) system utilization is increasing in various domains whether in the automotive domain with solar vehicles [1], [2], in aeronautics with the development of solar aircraft [3], [4] or in the industry for the users of electricity [5], [6]. Nowadays, no one can deny that the energy contribution of solar among other energy sources is increasing although not sufficiently when taking into consideration its availability. The Annual global amount of energy received by the earth from solar irradiation is huge and represents more than 8000 times the global energy consumption [7]. Earth received approximately 1015 petawatt-hours of solar irradiation while the global energy consumption is approximately equal to 133 petawatt-hours [8]. In contrast, the electricity production using a PV system only represented approximately 1% of the global production which is 570 TWh in 2018 [7]. According to the International Energy Agency (IEA), the growth forecasts in the solar sector will steadily increase and around 125 GW of energy capacity will be globally added per year between 2021 and 2025. This capacity might increase at a higher rate if decisive political action is taken by world leaders [7]. To encourage investors to invest more in renewable energy, many countries are revising their legislation in the energy production field.

For example, the National Energy Regulator of South Africa (NERSA) has moved from 1 MW to 100 MW

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solar energy production for each physical or legal entity.

This energy level allowed takes into consideration the citizens' need for electricity, the economic health of the main South African utility supplier ESKOM, the number of jobs to be created and the available space dedicated to PV panels' installation. The main objective of this study was to determine the financial impact of an investment in the domain of energy production using renewable energy and PV systems in particular. A case study of a micro-grid was proposed and its financial return was determined. Three questions will be addressed in this article. 1) What is the need for renewable energy? 2) How will the increase in green energy affect the world? 3) When will the financial return of a micro-grid investment in a PV system occur? Addressing these questions will lead to three contributions. First, offering investors a new area where the need for development is increasing daily and the return on investment can easily be evaluated. Secondly, identifying some of the reasons why investors remain hesitant to invest in this domain while the primary energy source is abundant and inexhaustible. Thirdly, evaluating a micro-grid PV system deployment in terms of financial return and determining a predictable return on investment 15 years after commissioning. The micro-grid proposed and being investigated belongs to a small industry based in South Africa where two systems are compared, one with and the other without a PV system.

The remainder of this article is organized as follows.

Section II reviews the existing literature. Section III addresses the necessity of deploying renewable energy in the world while Section IV emphasizes the situation in the South African environment. Section V addresses a case study of a small industry micro-grid and Section VI determines its financial return. Finally, a conclusion is presented in Section VII of this article.

II. Literature Review

Research in a scientific domain requires in-depth knowledge of prior research. This section contributes to justifying the need for renewable energy for our well-being. Several articles have been consulted and they are divided into three main parts. They are renewable energy applications studied with an emphasis on PV systems, the allocated finances for this domain and the evolving policy in the sector.

II.1. Renewable Energy Applications

In 2020, [9] used the open distribution system simulator (opendss) software to analyze a power grid with solar power sources and an energy storage system.

The simulation showed that the utilization of PV and energy storage systems could reduce the energy demand cost of the whole system and increase the system's capacity to the power grid system. Before this study [9], several studies had been done on solar storage systems for various reasons such as [10] who proposed a method that can be applied to determine the generator unit commitment, the scheduled battery energy storage system and the actual charge/discharge using mixed-integer linear programming. The efficiency of the proposed method has been verified using a Japanese power system via simulation. It has emerged that the proposed technique can reduce the energy shortfall.

In 2019, [11] investigated the stability of a PV system connected to a battery storage system to determine the strength of a weak grid. A mathematical model of the system was developed. The results obtained showed that the strength of a grid is directly related to the strength of the PV system. Thus, the strength of the PV system can affect the grid and vice versa. For a grid community analysis, implementation has been done by [12] to study the sharing of energy between two different renewable energies to achieve the demand/supply balance through the battery energy storage system. The analysis focused on a Cyprus system and analyzed the system integration, the control strategy as well as the overall system operation. It emerged that to have a reliable system, the performance of the battery energy storage system depends on PV and the battery system design parameters as well as system boundary conditions. One of the major problems in such a system is PV curtailment which was studied in [13]. An operational method for energy storage was used based on the day ahead and numerical simulations were done to evaluate the proposed method.

The result was that this was effective to improve the reliability of the PV systems.

Other PV storage systems such as pumped storage systems and hydrogen technology as well as phase change material were investigated in [14]-[17] to increase the storage capacity of a PV system. The drawback of these studies is that none of them made a financial analysis to support the deployment of these innovations.

II.2. Finances for Renewable Energies

One of the significant problems of PV deployment is financing [18]-[20]. Research is done to identify various financial factors that can improve capital investment and the financial infrastructure in renewable energy sectors.

In practice, the financial models developed should be associated with innovation and the investment climate in the region because each investment has its own risk profile associated with a socio-economic impact.

Investing in renewable energy leads to several advantages such as financial benefit, autonomy, security, and improving environmental and social conditions.

Moreover, the ban on interest in Islamic finance promotes profit-loss and a fair share between contracting parties. Thus, this advantage can be used to promote an innovation model in renewable energy [21]. Diversified financial strategies are proposed to overcome the huge demand of this sector to achieve sustainable development, such as strengthening the subsidies to encourage the deployment of renewable energy. In

Bangladesh, a study was done to determine some of these financial factors for PV deployment [20]. It was shown that deploying a solar system for home utilization can cost up to US$10/kWh for grid extension, while a stand-alone PV system could cost US$3. Thus, giving a loan to households for a standalone PV system could be one of the solutions applied in this context. In 2019, [22] provided a framework for how renewable energy technology should be analyzed for financial purposes under uncertain conditions. An extended technique for order of preference by similarity to an ideal solution and best worse methods were used for assessing the renewable energy technology financing models in developing countries using sustainability metrics. In 2018, [23] addressed the importance of investment tax credit and production tax credit in cost reduction of wind and solar technology, installed capacity of solar and wind energies, influence on electricity market prices, and modification in interconnection rules for renewable energy to provide reactive power support to the grid. The technique consisted of evaluating some of the findings of electric reliability of Texas and the results obtained showed that grid operators have some new challenges such as adequate reactive power support that needs to be provided by the renewable power source and the extension of the transmission line capacity. This leads to overcrowding in the transmission lines throughout the high renewable generation period, which could result in curtailment and negative prices. Nowadays, despite the increase in funds for renewable energy projects, many have not been deployed because of the prevailing policies in place. Some countries have problematic legislation which does not encourage the development of this sector.

II.3. Global Policy

The drivers for global renewable energy market development and their impact on the construction of renewable energy plants have to be examined [24], [28].

Some analysis shows that the main driving forces for global renewable energy sector growth are legislative factors, particularly the implementation of well-designed mechanisms to encourage renewable energy production.

For example, German legislation has obliged the network operators to connect green energy production to their grid even if the grid capacity was already achieved [25]. The German act on renewable energy was revised in 2004 to guarantee grid priority access to green energy.

However, the law did not provide a guarantee for non-purchase energy. Thus, if the legislation does not consider certain aspects of energy generation to regulate the amount of energy that can be added to the grid, the investment in this sector may decrease because of dissatisfaction. The solution that is being applied is to shut down some power plants when the green energy is enough to supply the area. Another example is the case of Lebanon where, due to imported oil dependence from other countries to generate its own electricity, the grid is underdeveloped [26]. Studies are formulated to attract investors in the area of renewable energy. Political commitment is the key to successfully migrating from the current energy dependence to complete energy self-sufficiency. Reforming the energy sector and promoting green energy should be accentuated with an emphasis on the financial incentive and financing mechanism. Some of the proposed solutions are also to set a policy to attract foreign direct investment such as in Chile where a techno-pole linked with academia and private industries has been investigated [27] because only innovation could drive investment. Thus, industries should work alongside large-scale renewable energy producers and enjoy mutual financial benefits. Nevertheless, some countries are setting up mechanisms to boost the renewable energy sectors. In 2018, [29] evaluated the effectiveness of a US portfolio standard that recommends a certain percentage of renewable energy in the total energy sale in all states.

It emerged from this study that the technology returns on the portfolio standard mandates are location-specific, and the capacity growth of renewable energy is not stable in time. Also, various areas of the country were identified with their best possible sources of renewable energy that can be developed to fulfill this requirement. In India, proposed legislation was done through technology implementation [30]. Based on Fortran 77, this study tends to obtain a better angle that will increase the reliability of the solar system in India and change the actual policy. Two systems were compared namely a tracking solar system and one without tracking. The results demonstrated that the Indian government should adopt the optimum angle tracking to reduce the installation area by 8.84% to meet the United Nations Framework Convention on Climate Change. In 2016, [31] proposed some opportunities that will help to achieve the goal of renewable energy implementation in Ethiopia while [32] provided an answer to the concerns of some electricity end-users who are worried about the cost of state support and the increase of electricity cost in Thailand. In ECOWAS countries, renewable energy potential concerning renewable energy policy was also investigated [33]. It emerged from these studies that higher investment in the near term is generating long-term benefits, which leads to modern and sustainable energy power for all. Thus, some of these countries should update their policy to improve the sustainability of this domain. Price control measures should also be implemented to attract investors. Finally in 2014, [34] analyzed and compared the performance of two mechanisms proposed by the European Commission to control the renewable energy sectors covering the implementation of a renewable energy quota obligation scheme or allocating feed-in premiums through a tender mechanism.

This study indicated that to improve the performance of the policy, more competition and lower price risk should be maintained. A floor price could also be introduced to decrease project risk. Many other policies have been proposed in several countries like Korea [35] and in China [36] to tackle the obstacles and existing problems such as the development of energy storage and energy management as well as demand response expand.

III. The Need for Renewable Energy

III.1. Globally

Energy is defined as being renewable when the quantity of energy consumed is insignificant compared to the production which is naturally reconstituted. Thus, five types of renewable energy can be identified namely solar energy, wind energy, hydraulic energy, biomass energy and geothermal energy [37]. All these forms of energy are nowadays globally developed and solar energy is the one with the highest increase in implementation.

Solar Energy: To provide for their energy need, humans have been able to develop numerous techniques to generate electricity to warm themselves during winter. Solar energy is used today in two major forms which are solar heating and cooling and solar PV systems [7]. In solar heating and cooling technology, the irradiation of the sun is used to heat a liquid which is mostly water for several purposes such as swimming pools, space heating and bath water; for the cooling technology, air passes through a drying material where a chemical is introduced to remove the air moisture. This chemical material is regenerated by utilizing solar heat to dry it again [38].

In solar PV system technology, solar panels are used to convert solar irradiation into direct current. This direct current can be used as it is or converted into alternating current in accordance with the needs. A solar panel is made up of thousands of photo-diodes p-type and n-type semiconductors leading to a p-n junction interconnected.

When irradiated by the sun, these semiconductors convert the heat of the sun into electric current [39], [40]. These solar panels are then connected in series to increase the electrical voltage and in parallel to increase the electrical current according to the need. There are several types of solar panels namely mono-crystalline, poly-crystalline, and thin-film panels. The difference is essentially characterized by the type of materials the photo-diodes have been made of [39]. The choice of a solar panel type depends on specific factors of the micro-grid and often depends on the allocated project amount.

Table I presents some advantages and disadvantages of various types of solar panels. The power of a solar system depends on the solar irradiation captured which depends on the orientation and inclination of the solar panels, the number of associated series-parallel panels, the power and efficiency of each solar panel, the deteriorated condition of the installation and the number of hours of sunshine. Equation (1) provides the formula to evaluate the total power of a solar system in Wp where A is the total panel area in square meters, r is the efficiency of the solar panel, H is the annual solar irradiation, γ is the yield the solar system comprises between 0.5 and 0.9 with the default value equal of 0.75:

$$P_S = A \times r \times H \times \gamma \quad (1)$$

TABLE I
CHARACTERISTICS OF VARIOUS SOLAR PANEL TYPES

Solar Panel Types	Advantages	Disadvantages	Accuracy
Mono Crystalline	High efficiency Aesthetics	Higher costs	15-24%
Poly Crystalline	Low cost	Lower efficiency	13-18%
Thin-film	Portable and flexible light weight and aesthetics	Lowest efficiency	7-16%

Wind Energy: nowadays behind solar energy, wind energy systems are mostly used in areas where the wind speed may be sufficient to turn the blades of an electric generator. The environmental impact of electricity production using wind power is much lower than that of fossil fuels [7]. There are two types of wind energy, and they are distinguished according to their operational mode such as onshore and offshore modes. The electrical power of a wind power system in W is determined by Betz's law given in Equation (2) where 0.37 is the wind constant at 1013 hPa, S is the covered surface by a wind tower and V is the wind's speed:

$$P_W = 0.37 \times S \times V^3 \quad (2)$$

From Equation (2) it can be seen that if the wind's speed doubles, the power generated will be equal to eight times the initial power and if the radius of the blade is doubled, the power will increase by four. These parameters are very important to consider when designing a wind system. Generally, to be more reliable, a wind system should rotate between a wind speed of 3 to 25 m/s [41]. One of the advantages of this system compared to the solar PV system is that where a wind system is installed, agriculture and other industrial activities can still be developed. One of its disadvantages is the fact that the deployment of a wind system into any geographic zone is limited due to some environmental conflicts such as visual and noise pollution.

Hydraulic Energy: Hydroelectric power generation is one of the first and most used renewable energy sources.

This type of renewable energy converts the power of water in motion into electricity via a turbogenerator. To permanently obtain the same frequency because the current generated is alternative, the same quantity of water should be allowed to flow downward through a gate where kinetic energy is created and to do so, a water reservoir should be constructed. Before this water hits the blade of the turbogenerator, mechanical energy is created and immediately converted into electricity. The largest dam globally was constructed in China in 2012 to generate up to 22500 MW. To evaluate the total power in Watt of hydraulic power generation, Equation (3) is used where η is the turbine's efficiency, ρ is the water's density, g is the gravity, h is the fall height in meters and Q is the flow rate in m^3/s:

$$P_H = \eta \times \rho \times g \times h \times Q \quad (3)$$

The need for developing different forms of renewable energy studied above comes from the need to preserve the environment even if each of these forms of energy at the environmental level has a certain drawback and could be the subject of more in-depth studies. However, compared to fossil fuels, these forms of renewable energies are more respectful of the environment. They emit practically no CO_2 apart from hydraulic energy. The need for developing these renewable energies comes from the abundance of raw material and sunlight available for solar energy as shown in Fig. 1. It is seen that the average value of solar irradiation per square meter is unevenly distributed but high enough to be exploited across the world. The need for developing alternatives also comes from the increase in the electricity cost.

In some countries such as South Africa, the tariff rate of electricity increases every year. It is good to remember that the cost increase of any commodity considers the supply and the demand. If the supply is higher than the demand the cost will drop and if the demand is greater than the supply the cost will increase. More electrical equipment is being developed in the field of telecommunications, construction and health to name only a few. All this equipment contributes to the well-being of humans but is dependent on the increasing demand for electricity, which in turn increases the cost of electricity. What is sometimes ignored is the effect of climate change with more hot summers and colder winters which lead to higher power demand. This causes a need for either more heating during winter or cooling in summer by using suitable electrical equipment which increases the electricity demand. Finally, the need for electricity autonomy favors a growing power demand for renewable electrical energy. Many industries and individuals do not have sufficient funds to deploy a gas, coal or hydraulic power plant for their needs. Renewable energy is used by these medium size companies to supply their grid because the raw materials are inexhaustible and it has been argued that the cost of a kWh of this renewable energy could be cheaper. In addition, small-size power plants are affordable and are constructed from a few kWh to several MWh according to the legislation of the specific country.

III.2. In South Africa

Like everywhere else, South Africa is working to reduce its energy consumption generated from fossil fuels. The country is among the largest electrical energy producers using fossil fuels, with approximately 90% the total present energy produced from this source.

Nevertheless, since the conference of the parties in 2015 (COP21) on climate change, the country has committed to reducing its carbon footprint to move to other sources of electricity production using renewable energies. Due to its geographical position, the country among various available renewable energies, is developing more solar energy even though the percentage of this renewable energy at present only stands at 24%. Irradiated for almost 12 hours a day the whole year and a winter season of only 13 weeks, South Africa has a maximum solar irradiation per year of about 2500 kWp/m^2 in certain provinces as shown in Fig. 2.

The whole country is generally very sunny, which allows the development of this form of natural resource compared to some European and American countries [8].

New legislation has been put in place by NERSA to further develop solar energy generation because the potential is huge and has not yet been exploited as everywhere else. However, the regulator has set a maximum of 100 MW of power generated for the solar sector by small industries, companies and personal use.

Thus, many small industries have taken advantage to deploy their own micro-grid. One of the reasons that motivate companies to invest in these renewable energies is the actual tariff rate of electricity which keeps increasing every year at an average of 8%. In 10 years, according to the national regulator, the tariff rate has increased by approximately 350%, which induces a huge operating cost for companies and individuals [43].

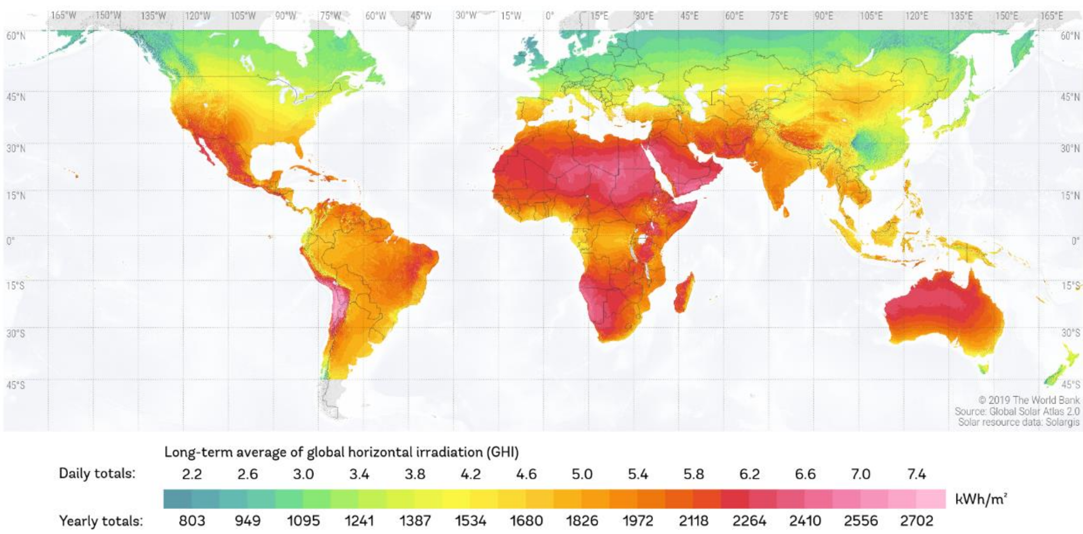

Fig. 1. Global Irradiation [8]

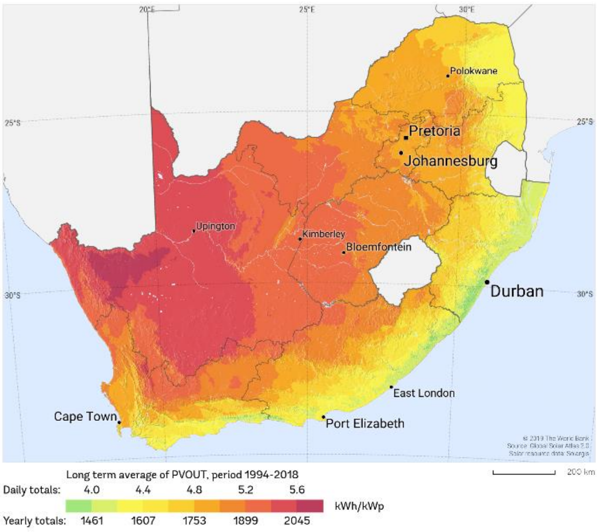

Fig. 2. South Africa Irradiation [42]

As demonstrated in this study, the deployment of a micro-grid can solve this problem. It should be noted that other forms of renewable energy are indeed deployed in South Africa especially biomass using underground heat near mountainous areas and wind energy in coastal areas of the country where the wind speed is high and sufficient to keep the wind blades in rotation. Several wind farms are also being deployed.

The problems encountered that slow down the development of renewable energy are almost the same as everywhere else such as the high equipment cost, the resistance of the population to transfer their land and the unfamiliar innovation. Today, much research is done to develop highly efficient batteries which can be quickly charged and slowly discharged with a long lifespan [44], [45]. A seven-year lifespan for solar batteries and 25 years for solar panels is not enough to encourage investment in this area. Thus, the lifespan of solar panels is being investigated to extend it by six years. Despite these shortcomings there is a potential gain for people and industries who dare to deploy a renewable energy system.

IV. Solar Systems in South Africa

Knowing that the average sunshine throughout the year in South Africa is approximately equal to 2500 kWp/m^2 compared to Europe with an average of 100 kWp/m^2 a year, the country is very well positioned to dominate the world in terms of solar system deployment. As in many countries, the price of solar panels in South Africa has considerably decreased over the past six years.

This was encouraged and facilitated by the growing demand via many projects all over the country. Recently in 2018, the highest African commercial surface was inaugurated, powered by a solar system and it became the most extensive rooftop solar system in the southern hemisphere. The solar panels of its installation cover an area of 45000 m^2 and produce 4755 kWp of electricity.

To accelerate and diversify such kinds of projects, the South African government in 2011 launched a Renewable Energy Independent Power Producer procurement (REIPP) plan with the desire to contribute to the social and economic development of the nation by producing alternative sustainable energy. Later, the installed capacity of solar PV systems was boosted and in 2018 reached more than 30% of the total renewable energy [46]. The main South African power utility, Eskom, is expected to sign numerous renewable energy projects with REIPP to increase the capacity of green energy and fulfil the country's aim of installing 8400 MW generation capacity of PV systems by 2030 under these independent producers [46]. The development of solar systems will have a vast impact on the South African economy, especially concerning the creation of job opportunities. Unemployment is a global issue and South African statistics indicate that the unemployment rate is steadily increasing and stood at in February 2021.

According to the South African Reserve Bank this has caused the GDP to fall by more than 7% [47]. Solar energy can create jobs that are guaranteed to stay domestic according to [48] and the money obtained could be used to stimulate economic growth. By 2030, [49] estimates the new job creation to increase by 788000 in the renewable energy sectors while in 2011, the annual increase in formal employment was approximately 365000, and 98000 jobs in renewable energy [50]. Thus, in the next eight years the renewable energy sector will significantly contribute to the well-being of the economy.

In addition, wages in the solar industry are higher than wages in similar industries and the majority of solar installer companies are small size industries. Supporting them will bring more cash into the local economy. The second type of solar energy used in South Africa is thermal solar systems. It is mostly used to heat water for various uses. Heating water for various reasons has always been the cause of excessive electricity consumption in homes and industries. As a result, solutions for heating water become the ideal way for users to save energy, although the initial investment for deploying such a system remains high for many South Africans. The benefits, however, are highly rewarding.

Solar heating can provide up to 3/4 of the hot water needed, and significantly impact on the monthly electricity cost. Its operational principle is to collect and embrace solar rays which are used to heat the water circulating in a tube. This hot water is then conducted into a tank and redirected to the shower and the taps.

To determine the real impact of an investment in the solar sector, the return on investment should be determined. In the majority of cases, the return on investment is calculated before the infrastructure is deployed, which produces approximated results. This study will use post-deployment data from a microgrid of a South African industry located in Midrand to evaluate and determine the return on investment by considering the daily consumption, the yearly tariff rate, the initial investment amount and the degradation coefficient of the solar system.

V. A South African Micro-Grid PV System

South Africa has been facing power cuts by Eskom for almost 8 years.

The origin of the shortages lies in the very high electricity demand from the customers, the Eskom production unit's obsolescence, the insufficient or wet raw material, the lack of cooling water and others.

Reasons are many and are generally stated during the media awareness campaigns regarding the rational consumption of electrical energy. Thus in 2017, an industry launched a micro-grid PV system with a capacity of 998 kW, just enough to respect the 1 MW limit set by the legislation at that time. The main objective of the deployment of this PV system was to reduce its energy dependency from the main supplier and increase its autonomy. The micro-grid has storage batteries of 140 kWh per unit and a diesel generator for energy security reasons. The architecture of this micro-grid is presented in Fig. 3, the batteries used is a Siestorage battery solution. This system stores energy from the grid during the low load periods and compensates the power needed during peak periods.

Thus, the company does not use power from the main supplier during peak periods to avoid high-rate charges. Fig. 4 illustrates a Siestorage battery which can be monitored via a SICAM controller. SolarEdge technology is used to achieve energy conversion using 30 × SE27.6K inverters. These inverters are controlled by a SICAM micro-grid controller via Modbus TCP and a user interface is accessible via an IEC 60870-5-104 port of the SICAM controller. This allows remote access to all the sections of the grid and easily monitors the installation. For more flexibility, all inverter information was stored in the cloud and is accessible via a computer as shown in Fig. 5. The PV system deployed was not enough to supply the whole installation and, therefore, a point of connection was made with the main supplier.

The power supplied is distributed into two parts to feed two transformers. Transformer 1 is used for non-priority loads and transformer 2 for priority circuits.

Thus, three power meters are connected to measure the load consumption of each transformer and the solar system as indicated in Fig. 6. These meters were also interfaced using the SICAM controller.

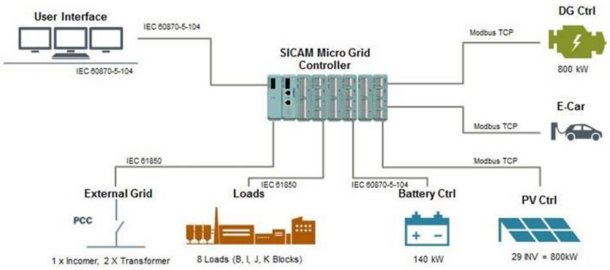

Fig. 3. Micro-grid Architecture

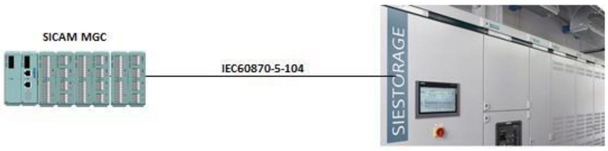

Fig. 4. Siestorage Battery with a SICAM Controller

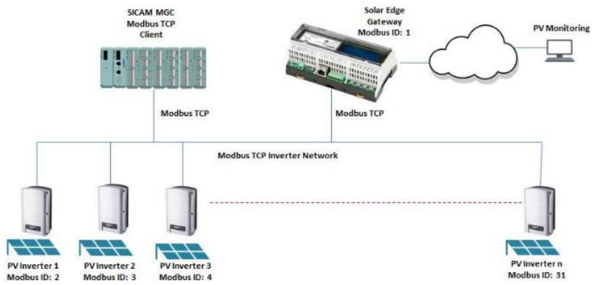

Fig. 5. Inverters Cloud Monitoring

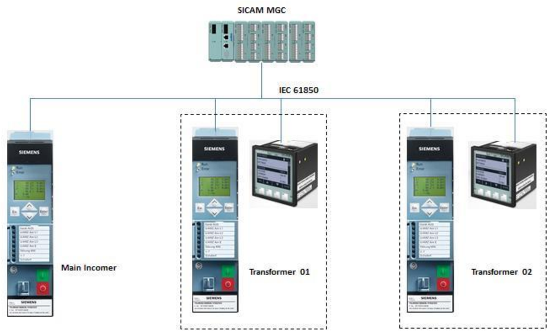

Fig. 6. Power Meters

VI. Financial Return of a Solar Micro-Grid

To evaluate the financial return of the micro-grid, the data of this industry were needed. These data such as the tariff rate and the consumption were collected after the micro-grid was deployed. The total asset and installation costs for such a micro-grid in the South African context are shown in Table II.

VI.1. Data Collection

Tariff Rate: The main supplier determines the tariff for the corresponding financial year following the national regulator's approved tariff increase. For every single day, three time-of-use periods are defined. The time-of-use periods are classifiable as standard periods, off-peak periods and peak periods.

TABLE II
INSTALLATION AND MATERIAL COSTS IN US DOLLAR

Asset	Installation and Material Costs
PV panels	1,092,724.68
Siestorage (140 kWh)	320,970.04
IoT solution	89,158.34
30 x SE27.6K inverters	61,433.66
Total	**1,564,286.71**

The days of the week such as Saturday, Good Friday, Christmas and other public holidays are considered off-peak periods. Thus, only two time-of-use periods are applicable on those days which are Standard from 07h-12h and 18h-20h, and off-peak from 12h-18h and 20h-07h. According to the main supplier, each financial year is divided into two distinct seasons which are the winter and the summer seasons. The summer rate is applicable for a period of approximately nine months from September to May while the winter season rate is applicable for three months from June to August. Thus, from the 2017/2018 financial year when the PV system was commissioned, the applicable tariff rate for industrial medium-voltage charges is given in Table III, where the time of the use periods is taken into consideration.

Consumption: The data for the consumption periods before the PV system were deployed starting from 18 September 2017 (38th week of the year) until 15 October 2017 (41st week of the year) and after the deployment starting from 17 September 2018 (38th week of the year) to 14 October 2018 (41st week of the year) were collected from the micro-grid for the summer season. For the winter season of the first year of commissioning, the data were collected during the first week of the winter in 2018 which is the date going from 1 to 7 June 2018.

To objectively analyze the kind of data collected, it is assumed that during the summer season, the monthly consumption stays the same but varies from one week to another a during the winter season, the weekly consumption stays the same as presented in Table IV.

VI.2. Evaluation of Energy Saved and Consumed

To evaluate the saving in energy during the summer and the winter seasons, the total consumption of these two periods was used before and after the PV system was deployed. Equation (4) was applied where E_S is the energy saving in percentage, P_{be} is the consumption before the PV system was deployed and P_{af} is the consumption after the commissioning:

$$E_S = \frac{P_{be} - P_{af}}{P_{be}} \times 100 \quad (4)$$

The results demonstrate that the PV system deployed for this micro-grid enables the reduction in the general consumption during the summer season by 49.22% and during the winter by 48.24%.

The cost of the energy consumed per day was evaluated using the corresponding financial year tariff and total daily energy consumed.

Thus, Equation (5) was used to determine the cost. In Equation (5), E is the energy consumed per day, CC is the cost of consumption in US Dollar and c denote the cent charge per 1 unit of energy consumed:

$$CC_{per\ day} = \frac{c}{kWh} \times \frac{US\$}{100c} \times E \quad (5)$$

The results presented in Fig. 7 and Fig. 8 show that the introduction of the PV system into the micro-grid has considerably reduced the total cost of consumption per day during the summer and winter seasons.

VI.3. Return of Investment

Through the energy savings, the financial return for the PV system deployed could be evaluated. The deployment of this PV system reduced the energy consumption from the main supplier's grid, resulting in energy savings and decreases in energy cost.

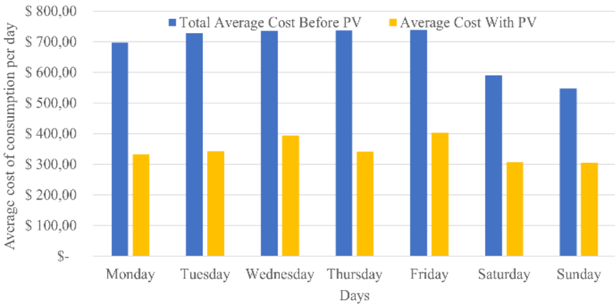

Fig. 7. Cost of Consumption for the Summer

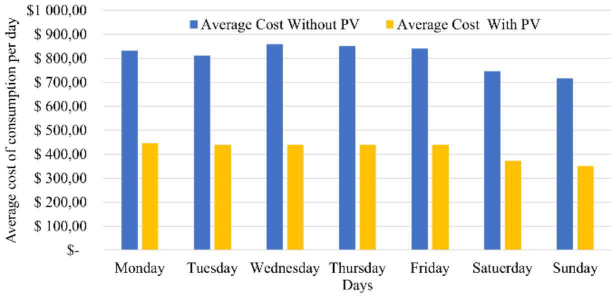

Fig. 8. Cost of Consumption for the Winter

TABLE III
TARIFF RATE IN US DOLLAR

Financial Year	2017/2018	2018/2019	2019/2020	2020/2021	2021/2022
Summer tariff (c/kWh)					
[Peak [7h-10h] and [18h-20h]	8.89	9.58	11.12	12.04	14.27
[Standard [6h-7h], [10h-18h] and [20h-22h]	6.91	7.40	8.37	8.37	10.75
[Off-peak [22h-6h]	5.31	5.69	6.43	6.43	8.26
Average tariff rate	**6.11**	**6.55**	**14.80**	**14.80**	**9.50**
Winter tariff (c/kWh)					
Peak (nil)	21.16	22.80	26.47	29.28	33.98
[Standard [7h-12h] and [18h-20h]	8.34	8.94	10.10	10.94	12.97
[Off-peak [12h-18h] and [20h-7h]	5.71	6.12	6.92	7.50	8.88
Average tariff rate	**7.02**	**7.53**	**8.51**	**9.22**	**10.94**

TABLE IV
ELECTRICITY CONSUMPTION IN kWh

Seasons			Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Summer	before PV	Week 38	11072	11252	11656	11704	12154	9104	8724	75664
		Week 39	10144	12532	12716	12832	12688	10656	9628	81196
		Week 40	12288	12260	11860	11872	11996	9684	9296	79256
		Week 41	12096	11640	11896	11788	11500	9216	8184	76320
		Average	**11400**	**11921**	**12032**	**12049**	**12084.5**	**9665**	**8958**	/
	After PV	Week 38	5276	5636	6204	6340	6960	4388	4292	39096
		Week 39	5188	6040	6484	4044	6940	5196	4656	38548
		Week 40	5488	5464	6840	5436	5052	3956	3992	36228
		Week 41	5772	5312	6244	6484	7396	6528	7040	44776
		Average	**5431**	**5613**	**6443**	**5576**	**6587**	**5017**	**4995**	/
Winter		Consumption Without PV	11825.91	11554.28	12222.57	12106.39	11965.83	10616.60	10196.16	**80487,74**
		Consumption With PV	6342.39	6244.43	6267.10	6263.49	6259.24	5294.88	4983.2	**41654,73**

TABLE V
COST OF CONSUMPTION FOR ONE WEEK DURING SUMMER AND WINTER SEASONS

Seasons		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Summer	Average Consumption Before PV (kWh)	11400	11921	12032	12049	12084	9665	8958	**78109**
	Average Cost Before PV (US$)	696.	92728.77	735.56	736.60	738.74	590.86	476.01	**4,703.49**
	Average Cost After PV (US$)	$332.	1 343.14	393.88	340.88	402.69	306.70	265.42	**2,384.76**
Winter	Average Consumption Before PV (kWh)	11825,90	11554,28	12222,57	12106,39	11965,83	10616,60	10196,16	**80487,74**
	Average Cost Before PV (US$)	831. 2	27812.17	859.15	850.98	841.10	746.26	582.82	**5,523.79**
	Consumption After PV(kWh)	6342, 3	9 6244,42	6267,10	6263,48	6259,24	5294,88	4983,20	**41654,73**
	Average Cost After PV (US$)	445.82	438.93	440.53	440.27	439.97	372.18	284.84	**2,862.57**

TABLE VI
FIRST YEAR COST SAVING

	Before solar PV installation	After solar PV installation
Weekly Consumption (summer)	78109 kWh	39662 kWh
Weekly Consumption (winter)	80487.74 kWh	41654.73 kWh
CC summer (US$)	4,703.50	2,384.76
CC winter (US$)	5,523.79	2,862.57
ACC (US$)	255,245.67	139,557.79
1st Year Saving	US$125,026.48	

To properly analyse and determine the financial return it is considered that the solar panels degrade each year with a coefficient of 0.8. Knowing that the energy is normally measured on a per-hour basis, and not having the data for every single hour, it is considered using the average daily consumption and the average daily cost of consumption.

It is also considered that the amount of load connected to the microgrid does not change over time and the average tariff increase rate per year of 8.18.1% is used for the financial year beyond 2021/2022.

Using these assumptions, a predictable return on investment could be determined. The first step was to calculate the first-year savings amount obtained from the commissioning of the PV system using the following Equation (6), where *CC* is the consumption cost, *n* is the number of week during the summer or winter season:

$$1^{st}\ Year\ savings = \\ = \left[\sum_{n=1}^{39}(CC_{summer}) \times n + \\ + \sum_{n=1}^{13}(CC_{winter}) \times n\right]_{Before\ PV} + \\ - \left[\sum_{n=1}^{39}(CC_{summer}) \times n + \\ + \sum_{n=1}^{13}(CC_{winter}) \times n\right]_{After\ PV} \tag{6}$$

The obtained cost of consumption per weekday is determined using Equation (5) for one week during the summer and winter seasons using the 2017/2018 financial year tariff rate.

Using the results obtained in Table V and applying Equation (6), the first-year saving can be obtained and the results are presented in Table VI.

To calculate the 2018/2019 savings, the coefficient of PV degradation will be applied for reducing the total power generated in the previous year and the corresponding financial year cost will be used. It will be considered what the total consumption would have been if the PV system was not deployed (No PV) and what will normally be paid with the actual grid when the PV system was connected to the grid (with PV).

TABLE VII
SAVINGS COSTS AND ENERGY GENERATED PREDICTED FOR FIFTEEN YEARS

Financial year	AC_{NoPV} (kWh)	AC_{PV} (kWh)	ACC_{NoPV} (US$)	ACC_{PV} (US$)	Savings (US$)
2017/2018	4092591.57	2088329.45	255,245.67	130,219.29	125,026.38
2018/2019	4109298.20	2071622.81	273,827.56	139,699.16	134,128.4
2019/2020	4125871.19	2055049.83	298,526.81	152,300.03	146,226.78
2020/2021	4142311.58	2038609.43	320,349.12	163,433.16	156,915.96
2021/2022	4158620,46	2022300.56	367,088.05	187,278.06	181,809.99
2022/2023	4174798.86	2006122.15	396,822.18	202,447.58	194,374.6
2023/2024	4190847.84	1990073.18	428,964.78	218,845.83	210,118.95
2024/2025	4206768.43	1974152.59	463,710.93	236,572.35	227,138.58
2025/2026	4222561.65	1958359.37	501,271.52	255,734.71	245,536.81
2026/2027	4238228.52	1942692.49	541,874.51	276,449.22	265,425.29
2027/2028	4253770.06	1927150.95	585,766.34	298,841.61	286,924.73
2028/2029	4269187.27	1911733.75	633,213.42	323,047.78	310,165.64
2029/2030	4284481.14	1896439.88	684,503.70	349,214.65	335,289.05
2030/2031	4299652.66	1881268.36	739,948.51	377,501.04	362,447.47
2031/2032	4314702.81	1866218.21	799,884.34	408,078.62	391,805.72
		TOTAL			**3,576,334.35**

Equation (7) is used:

$$Savings = (AC''_x)_{No\,PV}(AC'_x) - (EC''_x)_{PV}(EC'_x) \quad (7)$$

Using Equation (7) and substitute it into Equation (6) gives Equation (8) which is a general Equation that could be used to determine the savings for the other financial years beyond 2017/2018:

$$\begin{aligned} &Total\ Savings = \\ &= \sum_{n=1}^{39}\Big[\big[AC''_{x_{No\,PV}} - AC''_{x_{PV}}(1-\gamma)\big] \times \\ &\times EC'_x(1+i)\Big]_{Summer} \times n + \\ &+ \sum_{n=1}^{13}\Big[\big[AC''_{x_{No\,PV}} - AC''_{x_{PV}}(1-\gamma)\big] \times \\ &\times EC'_x(1+i)\Big]_{Winter} \times n \end{aligned} \quad (8)$$

where AC''_x is the annual consumption for the previous year, AC'_x is the energy cost for the current year, n is the number of weeks for each season, γ is the degradation of the solar panels, i is the increase rate, x is the index of the corresponding financial year. The savings cost and energy generated predicted for fifteen years are recapitulated in Table VII and represents a savings of US$3,576,334.35 for the industry. Fig. 9 shows a comparison between two cases and the data used to plot these graphs are those in Table VII. If the microgrid was utilized with and without a PV system, the total savings cost of these fifteen years is shown and it is observed that the savings curve looks like an exponential curve, meaning the savings will increase if the solar system has a long lifespan. To evaluate the total number of years required to return the investment, the successive savings per year have been added and the results compared with the initial investment in Table II until the break-even was obtained at year nine. Table VIII shows that at year nine, the total savings amount is equal to US$1,619,276.54 which is greater than US$1,564,286.71 of the initial investment. Thus, the extra obtained at year nine is approximately equal to US$54,989.83. For 15 years of power generating by the PV system as shown in Table VII, the total number of power generated by the PV system during this period is equal to 29,630,123.01kWh and the total cost is US$1,564,286.71. This means that the tariff rate of the solar system energy is US$0.053/kWh. However, the average tariff rate of the main supplier using the total consumption in Table VII which is 63,083,692.24 and the total annual consumption cost during this period which is US$7,290,997.44 will be US$0.116/kWh. It can be seen that the rate of the PV system energy is cheaper and the actual energy tariff rate is 2.18 times more expensive than the PV system tariff rate even though the lifespan of the PV system is 25 years and only 15 years have been used here. The PV system has the advantage of a stable tariff rate over a long period because its raw material does not depend on the stock market and remains indefinitely available.

VI.4. Impact of the Battery Storage System

The use of a solar battery storage system becomes compulsory anytime when the micro-grid will be supplied after sunset, especially if the peak consumption from the main supplier's grid is to be avoided.

The micro-grid studied has a storage of 140 kWh and the batteries supplied the industry from 7 am to 10 am and from 6 pm to 9 pm. However, from 6 pm to 9pm the load is reduced to 15%because the industry closes at 6 pm and only some restricted work is done at that time.

This represents a total of three hours with the full load allocated and another three other hours with only 15% of the load while the cost of the battery storage represents 20.51% of the total PV system deployment cost. The battery storage cannot supply all of the micro-grid in this configuration. If this becomes necessary, the cost of the storage system will increase to US$2,288,057.85which represents the rate of a kWh of battery storage multiplied by the number of kWh needed. Thus, if the storage system capacity doubles, the total capacity will become 280 kWh for an amount of US$641940.08. This will impact on the cost of the inverters and the total amount of the PV system will be equal to US$1,946,690.42.

Using Table VIII the break-even will be at year 11 with an additional savings of US$224,936.13.

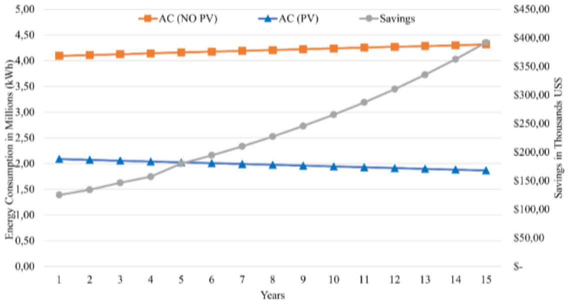

Fig. 9. Energy Consumption and Savings for 15 Years

TABLE VIII
THE RETURNS YEARS OF THE PV SYSTEM DEPLOY

Year	Financial Year	Savings	Returns
1	2017/2018	$125,026.47	$125,026.47
2	2018/2019	$134,128.39	$259,154.86
3	2019/2020	$146,226.77	$405,381.64
4	2020/2021	$156,915.95	$562,297.57
5	2021/2022	$179,809.99	$742,107.59
6	2022/2023	$194,374.60	$936,482.20
7	2023/2024	$210,118.94	$1,146,601.14
8	2024/2025	$227,138.58	$1,373,739.73
9	**2025/2026**	**$245, 536.80**	**$1,619,276.54**
10	2026/2027	$265,425.28	
11	2027/2028	$286,924.73	
12	2028/2029	$310,165.64	
13	2029/2030	$335,289.05	
14	2030/2031	$362,447.47	
15	2031/2032	$391,805.71	

This shows how costly the battery storage systems are at present and their financial impact on PV system investments.

VII. Conclusion

The importance of energy for the world's economic development is no longer in dispute. In the fields of power energy, several reports made are supported by major groups and international organizations to harmonize the development of these fields and to support green energies. It has been shown that the electricity demand will increase with the increase in the world's population and this will lead to increased environmental pollution if nothing is done. To solve this and have electricity for everyone, the renewable energy sectors must be developed. The study investigated the financial investment impact on the renewable energy sectors.

Various sectors where renewable energy could be applied and how to finance several projects as well as the study of global policies have been proposed. Moreover, a case study of the deployment of a PV system micro-grid was done. The characteristics of this micro-grid are the power generated equal to 998 kW, the Siestorage battery solution of 140 kWh of energy capacity, and the internet of things solution deployed to monitor the installation and the 30 x SE27.6K inverters used. This case study compared an initial investment of about US$1,564,286.71 against savings in energy cost for a South African industry based in Midrand. The predicted savings show that after nine years of commissioning, the total investment will be recovered with an extra US$54,989.83 and after 15 years of commissioning the total savings will increase to 2.3 times the initial investment. Moreover, the tariff rate applied by the main supplier is 2.18 times higher than that of the solar energy system per kWh. The main advantage of this study is the savings evaluation based on post-commissioning data, compared to research done using theoretical data collected before the deployment of the system. The limitation of this article is the fact that only a PV system has been proposed as a case study and the average electricity tariff has been used to determine the savings of financial years beyond 2021/2022. This could reduce or increase the final savings if the percentage taken respectively decreases or increases. Knowing that in South Africa and many other countries other renewable energies are successfully implemented such as geothermal and biomass energies, these forms of energy could be also investigated and proposed for further studies. The use of renewable energies remains the key to protecting the environment, supplying more energy to everyone and fulfilling the IEA's goals. At present, solar remains the more accessible and reliable resource to achieve this. However, the cost and the short lifespan of solar batteries and solar panels, and the policy in the renewable energy sectors remain the major drawbacks researchers are actively investigating. To solve these shortcomings, the South African government has recently invited investors to produce up to 100 MW of renewable energy without a license needed from the national regulator. This is 100 times more than what is allowed.

In general, despite several problems stated in this study and the reluctance of some investors this does not prevent the PV system from remaining financially profitable and with its inexhaustible quantity which will gradually contribute more to the development of the world's economy via job opportunities created.

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